For. review 44: 6-10. Skopje, 2013 ISSN 1857-9507 on-line: www.sf.ukim.edu.mk/sumarski_pregled.htm
UDC: 625.711.84:{528:[007:004(497.11)
Original scientific article
Article submission: May, 2013

THE STATE OF FOREST ROADS AND DETERMINING AN OPTIMUM DENSITY OF A FOREST ROAD NETWORK USING GIS

[1]DANILOVIĆ M., [1]STOJNIĆ D., [2]NOVKOVIĆ N., [1]GAČIĆ D.
[1]*University of Belgrade, Faculty of Forestry, Belgrade, Serbia*
[2]*Public Enterprise "Srbijašume", Forest Estate "Vranje", Vranje, Serbia*
Corresponding author e-mail address: milorad.danilovic@sfb.bg.ac.rs

ABSTRACT: This paper presents an analysis of forest roads and suggests new routes to increase the openness of FMU "Borovik", one of the least open forest management units in FE "Vranje" and thereby reduce the cost of skidding. The current openness of this management unit is only 2.96 m/ha, while its relative openness reaches 33.60%. Three new routes have been proposed, in order to achieve a density of 6.82 m/ha, i.e. the relative openness of 61.88%. The construction of these roads would reduce the total costs of skidding by 35%.
Keywords: planning of a forest road network, optimal density, forest opening.

1 INTRODUCTION

The establishment of an optimum forest road network in the field develops through several phases of work (Ryan, *et. al.,* 2004), including the planning, design, routing, construction and maintenance of roads. The planning of a forest road network is performed at forest area level and developed in detail in the *Program of construction and maintenance of forest roads*, which is an integral part of the *Development plan of that forest area*. This document serves as a review and analysis of the state of a forest road network. It also provides an insight into the need for the planning and expansion of that forest road network in accordance with the established functional units and purpose of the forest. The planning of a forest road network does not allow stereotypes and always represents original work, because each area has both a number of specific internal features and external diversity, so that each planning process requires a specific approach. The planning of a forest road network is a difficult and time-consuming task (Abdi, *et.al.,* 2009). The analysis of alternative routes in an office using the geographic information systems (GIS), can save days and even weeks during the planning process, and finally a better solution can be reached than by using traditional means (Rogers, 2005). Generally, the planning of a forest road network depends most on the economic and social criteria (Nasiri, *et. al.,* 2012).

This paper presents the planning of a forest road network in MU "Borovik", one of the least open management units in FE "Vranje". This planning was performed using GIS and, given that economic forests are concerned, the primary criteria included the economic, technical and technological principles.

2 METHOD

The determination of the optimum density of the forest road network was carried out in four phases, including development of the study area GIS, an analysis of the existing primary network of forest roads, design of possible routes of future forest roads, and an analysis of the newly designed forest roads.

An analysis of the existing forest road network includes the following (Pentek, *et. al.,* 2005):

- Classification of the infrastructure within the existing forest road network,
- determining of the current mean transport distance,
- determining of the current cost of skidding,
- calculation of the aimed mean transport distance,
- an analysis of the relative openness for a specific mean aimed transport distance and
- defining and identification of unopened areas.

The development of the study area GIS was performed using the ESRI ArcGIS 9 program (ArcMap 9.3). By connecting a database to a digitized map, the necessary information about each stand were obtained, which served as a basis for the production of the needed thematic maps.

The analysis of the existing forest road network was performed using detailed field observations and data on the length of roads were obtained by categories. The current mean transport distance was calculated using the centre of gravity method. The skidding costs were calculated for the LKT 81 Turbo transport vehicle that is commonly used in this forest estate for the first phase of transport. The mean aimed transport distance was determined on the basis of the optimum distance between the forest roads.

The relative openness was determined using the method of confined surfaces, with double target transport distance taken as the distance from a forest road to the edge of the confined surface. The unopened parts of the management unit were defined on the basis of the produced maps of relative openness and the maps of unit costs and total costs of skidding.

Given the purpose of the forests, the basic aspects of optimization were the economic, technical and technological principles. Therefore, the primary objective of conceptual routes was to open certain parts of the forest management unit with the largest felling volume, in order to reduce the mean transport distance and hence the cost of production.

After construction of the new routes of forest roads, we carried out the analyses of classical (absolute) and relative openness, mean transport distance and skidding costs.

3 RESEARCH AREA

This research was conducted in the management unit "Borovik", which is managed by the forest estate "Vranje" from Vranje and is part of the public enterprise "Srbijašume". The forest estate "Vranje" belongs to the South Morava forest area of the Republic of Serbia.

