ECOLOGICAL CRITERION EFFECT ON THE FOREST ROAD NETWORK LONGITUDINAL GRADIENT

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Abstract

HRŮZA PETR: *Ecological criterion effect on the forest road network longitudinal gradient.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 6, pp. 1715–1723

The specific way in which a forest road is designed affects the management in the forest environment and timber transport. The aim of this study was to find out whether an inclusion of the ecological criterion in the forest road design will change the parameter of the longitudinal gradient of forest hauling roads and whether these changes will have an effect on the accessibility of forest stands by timber hauling machinery. The possible changes in the longitudinal gradient can also affect the technology of forest road surfacing and the selection of the appropriate surface type. We can state that an inclusion of the ecological criterion in the forest road network design will bring statistically significant changes in longitudinal gradients of forest hauling roads. The mean longitudinal gradient of the current forest road network is 2.82 % and the mean longitudinal gradient of the forest road network designed with inclusion of the ecological criterion is 4.82 %. The results show statistically significant changes in the longitudinal parameters of forest hauling roads. However, it will not bring a need for a change in construction technology, and will not affect the accessibility of forest stands by timber hauling machinery.

forest road, longitudinal gradient, ecological criterion, forest accessibility

Matthews (1942) was one of the first researchers who designed the layout of forest road network in flat forest areas. His design is based on the estimation of the right volume of forest road density according to the economic calculation based on minimum costs of timber skidding and transport. Segebaden (1964) involved a terrain factor to the Matthews's method of designing forest road network. Lately Heinimann (1998) proposed a forest road spacing model for steep slope conditions and implemented a total cost model for cable yarding system. Adapted versions of this economic solution are still used to present time. Currently, Ghaffarian and Sobhani (2007) as well as Rafiei *et al.* (2009) adapted designs of forest road network based on minimization of economic costs in flat areas in their studies in Iran. In the Czech Republic it was Beneš (1973, 1982, 1986a, 1986b) who dealt with the issue of forest road construction and forest road network optimization in the past. In his studies he worked with the

factors which affect the development of the forest road network and he divided them into natural and economic factors. Recent studies (Sessions and Boston, 2006; Ghaffariyan *et al.*, 2010) are more focused on the parameter of optimal road spacing instead of optimal road density as this parameter better expresses the distribution of forest roads in the area. But all these solutions are based mostly on the economic and technical principles and do not include the forest ecosystem as the criterion for forest road network design.

Increasing popularity of using GIS in the natural sciences and its increasing availability means that companies developing the related applications are interested in incorporating tools for road network designs. Pryimachuk (2010) emphasizes that forest accessing must be a part of long term forest management planning and using GIS is essential. Pentek *et al.* (2005) created the process for analysing a forest road network using instruments easily

obtained with GIS. Hayati *et al.* (2012) highlighted that each transportation network has to be assessed and optimized to minimize the total costs of road construction and its environmental impact and claimed to use GIS for the evaluation of forest road networks as well.

An inclusion of ecological requirements in today's design forest road network approach is attempted in e.g. Pentek *et al.* (2008, 2011). Methodological procedures in their studies are based on the philosophy of minimum ecological damage caused by the technical solution and do not include a reduction of the production properties of the forest stands themselves. Hosseini and Solaymani (2006) produced and analysed digital maps from the ecological point of view using Arcview GIS software in their work. The maps of slope and directions of slope, soil, bedrock and their volume per hectare were categorized and classified in tables to divide the research area to different units for road selection. Finally, the best area to plan a forest road with effective factors was selected. They used the GIS techniques to design the optimal forest road. It was concluded that using GIS and computerized analysing leads to economizing in time and costs and minimization of environmental damage. A different approach to the forest access roads layout resolves Demir (2007). This includes the production of forestry products and the functions related to anti-erosion, climate benefits, community health, aesthetics, environmental protection, recreation, national defence and scientific aspects. He emphasises that each step has to be taken with respect to functional planning of forest roads. In contrast with GIS, Pelikán and Šlezingr (2011) used AutoCAD to find detailed basin characteristics. They explored the possible ways to use the program for terrain shape establishment. Their work shows that AutoCAD can be used even for detail analyses of areas.

