INFLUENCE OF EXISTING SECONDARY FOREST ROAD NETWORK ON THE SELECTION OF TIMBER EXTRACTION TECHNOLOGIES AT THE TACTICAL LEVEL OF PLANNING

Kruno Lepoglavec, PhD, Faculty of Forestry, University of Zagreb, Croatia, lepoglavec@sumfak.hr
Tibor Pentek, PhD, Faculty of Forestry, University of Zagreb, Croatia
Ivica Papa, PhD, Faculty of Forestry, University of Zagreb, Croatia
Mario Šporčić, PhD, Faculty of Forestry, University of Zagreb, Croatia
Matija Landekić, PhD, Faculty of Forestry, University of Zagreb, Croatia
Hrvoje Nevečerel, PhD, Faculty of Forestry, University of Zagreb, Croatia

Abstract: Planning is an intellectually demanding process that requires a conscious determination of actions and decisions based on related purpose, knowledge and right decisions. During planning timber harvesting it is very important to choose the best possible technology for timber extraction. The use of multi-criteria-decision-making models is a very good way of dealing with various forestry issues especially in terms of choosing the best applicable technology for timber extraction. Modern forest management in the Republic of Croatia in terms of timber harvesting mostly relies on ground based wheeled systems. The goal of this research is to show how the current way of planning timber harvesting (timber extraction) and accordingly the construction of secondary forest road network affects future planning and introduction of »new« technologies for timber extraction i.e. forest cableway. Analysis of suitable forest stands for different timber extraction technologies was carried out in the management unit Garjevica-Čazma with an area of 4380.20 ha. The paper presents multi-criteria-decision-making model for defining terrain suitable for ground based wheeled systems (skidder with a winch and forwarder) and forest cableway on the base of raster maps (grid of 20×20 m i.e. 0.04 ha). The criteria used to select different technologies for timber extraction were: terrain slope, distance from the forest road, distance from the skid road and harvesting density. Analysis using GIS tools in ArcGIS and Idrisi applications goes in two directions, first the analysis of suitability of using selected technologies for timber extraction using four criteria, and comparison with results of the analysis where the criterion »distance from the skid road« has been excluded.

Keywords: harvesting technologies, multi-criteria analysis, secondary forest roads, GIS tools

INTRODUCTION

One of the main objectives of forest management, while maintaining sustainable forest ecosystem is gaining revenue from timber itself. Efficient timber harvesting is based on good quality forest road network, proper selection of work equipment and technology for timber extraction and experienced forestry workers (Stampfer, 2010). In many cases the selection of technologies depends on the existing forest transport infrastructure (forest roads, skid roads, skid trails), and sometimes
it is impossible to ignore the investment in the construction of secondary forest roads used for ground based wheeled technologies used of timber extraction. A well developed network of secondary forest roads in many forest areas of Croatia is certainly one of the reasons why cableways are not usual in forestry practice opposed to forwarders and winch skidders. So far, in Croatia selecting the most appropriate technology for timber extraction was mostly based on experiential selection of responsible persons without defining a strategy or with regard to terrain characteristics of a specific area. To avoid subjectivity in decision making more often different methods of multi-criteria decision-making and the different techniques of group decision-making are being used, which proved to be a good way of dealing with forestry issues (Lepoglavec, 2014). Models of multi-criteria decision making are usually applied in cases where it takes a holistic review and evaluation of various alternatives, where the overall analysis is more difficult because of the high number of hardly comparable criteria and conflicting interests that influence the decision-making process (Šporčić et al., 2010). In this way, the application of multi-criteria decision making models in today’s demanding and complex forestry management planning can be simplified. Although multi-criteria decision making in forestry is known for more than 30 years (Field, 1973), newer approaches and techniques and multi-criteria group decision making are starting to use significantly only in the early 90s (Kangas, 1992), and this is confirmed by many other scientists (Vincke, 1992; Triantaphyllou, 2000;Koksalan and Zionts, 2001; Kahraman, 2008). Krč (1995) used the AHP method in combination with GIS application Idrisi, where on the basis of six criteria selects the most appropriate harvesting systems. Later, Košir and Krč (2000) used the same model for multi-criteria decision making for comparison of terrain data obtained by the model with data gained form the management plan for area Jezersko in Slovenia. Rauscher et al. (2000) with regard to a number of criteria, with the use of AHP method, evaluate four alternatives in forest management. Kangas et al. (2001) analyze the case of forest management in Eastern Finland with three multi-criteria techniques: MAUT, ELECTRE and PROMETHEE.

