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FOREST ROAD NETWORK PLANNING WITH STATE OF THE ART TOOLS IN A PRIVATE FOREST DISTRICT FROM LOWER AUSTRIA

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Abstract: *Forest road network planning plays a crucial role in sustainable forest management. The goal of this paper is to develop a road network in a 400 ha forest from Lower Austria, in order to solve the problem of accessibility and to reduce the harvesting costs. State of the art tools RoadEng®, ESRI® Arc GIS and MS Office Excel® have been used. The designed forest road network consists of slope roads with total length of 17.11 km. The resulted road density in the project area is 42.77 m/ha and the road distance is 234 m. The construction costs are estimated to 36.80 €/m, and the harvesting costs have decreased from an average of 27.90 €/m^3 before the road network was planned to an average of 22.60 €/m^3 after planning the road network.*

Key words: *forest road network, road designing, forest engineering.*

1. Introduction

The need for a sound and sustainable use of forests in mountainous regions requires a better access to forest stands through a properly developed forest infrastructure. Strategic decisions in timber harvesting have long term consequences on the further development of forests [7] and efficient harvesting systems are based on well established forest road networks [8]. Under these circumstances, forest road network planning plays a crucial role in fulfilling the goals of sustainable forest management and both in valuing the multiple uses of forests and in finding the pragmatic solutions which are best adapted to the local socio-economic and environmental conditions [3]. Therefore it is of critical importance that all phases in the designing and construction of forest road networks are carried out in a manner that is compatible with environmental values and sustainable forest management, taking also into account the important multipurpose benefits of forest road networks [2]. Therefore, a functional approach is needed in forest road planning [5] and this problem must be regarded in the context of multi-purpose management and by making use of state of the art tools and techniques.

The aim of this paper is to develop a forest road network in a project area of 400 ha from Trauch Forest District, Lower Austria which has restricted access to the forest

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stands. These stands can be reached only through old valley roads which are exposed to the risk of damages by natural calamities (e.g. melting snow, high level of summer precipitations) at an interval of 2-3 years. Moreover, existent valley roads cannot provide easy access to all forest compartments and the activities of sustainable forest management cannot be realized in an appropriate manner. The following issues have to be solved: restricted access to the forest stands and tending operations difficult to realize, increased costs of road maintenance, high harvesting costs and high risk of accidents among forest workers. Because of damaged valley roads, the access to the stands from upper part of the slopes is limited, making forest operations possible to be realized only by use of downhill cable yarding systems. This harvesting technology involves high costs in comparison with other harvesting systems, and a particularly increased risk of accidents among the forest workers. Therefore, feasible solutions must be found in order to solve the identified issues, to promote sustainable forest management and to reduce the amount of values at risk (e.g. forest workers, fixed assets).

In line with the identified issues, the main goal is to develop a new forest road network with slope roads using state of the art tools in order to: improve the access to forest stands and to facilitate tending operations and other forest management activities; to reduce harvesting costs; to create possibility for using harvesters, forwarders and uphill cable yarding systems; to assess the construction costs of the forest road network.

2. Materials and Methods

A combined approach of project management and utilization of state of the art tools in road network planning has been used for achieving the set goals.

2.1. Project management

The methodological approach followed the fundaments of project management [4], the study being carried on in several stages. During the start phase of the project the problem statement was defined and the project objectives, goals, tasks and responsibilities of the team members were set. The project team consisted of project owner, project coordinator and project team member which have consistently communicated and agreed important issues in project elaboration. Then followed the literature research, the first survey of the project area and the general planning, consisting of the compass step method and zero line designing followed by field measurements and data collection phase. The office work phase, marked by the data processing and elaboration of analysis and assessments, required the use of state-of-the-art tools for forest road network planning (RoadEng®, ESRI® Arc GIS and Microsoft® Excel). The results phase, gathered the achievements of previous stages which were communicated to the project stakeholders and after experts´ approval, the project was closed down by the project owner.