An example of the environmental impact approach published in their study Gumus *et al.* (2008). Their methodology was based on the evaluation of the ability of the existing road network to meet wood-production management goals, opening up capacity, economic analysis of the requisite new road segments cost and, finally, environmental impact assessment (EIA) of the new planned road layout. This method can be applied equally well to roadless areas. They noticed that more than a half of the existing roads which were constructed based on the previous network plan are located in negative environmental impact areas. Another good example of the environmental impact Potočnik *et al.* (2008) also tackled the reduction of negative effects on the forest ecosystem, but mainly from a technical perspective as he deals with the width proportions of the road formation and the loss of the forest production area.

Messingerová and Tajboš (2006) searched for a different way to eliminate the consequences of extraction technologies for the environment using the timber air extraction. The aim of their work was to elaborate a design of technological procedures for timber transportation by helicopters depending on the type of felling, terrain configuration, technical aids, assessment of performance characteristics, design of work safety and assessment of noise level in the forest environment.

All these authors approach the issue of forest ecosystem access from the technical and economic points of view.

Hrůza (2004) incorporated all social functions of a forest ecosystem in the forest road network design; i.e. not only the bioproductive function, in some cases even narrowed down to the timber-production function. He proposed a method for forest road network layout in which the standard approach to forest accessing based on technical and economic criteria is complemented by the ecological criterion in the form of the biotic component represented by the forest ecosystem and its functions. The forest road network optimization design with the included ecological criterion is based on the principle that the forest hauling road is designed so that the forest stands with a high value of the total function potential (Vyskot, 2003) are considered; naturally, the optimum density of forest roads based on the transport segment within the Territorial Plans of Forest Development (Macků *et al.*, 1996) and all technical requirements included in Czech standard specification Forest transportation network (ČSN 73 6108, 1995) need to be respected. In other words, the road is designed so that these forest stands are disrupted as little as possible and the value of the potential is not considerably reduced. Forest hauling roads are then designed in the stands with a low value of the total function potential as this value will not be significantly reduced by the road construction and its use.

The aims of this study were to find out whether an inclusion of the ecological criterion in the current method for forest accessing designs will change the parameter of the longitudinal gradient of forest hauling roads and whether these changes will be statistically significant; further, whether the potential changes of the gradient relations will affect the construction of the forest hauling roads and whether these changes will have an effect on the accessibility of forest stands by timber hauling machinery.

MATERIAL AND METHODOLOGY

The statistical evaluation of the changes in the longitudinal gradient is supposed to confirm or reject the zero hypothesis that there is no statistically significant difference between the values of longitudinal gradient of the current forest hauling roads designed on the basis of technical and economic criteria as well as needs and possibilities of forest management (the current forest road network) and the values of the longitudinal gradient of a comprehensively optimized design of a forest

I: *Classes of the real potential for all functions defined by Vyskot (2003).*

Class of the real potential	Resulting value for all functions	Functional value interval 0–100%	Verbal description
I	1–11	1–30	very low
II	12–16	31–45	low
III	17–20	46–55	average
IV	21–26	56–70	high
V	27–32	71–90	very high
VI	33–36	90+	outstanding

road network with the inclusion of the ecological criterion based on functions of the forest ecosystem (comprehensively optimized forest road network).

Ecological criterion is based on all functions produced by the forest ecosystem. These are defined by Vyskot (2003) as the bio-productive function, function of ecological stabilization, hydric function, edaphic–soil protective function, function of social recreation, and health and hygiene function. The ability of forests to produce functions is highly differentiated. Forest functions are produced by each specific forest ecosystem and can gain different values. The way of the establishment of these values was published by Vyskot (2003), who at the same time introduced the term of the real potential of functions. The values of real potentials can be established for forest ecosystem units of the entire territory of the Czech Republic. The resulting value of the real potential of all functions is divided based on the functional interval 0–100% into six classes I–VI and each is verbally described from very low to outstanding (Tab. I).

The optimization of the forest road network including the ecological criterion is based on respecting forest stands with a high value of the real potential of forest functions within the accessed area so that these stands could be disrupted as little as possible and the real potential of forest functions would not be reduced considerably in consequence of construction and use of the forest road network. The forest road network is therefore designed in the stands with a low value of the real potential. The real potential there is reduced in consequence of the construction and use of the forest road network but its reduction is not so considerable. The stands with a high value of real potential thus remain intact and their value does not drop by construction and use of the forest road network.