Applying DEA methods Kao (1998) measures the efficiency of forest districts in Taiwan. Pentek et al. (2008) applied a decision support system in the area of commercial forests of the national park Northern Velebit. Lubello (2008) developed a spatial decision support system (SDSS) with the use of the digital elevation model, soil properties, the annual amount of precipitation, road network, data on growing stock all with use of ArcGIS software package for complete planning of forest harvesting in the region of Veneto in Italy. In the last ten years numerous scientific papers have been published rating the application of multiple criteria decision making (MCDM) and tools for joint decision-making on issues related to forest management. In this respect, Kangas et al. (2008) as well as Ananda and Herath (2009) presented a comprehensive review of the literature identified and described several multiple criteria decision making methods which have been tested and applied in forest management. Using multiple criteria SDSS methods Kühmaier and Stampfer (2010) determine suitable areas for ten selected harvesting systems. Decision support planning for the construction of forest roads Samani et al. (2010) developed a model of planning forest roads using GIS and AHP methods at the same time. The research method in AHP considered influential factors: terrain slope, soil type, geology, hydrological conditions, exposure, growing stock, species and digital maps. Given that the most commonly used method in forestry is MAUT, Enache (2013) also uses this method in the evaluation of forest road alternatives to the preferences (needs) of test participants.

Analysis of different timber extraction technologies use spatial data at the level of department (sub-department) or at the level management units (MU) with the help of GIS technologies which use has led to the integration of different tools, including methods of multiple criteria decision making. Decision-making is based on various raster maps, multiple layers of digital maps, i.e. cells which are the basic elements of each raster map. The possibility of making automated models is faster data analysis, easy repetition and simulation of different versions with regard to the set priorities and used input database (Lepoglavec, 2014).
The aim of this study is to show, based on the model of multi-criteria analysis, the impact of existing secondary forest transport infrastructure in the future selection of technologies for timber extraction with regard to several criteria (terrain slope, distance from the forest road, distance from the skid road and harvesting density). Results of the analysis suggest suitable areas for different harvesting systems and potential areas for possible change in technology of timber extraction.

RESEARCH METHODOLOGY

Forest road cadastre (field measurements and data collection)

For recording forest roads in the field GPS device Garmin GPSMAP 62S was used. External antenna of GPS receiver was placed on the roof of a car and with a slow movement of the vehicle on the forest road, with a maximum recording interval of 5 seconds, data was recorded. When recording skid roads, one must walk and recording interval is also 5 seconds. The measurement of primary forest roads is carried out by one pass with a GPS device and with additional corrections using ortho-photo maps of the study area. The recording of secondary forest roads is also carried out by one pass and on the basis of the line and point data the route is plotted on topographic maps at the scale of 1: 5000.

The process of data collection includes recording of forest road route (track log) with marking each intersection and both beginning and end of recorded forest roads. Marking gives a better possibility of interpretation of data and enables easier mapping of roads in GIS and eliminate the errors of GPS during a poor signal.

Rasterization of input data

Stand information and data on forest transportation infrastructure were gained from the company Hrvatskešume Ltd., but those collected in the field by GPS recording were in vector form (points, lines and polygons). After the establishment of the GIS and design of database in ArcMap, all vector data were assigned certain values that describe individual stands, forest road, skid road etc. For the purpose of implementing the analysis program in Idrisi it is necessary, for each criteria entry used in the analysis to prepare maps in raster format. Converting vector to raster data characteristics of particular criteria, each cell gained its data (covering MU/department/sub-department area). During vector to raster data conversion it is extremely important to align the coordinates of each cell layer in order to make further analysis.