The total area of the management unit is 3449.36 ha. An area of 3116.21 ha within this unit is covered by state owned forests and the remaining area of 333.15 ha is

ISSN 1857-9507 on-line: www.sf.ukim.edu.mk/sumarski_pregled.htm

occupied by privately owned forests. High forests occupy 33.87% of the territory, 40.38% is covered by coppice forests, and the rest is occupied by artificially established stands, scrub, brushland and bare forest land.

According to the applicable *Special forest management plan for MU "Borovik"* (2011-2020) , the total annual felling volume for the whole period amounts to 62 748.3 m^3, i.e. on average 6 274.8 m^3 per year.

In accordance with the site and stand conditions, the type of management prescribed for the South Morava forest area is stand management. The method applied for felling and cutting of assortments in this management unit is the assortment method, with the production of assortments carried out in the stump area of the felling site. The skidding of technical wood to the landing located near a hard forest road is performed mechanically using LKT cable skidders. Firewood is usually skidded by a horse-drawn carriage or sold directly in the stump area.

4 RESEARCH RESULTS AND DISCUSSION

The GIS data for the management unit "Borovik" were taken from the *Special forest management plan of MU "Borovik" (2011-2020).* A thematic map of felling volume was produced on the basis of these data for each department. Felling volume was the starting point in the design of new routes. A digital terrain model (DTM) was produced for this management unit in order to analyze terrain slope and exposure, as important factors in the planning of a road network.

Although MU "Borovik" involves both public (asphalt) roads and gravel and unpaved forest roads, this management unit is still one of the least open units of the forest estate "Vranje". The length of roads passing through this management unit is only 1375 m, while 12914 m of forest and public roads or 77.6% of the length of all roads pass near the edge of the forest or up to 300 m from forest edge, which limits the skidding to one side of the road. In the calculation of forest openness, only 50% of the length of forest roads is calculated as their length (Šikić, *et. al.*, 1989). In the calculation of the current openness of MU "Borovik" unpaved forest paths with truck road elements were also calculated, even though they are usually not taken into account. Together with these paths, the current openness reached only 2.96 m/ha.

The mean transport distance was obtained using the centre of gravity method (Fig. 1). The shortest distance from the centre of gravity of each stand to the nearest forest road was determined automatically using the ArcMap 9.3 program. The mean transport distance was obtained as the mean weighted value multiplied by a 1.44 terrain correction factor. This coefficient was taken as the average value for the hilly and mountainous regions (Abbeg, 1978). The mean transport distance of the study area was 1357 m.

After determining the daily cost of skidding with a cable skidder, the unit costs were calculated (Fig. 3), which was followed by the calculation of the total costs of skidding for all stands in which felling was planned (Fig. 2). The daily skidding output of the LKT 81 Turbo cable skidder at the mean transport distance of 1357 m was 18 m^3, and the price of skidding amounted to € 6.59/m^3. The total costs of skidding for the entire observed area amounted to € 393437.

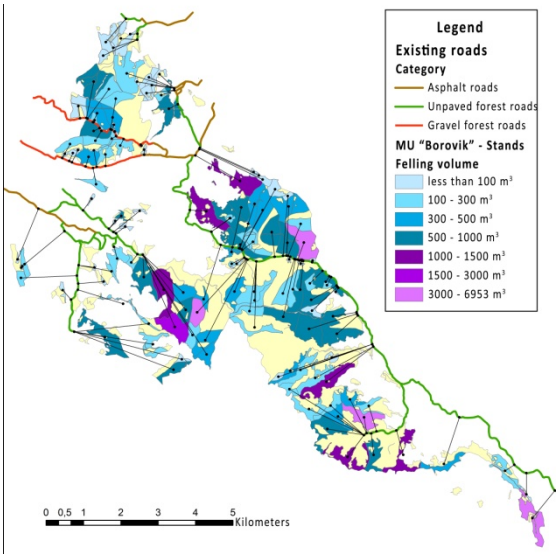

Figure 1: Felling volume and the shortest distance from the gravity centre of the stand to a forest road