2.2. Proceedings of the road network planning

In the inception phase of the road network planning the borderlines of the project have been defined and clear demands and restrictions have been set by the project owner [9]. Then the basics for the planning that were needed for mapping out the project area have been prepared (e.g. maps, aerial views, terrain models etc.). The project area was thoroughly investigated and a map of construction difficulties was developed. On the map were pointed out the existing roads (e.g. public and hauling roads, skidding tracks) and the suitability of those. During this surveying phase a rough mapping of slopes, description of local morphology of the terrain and of the geomorphologic and hydrologic characteristics has also been made. Further on, in the field, the positive and negative cardinal points were identified and marked on the map.

After fulfilling these inception steps the technical planning of different alternatives started and a general planning with the compass step method [9] has been developed on a contour line map, followed by field measurements and zero plane marking in the field [3]. The project entered then in data processing phase, meaning detailed project planning; horizontal alignments, cross sections, longitudinal profiles and plans have been designed using RoadEng® software.

The final stage of the proceedings was the preparation of the documents for the authority approvals: general map of the project area (scale 1:50000), data collection protocols, plan of the forest road network (scale 1:2000), longitudinal profiles (scale 1:500), cross sections (scale 1:50) and technical report.

2.3. State of the art tools used for detailed road network planning

The data has been analyzed and processed using the state of the art tools for forest road network planning: RoadEng® software for detailed project planning (calculation of earth mass movements; serpentine design, horizontal and vertical curvature corrections; cross sections design; plan of the designed road; longitudinal profile; technical report), ESRI® Arc GIS for mapping of the new forest road network and Microsoft® Excel data sheets and synthetic tables.

RoadEng® Forest Engineer version is especial Canadian software for planning and designing forest operations and forest roads, consisting of three modules [10]: Survey/Map, Terrain and Location.

The Survey/Map module provides facilities for field note capture, adjustment and display. It can be used with a variety of survey equipment and accuracy requirements, including clinometer, compass and theodolite. A complete range of survey data management facilities from field note entry to production of scaled maps are provided. A plan window allows user to review one or more traverses. Traverses can be closed, adjusted, shifted and joined in a variety of ways. Raw data, reduced coordinates, closing errors and areas can be displayed, printed or exported to other software such Microsoft® Excel or ArcView® GIS [10].

The Terrain module is a mapping package where features can be selected, edited, formatted and manipulated by name, coordinate range, property or layer. Digital images in formats like BMP, JPG, TIF, DXF, DWG can be imported and used for reference. Imagery such as orthophotos with georeference information can also be included. Images can be scaled, rotated and positioned, and used as a background on which to trace features, calculate areas, distances and angles. Features can be edited in the Profile window allowing for creation of detailed site plans. Output can be printed or exported to CAD or GIS [10].

Using the outputs of Terrain module, the GPS coordinates collected in certain surveyed points from the project area were assigned in AutoCAD® to points on the alignment of the designed road and in this way geo-referencing the plan of the road network was realized [3]. The geo-referenced plan of the road network was imported in GIS, where, together with available orthophotos and forest data base, a map of the project area with the designed forest road network was generated.

The Location module (Figure 1) uses four main windows: Plan, Profile, Cross Section and Data, plus the sub-windows: Horizontal curves, Vertical Curves and Culverts. Each of these windows provides customizable feedback during design. An adjustment made to the alignment in the cross section window will immediately affect the data window volumes, and the slope stake projections displayed in the profile and plan windows. A template editor allows the creation of turnouts, curve widening, bridges and cut benches. Culverts can be interactively positioned, accounting for size, length and gradient. A configurable data reporting window allows the user to display, print or export design data [10].

RoadEng® software has been used for detailed planning of the Trauch forest road network. The field data that has been introduced in the Survey module was processed in the Location module following the next procedure:

- Defining special templates (Earthwork, Rocky area, Culverts);
- Assigning the defined templates to certain sectors of the forest road;
- Making the final adjustments (horizontal and vertical curves alignment);
- Printing out the results (e.g. cross sections, situation plan, longitudinal profile, reports).