Selecting harvesting systems

Given the current availability, tradition and the possibility of applying different systems in Croatian forestry, three harvesting systems were selected. Between them the selection of the most suitable one for the given MU was carried i.e. the most suitable areas for given technologies were selected.

Selected three harvesting systems:
- Chainsaw – Forwarder
- Chainsaw – Skidder with winch (60 m length)
- Chainsaw – Forest cableway (with grapple)

In determining surface that are the most appropriate for a particular timber extraction technology multiple criteria decision making model (Krč, 1995) was used with the following input criteria: terrain slope, distance from the forest road, distance from skid road and harvesting density for first half-period of management plan. Such selection of criteria is based on the studied literature where a large number of authors referred to terrain characteristics and forest transportation infrastructure influence the most the selection of timber extraction technology. MacDonald (1999) gives the highest importance to terrains characteristics, whereby terrain slope is the most important factor, because it directly affects the selection of technologies. Favourable terrain allows the use of a wide range of different harvesting systems, and as it becomes more demanding, the choice is reduced (Parker and Bowers, 2006). The choice of timber extraction vehicles (skidder, forwarder, forest cableway) refers to field factors (relief areas) and the level of primary and secondary forest openness as the most important determinant of the entire harvesting systems (Poršinsky, 2008).
Questionnaire for defining weight relationship of criteria

In order to find weight relations in the analysis of suitable terrain for selected technologies a questionnaire was used. The purpose of the questionnaire was that based on the opinion of scientists dealing with harvesting technologies and forest opening gave the relationships between the selection criteria for the spatial analysis and applying certain technology. The questionnaire included the evaluation scores on a scale of 1 to 4 for each criterion of selected technology for timber extraction. Questionnaire included 20 scientists from Croatia and from several European countries. Based on the collected, rating values were standardized to scale of 0–1 from which mutual relations were calculated and a square-reciprocal matrix to obtain the ratio by weight of each criterion was created.

Multi-criteria decision making

Using designed database in program Idrisi, a model for multiple criteria decision making has been developed. It has its application in the process of strategic and tactical planning. The method of multi-criteria decision-making – the objectives of individual analysis have been formulated, for each of the target criteria and their evaluation have been defined. Analysis using GIS tools in ArcGIS applications and Idrisi goes in two directions, analyzes of possibility to use selected technologies for timber extraction and comparison with results of the analysis where the criterion »distance from skid road« has been excluded. Thus obtained two scenarios that were ultimately compared and a conclusion on the significance of the secondary forest road network on the choice of timber extraction technology can be gained.

Model of multi-criteria decision-making in Idrisi program uses tools Reclass, Fuzzy, MCE and MDChoice, according to Krč (1995) guidelines. Applied algorithm (Krč, 1995) can be identified with MAUT method, which is used by a large number of authors in selecting harvesting technologies based on various criteria.

In order to find weight relations in the analysis of suitable terrain for selected timber harvesting technologies, results of the questionnaire given to scientists specialized in timber harvesting and forest road planning were used (Lepoglavec, 2014).

Square-reciprocal matrix on the basis of the average value of the results of the questionnaire and the relationships between them were made. Matrixes were standardized by scale interval 0–1 which established the weight of each criterion for each of the alternatives.

Data were standardized by this formula:

\[ x_i = \frac{(R_i - R_{\text{min}})}{(R_{\text{max}} - R_{\text{min}})} \cdot X_{\text{max}} \]

Where is:

- \( x_i \) – standardized value
- \( R_i \) – base value
- \( R_{\text{min}} \) – lower value of base scale
- \( R_{\text{max}} \) – upper value of base scale
- \( X_{\text{max}} \) – upper value of standardized scale

For fuzzy criteria evaluation (also value scale from 0 to 1) data from the dissertation Lepoglavec (2014) were used, and they represent the synthesis of a large number of research data in the area of selecting different timber extraction technologies and the importance of each criterion in their selection. Fuzzy curve defined by four points were used and for each technology, according to the criteria, the most suitable curve were selected (Figure 1, Figure 2 and Figure 3). Used parameters for curves are shown Table 1.