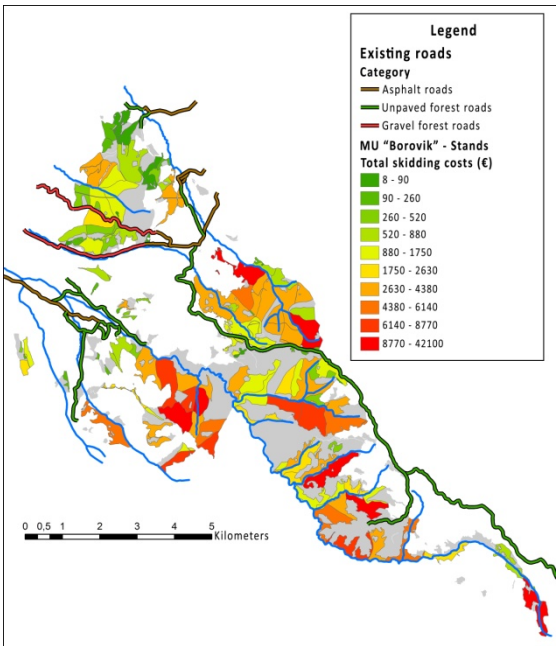

Figure 2: Total costs of skidding

The aimed mean transport distance was calculated on the basis of the optimum distance between forest roads. The optimum distance for this management unit was 1175.4 m and it was calculated using the formula (FAO, 1998):

$$S = \sqrt{\frac{4000 \cdot R}{h \cdot V}}$$

where: S – the optimum distance between forest roads (m); R – the costs of construction and maintenance (€/km); h – unit costs of assortment skidding (€/m^3/100 m); V – total felling volume obtained during the existence of a forest road (m^3/ha).

The optimum mean transport distance is S/4, i.e. 293.9 m.

The optimum openness of the forest management unit is 8.51 m/ha, and it was calculated using the formula:

$$Oopt = \sqrt{\frac{100000 \cdot h \cdot V}{4 \cdot R}}$$

The relative openness of the forest management unit is 36.20%, (Fig. 4) which means that this unit is insufficiently opened and marked with mark 1 (one) according to Pentek, *et. al.* (2005).

Given that one of the main tasks of optimizing the existing road network is the reduction of skidding costs, the parts of the forest area where it is necessary to expand the existing network were identified on the maps of unit and total costs of skidding and a map of relative openness of the management unit.

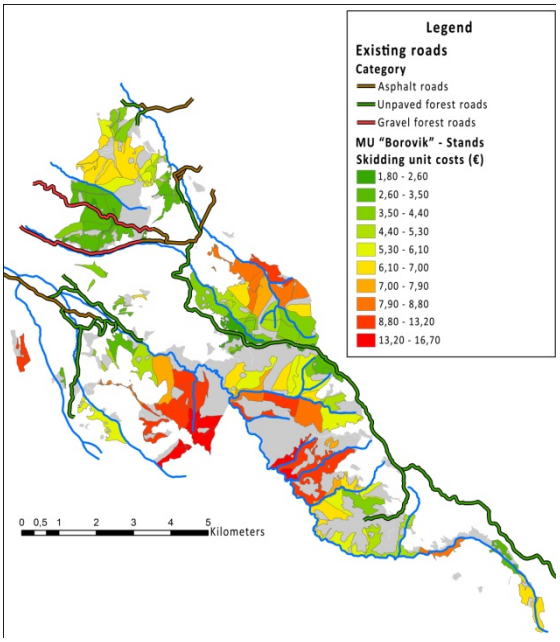

Figure 3: Current unit costs of skidding

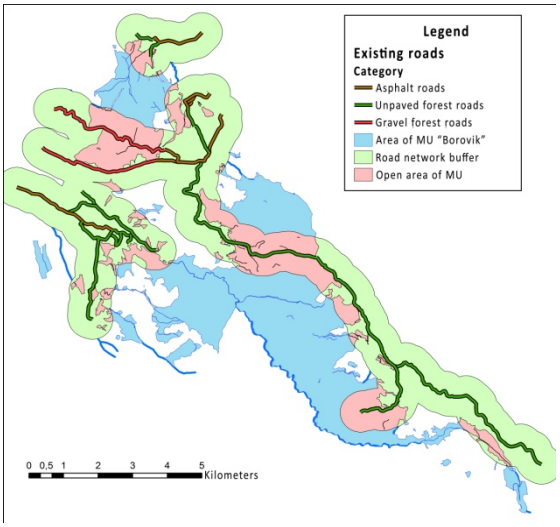

Figure 4: Current relative openness

The unit costs of skidding were the highest in the stands with the longest mean transport distance, i.e. the stands that are the farthest from the existing landings (Fig. 3). The total costs of skidding are the highest in the departments that have large felling volumes and those remote from the existing landings (Fig. 2). Looking at the map of the total costs of skidding, we can immediately see that the costs are the highest in three parts of the management unit. These parts should further be opened and new road routes should be designed in them.