The templates refer to special elements of the road that must be applied during designing, depending on the type and characteristics of terrain geomorphology, slope and difficulty of the terrain. They include details regarding the width of the road bed and of the pavement, ditches, side slopes and type of the profiles (mixed, cut, fill). In case of rocky terrain the width of the road bed was defined to 4.50 m and in case of earthy terrain to 5.00 m. In both cases the pavement was designed in a crown shape with slope of 3% on each side. The width of the pavement was defined to 3.50 m for rocky terrain and to 4.00 m for earthy terrain. The slopes of the cuts and fills were defined accordingly with the side slopes of the terrain in the surveyed points. In the culverts template, the distance between pipes was set to 70 m, and the type and the diameter of the culverts was also defined (metallic pipes with diameter of 400 mm for ditch water evacuation, and of 600 mm or 800 mm for existing streams). The position of the culverts was adjusted according to the longitudinal profile.

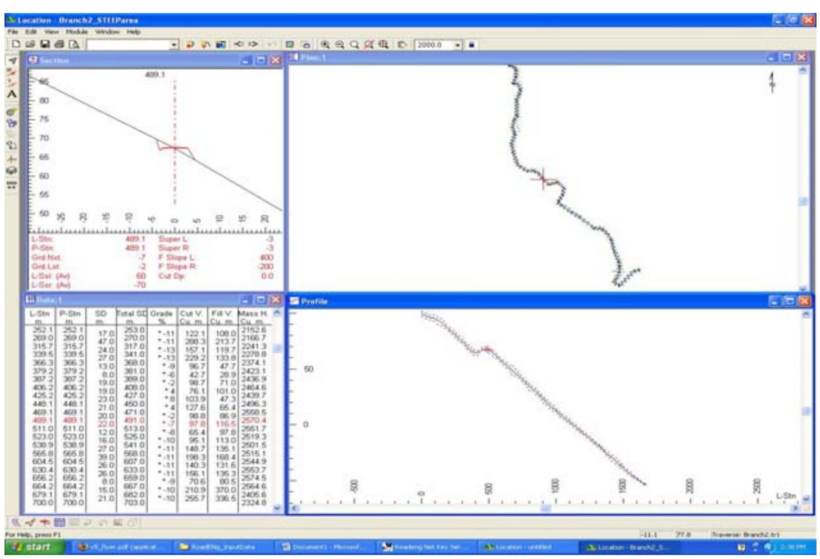

Fig. 1. *Location Module in RoadEng®*

2.4. Project area

The project area of 400 ha is located in the southern part of Lower Austria, in Trauch Forest District. The elevation varies between 750 m and 1300 m above sea level. Beech forests (*Fagus sylvatica* L.*)* with fir (*Abies alba* Mill.), maple (*Acer pseudoplatanus* L.) and ash (*Fraxinus excelsior* L.), spruce - fir - beech forests (*Picea abies* L.) and spruce - fir forests with oak (*Quercus robur* L.) represent the natural type of forests in this region [6]. The climate is characterized by cold winters with average January temperatures of –2.6 °C, and hot summers with average July temperatures of 15.5 °C. The annual average temperature is 6.5 °C and the annual average precipitation is about 1300 mm, with 800 mm during vegetation season. The yearly average new snow deposit is of 286.2 cm, from November till April, with a maximum in March (108 cm) [11]. The main wind direction is from north as the Alpine mountain range acts like a belt in the southern part. However, southwestern winds must be considered, as they might cause damages to the forest stands, especially because of the mainly northern exposition of the project area. The geomorphology is characterized by dolomites and limestone (96%), and by alluvial valley deposits (4%). About 7% of the project area is located in flat terrain (slope <25%), 45% in moderate slope conditions and 48% in steep terrain (>55%, Figure 2). Current forests in the project area are dominated by maple (41%), beech (32%) and Norway spruce (22%), more than 50% of these forests being over aged (>120 years). The forest road density in project area is about 18.5 m/ha, due to mainly surrounding valley roads, but taking in consideration damaged valley roads the density reduces to 14.9 m/ha.