The result of MCE tools is a map of specific criteria suitability on a scale from 0 to 1 for each alternative. MD Choice tool compares (gives) the best alternative, i.e. the final selection of the most suitable timber extracting technology for each cell measuring 0.04 hectares. Schematic representation of MCE and MD Choice tools is presented in figure 4. In addition to the suitability map, a map of absolute limits, which has values of 0 and 1, can be included. The program gets a command to perform the calculation if the value of limiting cell is 1 and assign the overall value to 0 if on those coordinates limiting cell value 0 is present (not the research area or there is a limitation on forest management).
Table 1. Parameters of fuzzy curves evaluating for selected timber extraction technologies (Lepoglavec, 2014)

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Forwarder</th>
<th>Skidder</th>
<th>Forest cableway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sigmoidal curve, decreasing</td>
<td>Sigmoidal curve, decreasing</td>
<td>Sigmoidal curve, symmetric</td>
</tr>
<tr>
<td>Terrain slope</td>
<td>a, b, c = 10 %</td>
<td>a, b, c = 35 %</td>
<td>a, b, c = 0 %, d = 35 %</td>
</tr>
<tr>
<td></td>
<td>d = 30 %</td>
<td>d = 60 %</td>
<td>c = 100 %, d = 120 %</td>
</tr>
<tr>
<td>Distance to road (forest+public roads)</td>
<td>Linear curve, decreasing</td>
<td>Linear curve, decreasing</td>
<td>Linear curve, decreasing</td>
</tr>
<tr>
<td></td>
<td>a, b, c = 0 m</td>
<td>a, b, c = 0 m</td>
<td>a, b, c = 0 m</td>
</tr>
<tr>
<td></td>
<td>d = 2000 m</td>
<td>d = 1000 m</td>
<td>d = 1600 m</td>
</tr>
<tr>
<td>Distance to skid road</td>
<td>Linear curve, decreasing</td>
<td>Linear curve, decreasing</td>
<td>No impact value = 0</td>
</tr>
<tr>
<td></td>
<td>a, b, c = 0 m</td>
<td>a, b, c = 0 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d = 20 m</td>
<td>d = 60 m</td>
<td></td>
</tr>
<tr>
<td>Harvesting density (annual cut)</td>
<td>Linear curve, increasing</td>
<td>Linear curve, increasing</td>
<td>J curve, increasing</td>
</tr>
<tr>
<td></td>
<td>a = 0 m³/ha</td>
<td>a = 0 m³/ha</td>
<td>a = 0 m³/ha</td>
</tr>
<tr>
<td></td>
<td>b, c, d = max</td>
<td>b, c, d = max</td>
<td>b, c, d = max</td>
</tr>
</tbody>
</table>

Figure 1. Forms of linear fuzzy graphs

Figure 2. Forms of sigmoid fuzzy graphs

Figure 3. Forms of “J” shape fuzzy graphs
Calculation of suitable areas for defined technologies

Upon completion of the analysis, final maps include terrain divided into three categories: the most suitable terrain for forwarder, the most suitable terrain for skidder and the most suitable terrain for cableway. Each category is displayed by different colour (blue, red, green). Spatial analysis with ArcGIS exclude the surface of each selected technology within the MU (compartments) so that the number of cells belonging to a particular technology is multiplied with a known surface area of one cell (0.04 ha or 20×20 m).
RESEARCH AREA

For the purpose of this research MU Garjevica-Čazma, Čazma Forest Office, Forest Administration Bjelovar was selected. It is located in the continental part of Croatia, dominated by terrain slopes that from the point of forest opening and timber harvesting present difficult terrain conditions. It covers the area of the mountain massif Moslavačkagora between 16°35′ and 16°55′ longitude of Greenwich and 45°40′ and 45°45′ north latitude. Forests of today’s MU Garjevica-Čazma are remains of a former forest of pedunculate oak and European beech, which covered the whole Moslavačkagora. It is situated in one forest complex and in the economic, gravitational and stand sense represents a single entity. Area of MU is very well indented with distinct ridges and ditches to the north and south as well as a large number of small ridges and ditches in all directions. The slopes of small inclination are located mainly in the north and western part of the management unit. The MU covers an area of 4,380.20 hectares and is divided into 84 compartments and 327 sub-compartments. The maximum altitude is in department 47 and is 350 meters above sea level, and its lowest point of the terrain in 27th department and is 110 meters above sea level. Total length of forest roads in MU is 48.70 km and with 10.45 km of public roads, which gives a primary forest road density of 13.50 m/ha (Lepoglavec, 2014).