After defining the insufficiently opened parts of the management unit and areas suitable for road construction, we started designing the conceptual routes and care was taken that the future routes meet all aspects of optimization, i.e. the economic, technical, technological and environmental principles. Considering all the above mentioned facts, three newly designed routes were proposed in this article (Fig. 5).

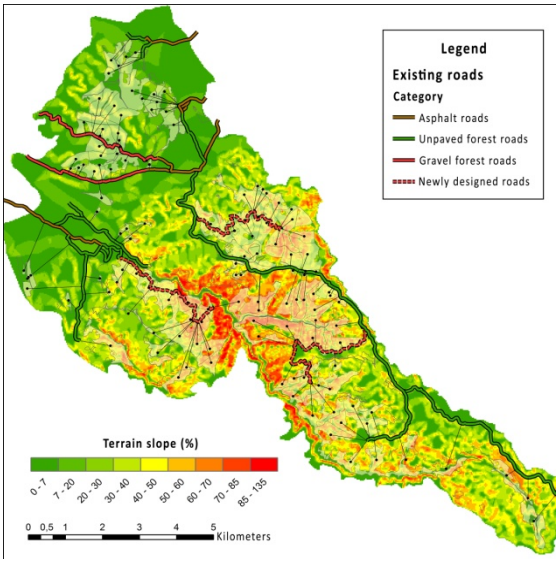

Figure 5: Terrain slopes and distances from the centre of gravity of a stand to the nearest road

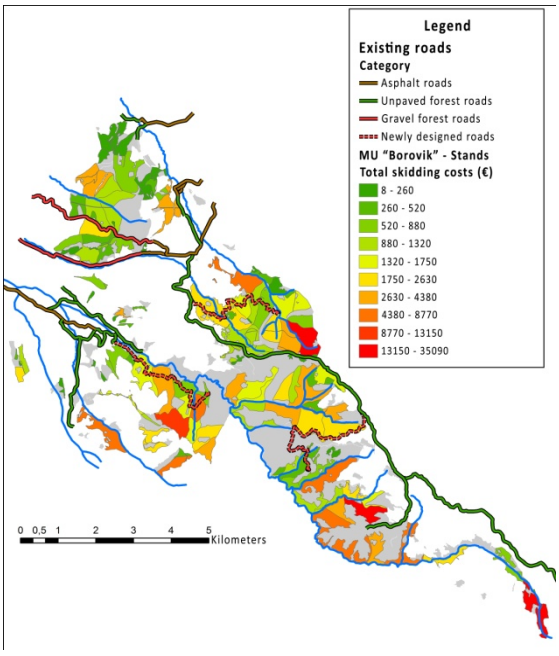

Figure 6: Total costs of skidding after construction of the newly designed roads

ISSN 1857-9507 on-line: www.sf.ukim.edu.mk/sumarski_pregled.htm

The construction of three newly designed roads, with a total length of 13344 m, would open the three parts of MU "Borovik" that have so far been completely unopened. Therefore, the mean transport distance would be significantly reduced to 674 m. This would be reflected in a higher daily output of the LKT 81 Turbo cable skidder that would reach 29 m^3 at this distance. The cost of skidding for the mean transport distance of 674 m would amount to € 4.19/m^3 (Fig. 7), and the total costs of skidding would reach € 257895 (Fig. 6).