Current main harvesting technology used in the project area is downhill cable yarding systems (medium and long distance). This technology is rather expensive and involves an increased level of work complexity and stress for the labor, which is always exposed to risk due to the payloads that are hauled downhill. A new slope road network would reduce the harvesting costs, the risk of accidents and would provide safer work conditions and less stress for forest workers.

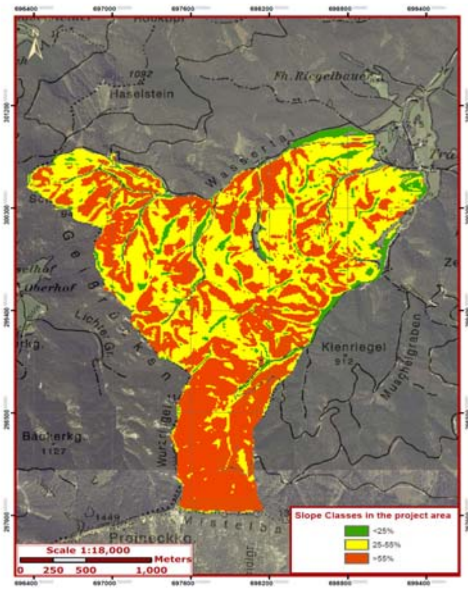

Fig. 2. *Structure of forest stands by slope classes in the project area* [3]

3. Results and Discussions

The general planning of Trauch Forest Road Network consisted in planning and marking in the field the zero plane of the forest road. The main focus was on driving the future road on the upper part of the slopes in order to make possible the use of uphill cable yarding systems. For areas with moderate slopes, the use of harvesters and forwarders are recommended and therefore attention was paid to reach such areas by the designed forest road.

The decision making process regarding the choice of best solution of road network followed a sequential pattern. In the early stage of designing process resulted a road network consisting of one main road and of two branches, in which two variants were proposed for opening up the "Geisstein" region in the project area: first one on the NW side and the second one on the SE side of the Geisstein ridge. These solutions were presented to the project owner, underlining that the SE variant for opening up the Geisstein region has to cross two negative cardinal points: first one, the habitat of an important chamois goats family, and second one, the Geisstein Stone with a surplus of blasting and rock excavation needed due to the difficult terrain. However, through a participatory process of the project stakeholders, the SE variant was chosen, even though two negative cardinal points had to be crossed. During zero plane designing phase in the field, other variants for opening the project area were identified and agreed with the project owner, resulting a final road network with a main road and four branches (Table 1). The main branch has a length of 13.35 km and the secondary branches are in length of 0.75 km, 1.68 km, 0.32 km and 1.00 km respectively, resulting a road density of 42.77 m/ha and a road distance of 234 m. Special attention was paid to slope gradient of the new forest road so that the traffic could develop with easiness and the negative impacts of erosion would be reduced to minimum. Accordingly, slope gradient change in between consecutive pegs was kept in the range of 3-5%, resulting a road network with slope gradients below 9% for 12.35 km and slope gradients between 10-12% for 4.15 km. For short distances, slope gradients of 14% to 16% have been used. For the road drainage, 250 metallic pipes with diameter of 400 mm were set at an interval of 70 m. For crossing permanent water streams, metallic pipes of bigger diameter (7 x Φ600 mm and 5 x Φ800 mm) were designed in combination with fords and downhill stabilizing stone walls, in length of about 150 m.

Approximately 14.50 km (85% of the road network length) can be built in cut/fill profile. The rest of 15% (2.60 km) passes through rocky and steep terrain and will be built in full cut profile. An important aspect of the designed forest road network is the cost efficiency analysis. Using RoadEng® a data report has been generated with information about the longitudinal and side slope gradients, direction, distance between surveyed points (pegs), the positioning of curves and their radius and about the earth mass movements. These data represented the basis for the cost calculations and technical report elaboration.