Length of secondary forest roads amounts to 619.62 km on the entire surface of the MU, and the density of the secondary forest road network is 141.50 m/ha. Allowable cut is determined for each management class, by sections and tree species, and is divided to the following groups of assortments at the level of MU. 17.9% of growing stock is cut, or 73.9% of the increment. The most common tree species is beech with 50.4%, followed by pedunculate oak with 27.4%, 10.2% of linden, common hornbeam with 8.9%, with 0.8% of spruce and alder to 0.7%. Other tree species account for a very small percentage or individually. Timber extraction technologies used on almost the entire surface is cut by, combined with the double-drum winch skidder (rope length 60 m) (Lepoglavec, 2014).

RESULTS

Weight relations between criteria

The end result of standardization of criteria and their weight for a particular technology is shown in figure 6. In the opinion of scientists the suitability of timber extraction by forwarder, the greatest impact criterion is terrain slope, and the lowest criterion is harvesting density. For skidder the greatest weight is on criterion of distance from forest roads and distance from skid road and lowest is harvesting density. In the application of forest cableway the most scored criterion is harvesting density and minimum is distance criterion (skid road).

![Figure 6. Weight relations of defined criterions by given questionnaire](image-url)
Analysis of terrain suitable for scenario 1 and 2

Based on suitable terrain maps for selected technologies in MU maps of both scenarios (with and without the criteria of distance to skid road) were made. Each map contains a representation of the terrain divided into three categories: the most suitable terrain for a forwarder, the most suitable terrain for a skidder and the most suitable terrain for a forest cableway (Figure 7). You can clearly see the prevalence of the skidder in scenario 1, because of the dense secondary forest roads network that are in the first scenario taken into consideration when choosing the technology, while in scenario 2 it leads to significant changes — the share of forwarder increases by 13%, forest cableway by 22%, while the share of land suitable for skidder decreases by 35%. Surfaces in both scenarios presented in the relative level of the entire MU are displayed in Figure 8. Finally, in both scenarios the dominant technology for the entire MU is the skidder (> 50%), suggesting the result of multi-criteria analysis.

Figure 7. Map of the terrain suitable for different technologies in two scenarios
In order to get a share of each technology within compartments and to determine compartments in which there are considerable differences between scenarios 1 and 2, surfaces suitable for selected technologies were excluded. The result is displayed in charts for scenarios 1 and 2 (Figure 9), where a percentage of selected technologies is visible in every department. Unlike scenario 1, where in all compartments the prevailing technology is skidder, it is notable that scenario 2 leads to significant changes in several compartments. So, in a total of 5 compartments the forwarder becomes the dominant technology, and in 12 departments the prevalent technology is the forest cableway. In the other 67 compartments the skidder still remains dominant.
Statistical significance between scenario 1 and 2 – T test

T-test of dependent samples (Table 2) estimated the resulting benefit to the work with selected timber extracting technologies (forwarder, skidder, forest cableway) in both scenarios, i.e. the analysis of the existence and use of secondary forest transport infrastructure (scenario 1) and the lack of secondary forest road infrastructure within the same management unit (scenario 2).

All three selected technologies seen from the standpoint applicability/benefits for use in the context of scenarios 1 and 2, showed a statistically significant difference with T-test (Table 2). However, the resulting tabular results do not show the actual size differences between the applicability/benefits of different technologies for timber extraction. Size differences between the compared technologies were calculated according to Cohen (1988) by the use of eta square. The maximum value of eta squares obtained in terrain suitable for the skidder (0.892) is compared within two scenarios, which is visually confirmed in Figure 10. In the application of the forest cableway within two scenarios a minimum difference (eta squared = 0.648) was recorded, while in comparisons for forwarder eta squared was 0.803.