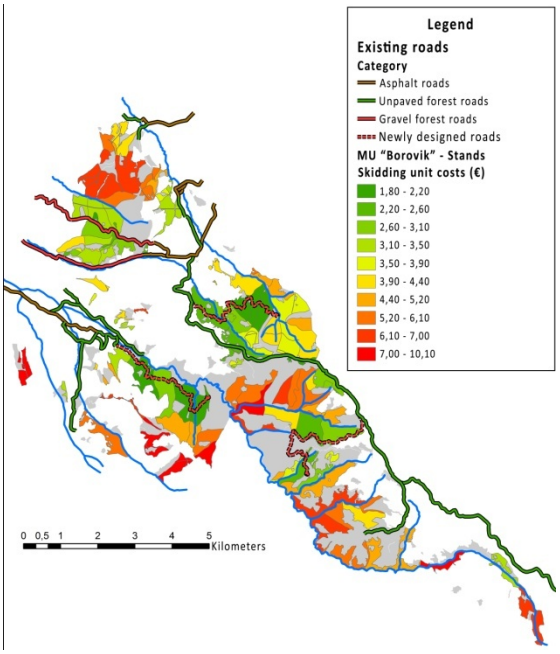

Figure 7: Unit costs of skidding after construction of the newly designed roads

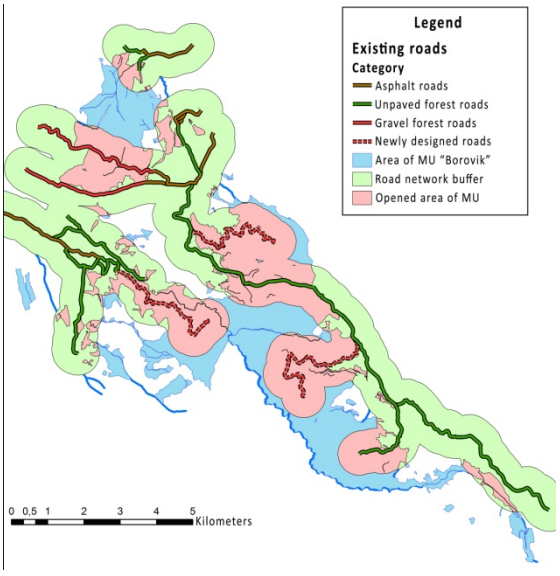

Figure 8: Relative openness after construction of the newly designed roads

The construction of newly designed roads would increase the density of the primary network to 6.82 m/ha, which is lower than the optimum density of 8.51 m/ha. It would also increase the relative openness of the management unit to 61.88% (Fig. 8). Despite a significant increase in the relative openness of MU "Borovik" it would still be considered low and marked with mark 2 (two).

5 CONCLUSIONS

The following conclusions can be presented on the basis of this research and the analyses performed:

- The optimization of a network of roads was performed in MU "Borovik" with special attention paid to the economic, technical and technological aspects;
- The program of opening that envisages the construction of three forest roads with a total length of 13.34 km was produced for MU "Borovik". These three roads should open the parts of the management units that are completely unopened, where the felling of 23673 m^3 of wood was planned;
- The current density of the forest road network in MU "Borovik" is 2.96 m/ha, when all the roads with truck road elements are taken into account (asphalt roads, gravel and unpaved forest roads). The optimum density for this management unit is 8.51 m/ha, and after construction of the newly designed routes this density would reach 6.82 m/ha;
- The current relative openness of MU "Borovik" is 36.20%, and after construction of the newly designed routes it would be increased to 61.88%, which still represents low relative openness;
- The current mean transport distance is 1357 m and the unit costs of skidding amount to € 6.59/m^3. The total costs of skidding amount to € 393437 for the entire management period;
- In addition to increasing the density of the forest road network, the construction of the newly designed routes would reduce the mean transport distance to 674 m and the unit costs to € 4.19/m^3. The total costs of skidding would be reduced by nearly 35% and amount to € 257895;
- The required workload in terms of days needed for the skidding of the total volume of wood assortments would be reduced from 3137 to 1947 days.

6 REFERENCES

[1] E. Abdi, B. Majnounian, A. Darvishsefat, Z. Mashayekhi, J. Sessions, A GIS-MCE based model for forest road planning, Journal of Forest Science, Vol. 4, (2009), pag.171-176.

[2] B. Abegg, Die Shatzung der optimalen Dichte von Waldstrassen in traktorfahrbaren Gelande, Eidg, Anstakt fur das forstiche Versuchswesenm Mitteilungen 54, 2, (1978).

[3] FAO, A Manual for the Planning, Design and Construction of Forest Road in Steep Terrain, (1998).

[4] M. Nasiri, M. Lotfalian, Programming and Forest Road Planning, Journal of Ecology and Environmental Sciences, Volume 3, Issue 2, (2012), pag. 68-73.

[5] T. Pentek, D. Pičman, I. Potočnik, P. Dvorščak, H. Nevečerel, Analysis of an existing forest road

network, Croatian Journal of Forest Engineering, 26(2005)1, pag. 39-50.

[6] T. Ryan, H. Phillips, J. Ramsay, J. Dempsey, Forest Road Manual, Guidelines for the design, construction and management of forest roads, COFORD, National Council for Forest Research and Development, Ireland, (2004), pag.170.

[7] L. Rogers, Automating aontour-based route projection for preliminary forest road designs using GIS, MS Thesis, Wsahington, University of Washington, (2005), pag.87.

[8] D. Šikić, B. Babić, D. Topolnik, I. Knežević, D. Božičević, Ž. Švabe, I. Piria, S. Sever, Tehnički uvijeti za gospodarske ceste, Znanstveni savijet za promet, JAZU, Zagreb, (1989).

[9] Special forest management plan of MU "Borovik" (2011-2020).