The efficiency analysis counted the benefits the forest owner will earn by implementing this project. Investment effort, improved

General characteristics of Trauch Forest Road Network Table 1

Specification	Branches					Total
	Main	B1	B2	B3	B4	
Total Length [km]	13.35	0.75	1.68	0.32	1.00	17.10
Rocky area [km]	1.74	0.13	0.65	0.00	0.06	2.58
Fords /Stone Walls [m]	0.00	99.20	45.00	0.00	8.00	152.20
Φ 800 mm culverts	4	1	3	0	2	10
Φ 600 mm culverts	2	0	2	0	1	5
Segments ≤9% [km]	10.53	0.55	0.52	0.32	0.43	12.35
Segments 9-12% [km]	2.47	0.20	1.08	0.00	0.40	4.15
Segments ≥12% [km]	0.35	0.00	0.08	0.00	0.17	0.60

access to forest stands for tending operations and the safety of labor in forest operations were equally important in assessing the overall benefits of the new road network. The return on investment was calculated considering road construction costs, its maintenance costs and timber harvesting costs [1] for 30 years, at an interest rate of 4%. The overall average construction cost is 33.52 €/m. Construction costs vary from 25-30 €/m in moderate terrain conditions to 49.00 €/m (branch B1) and 62.50 €/m (branch B2) in difficult terrain conditions. Before the new road network design only 14% (56.18 ha) of the project area could be harvested by skidder or tandem harvester - forwarder, for the rest of 86% of the area (345.02 ha) downhill cable yarding system has to be used. Under these circumstances, the average extraction costs were 27.90 €/m^3. With the new road network, the area where the use of skidder, harvester and forwarder technologies became possible is reasonable, increasing to 211.60 ha and 189.60 ha can be harvested by uphill cable yarding systems. Thus the harvesting costs decreased to 22.60 €/m^3.

The *Plan* window (Figure 3) of *Location module* in RoadEng® for branch B2 shows details of alignments and horizontal curves, culverts positioning and earth mass movement. The black line represents the zero planes marked in the field and the red

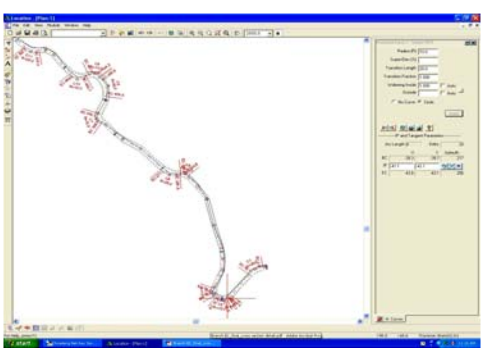

Fig. 3. *Plan window in Location module, RoadEng®* [3]

dotted line represents the alignment of the road after adjustments in RoadEng® have been made. Each curve has specified its radius, starting, center and ending points.

The assessment made using state-of-the-art RoadEng® software had an essential importance for the successful achievement of the project objectives.

4. Conclusions

The aim of this paper was to design a forest road network in project area of 400 ha from Lower Austria in order to improve the access to the forest stands, to reduce the harvesting costs and the amount of values at risk from the project area. The forest road network designed has a total length of 17.11 km and consists mainly of forest roads conducted in the third upper part of the slopes. The main advantage of this fact is that construction and maintenance costs will be cheaper than in the case of existing valley roads. The combined use of RoadEng® and ESRI® Arc GIS proved to be very useful in the decision making process, as it provided sound information regarding the cross sections, earth mass movements, longitudinal profile, drainage system and possible road variants, data which represented the back bone for the cost efficiency analysis. The average road construction costs is 33.52 €/m, and the harvesting costs have decreased from an average of 27.90 €/m^3 before the new road network planning to an average of 22.60 €/m^3 after planning the road network. The increased road density and the opened access to the third upper part of the slopes make forest operations easier, cheaper and in safer conditions to be realized.

As presented in this paper, using state of the art tools for planning forest road networks, for making assessments and sensitivity analysis facilitates the decision making process in forest engineering.

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