Table 2. T-test results between scenario 1 and 2 by compartments

<table>
<thead>
<tr>
<th>Harvesting technology</th>
<th>Mean (%)</th>
<th>Std.Dv (%)</th>
<th>N</th>
<th>T</th>
<th>df</th>
<th>p-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Forwarder</td>
<td>9.7</td>
<td>8.7</td>
<td>84</td>
<td>-18.369</td>
<td>83</td>
<td>0.00*</td>
</tr>
<tr>
<td>2 Forwarder</td>
<td>22.5</td>
<td>12.7</td>
<td>84</td>
<td>26.189</td>
<td>83</td>
<td>0.00*</td>
</tr>
<tr>
<td>1 Skidder</td>
<td>87.0</td>
<td>8.3</td>
<td>84</td>
<td>-12.502</td>
<td>83</td>
<td>0.00*</td>
</tr>
<tr>
<td>2 Skidder</td>
<td>52.3</td>
<td>13.4</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Forest cableway</td>
<td>3.3</td>
<td>3.6</td>
<td>84</td>
<td>-12.502</td>
<td>83</td>
<td>0.00*</td>
</tr>
<tr>
<td>2 Forest cableway</td>
<td>25.2</td>
<td>18.7</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* marked differences are significant at p < 0.01; 1 scenario 1; 2 scenario 2

Figure 10. T-test of terrain suitable for chosen technologies between scenario 1 and 2
CONCLUSIONS WITH DISCUSSION

Designed computer database of attribute and spatial data of the study area, combined with GIS and the related tools within the computer software (ArcGIS and Idrisi) provides the possibility of different multi-criteria decision making analysis using a large number of input data to obtain results which interpretation can greatly simplify decision-making and future action. With the presented multi-criteria model (especially due to its flexibility) it is possible to plan at the tactical level of planning the opening of unopened areas, where we can find the most appropriate technologies for timber extraction for specific forest terrain in an objective and fast way.

An analysis of a suitable terrain for the selected technologies for timber extraction was carried out on the basis of four criteria that at the tactical level of planning extract suitable areas for different technologies. For the lowest, operational planning level, it is necessary to introduce additional criteria such as: soil bearing capacity, stoniness and rockiness, sites of high ground obstacles, distance from the landing site etc. Certainly, we should mention the need for the use of some economic, sociological and ecological criteria in the operational planning of forest harvesting operations in order to satisfy all requirements for a sustainable management of forest ecosystems as used by Kühmaier and Stampfer (2010). Kühmaier (2011) used contribution margin as the criterion for better defining the most appropriate Harvesting system from the economic point of view.

Selected technology of timber extraction in this paper should certainly be upgraded with additional technologies, in the presented model, which could be used in a particular forest area, for example tractor equipage, adapted agricultural tractor, tractor cableway, etc.

The hypothesis stated in the title of the paper is confirmed as well as the significance of secondary forest roads during selecting the technology for timber extraction on the basis of the multi-criteria model was statistically confirmed. According to the results of the analyses for both scenarios and their comparison with the currently used technology for timber extraction (skidder) in the Management Unit Garjevica-Čazma, a part of the MU should consider using forwarders and forest cableways as technologies for timber extraction. Such a scenario should especially be considered if skid roads are closed because of high maintenance costs or unfavourable longitudinal slope in places that are more convenient for working with a forest cableway or a forwarder, as shown in Scenario 2. The results indicate that quality planning at the tactical level in the past, before the construction of secondary forest roads could set aside a certain portion suitable for the operation of forest cableways and forwarders to a greater extent than currently applied in practice.

REFERENCES


Stampfer K., (2010): Forest Engineering – Course Script. Institute of Forest Engineering, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences – BOKU, Vienna, Austria, CD–ROM.


http://portal.hrsme.hr/ (accessed 16.05.2015.)