The evaluated parameter of longitudinal gradient has been selected for the reason that its potential changes may have an effect on the accessibility of the forest by timber hauling machinery. The possible changes in the longitudinal gradient can also affect the technology of forest road surfacing and the selection of the appropriate surface type. For a proper operation and the maximum duration of forest hauling roads, a specific minimum longitudinal gradient is necessary for the drainage of water into the longitudinal draining ditch. The recommended minimum longitudinal gradients

for earth roads and surfaced roads are 2% and 0.5%, respectively. Another important value of the longitudinal gradient is the optimum longitudinal gradient, which is stated to be 5–7% (Hanák, 2002). With a longitudinal gradient of up to 7%, water is drained from the road without necessity to tackle the problem of rill erosion. When the gradient of unbound surfaces exceeds 7%, it is necessary to insert lateral draining structures, such as open top culverts or water bars, or design a sealed surface. The maximum longitudinal gradient in compliance with ČSN 73 6108 (1995) is 10% for forest roads of class 1L and 12% is possible in short sections of forest roads of class 2L. The maximum longitudinal gradient is based on the gradient accessibility of timber hauling machinery and its safe operation in forest hauling roads. When designing the longitudinal gradients, it is necessary to adapt the road layout to the terrain shape and respect the places where the road crosses water streams, sloping and sliding territories, steep slopes (over 50%), rock cliffs and other natural as well as manmade obstacles. Other as important design factors to be respected are the design speed and routing, especially routing of curves.

The area of study, used for the examination of the effect of the ecological criterion inclusion in the current methodology for forest road network designing on gradients, is located in the Bohemian-Moravian Upland (in Czech Českomoravská vrchovina) in the district of Forest Administration Nové Město na Moravě, state-owned company Lesy České republiky, s.p (Fig. 1). In total, five transport segments were used; these are called Smuch, Blatka, Řásník, Kostkovica, and Spálená paseka (Tab. II).

The map documents for the evaluation of the longitudinal gradient changes have been created in the software ArcGIS. Raster data were used to define the research transport segments – the current orthophotomap of the area and its descriptions from the geoportal of the Czech Environment Information Agency (CENIA) and a forestry map from the web map service of the Forest Management Institute. This map was complemented by altitude vector data (contour lines with 1m interval) from the Database of Geographical Data (ZABAGED) so that the evaluation of the gradients could be performed. The shape and general drawing of the contour lines illustrate the shape of the terrain and thus also the gradient relations of the area; from this, the gradient

1: *Location of the study area*

II: *Transport segments*

Transport segments	Area (ha)	Length of forest hauling roads (m)	
		Current	Comprehensively optimized
Smuch	325	4 405	5 460
Blatka	334	5 674	5 527
Řásník	327	5 962	3 693
Kostkovica	228	5 284	5 527
Spálená paseka	448	6 578	9 049

relations of the evaluated forest road network can be derived.

The situation of the current forest road network has been processed based on the data from a survey that is performed by the Forest Management Institute for the creation of Territorial Plans of Forest Development (ÚHUL, 2009). The layout of the optimized forest road network with an included ecological criterion was taken from the author's previous study (Hrůza, 2004).

The forest hauling roads of both networks in each transport segment were divided into sections with the same longitudinal gradients, in dependence on the horizontal distance and shape of contour lines in the contour plan (Fig. 2). The length of each section was measured, the minimum and maximum altitudes were derived from the spot heights, the drop in meters was calculated and the longitudinal gradient was established in per cents. This provided us with two datasets with longitudinal gradients – of the current and a comprehensively optimized forest road network – for each of the five segments (Smuch: 1_S, 1_O; Blatka: 2_S, 2_O; Kostkovica: 3_S, 3_O, Řásník: 4_S, 4_O; Spálená paseka: 5_S, 5_O) (Fig. 3).

RESULTS

The statistical evaluation of the longitudinal gradient was to confirm or reject the zero hypotheses that there is no statistically significant difference between the values of longitudinal gradient of the current forest hauling roads and a comprehensively optimized forest road network.

In total, the current forest road network was measured five times (1_S, 2_S, 3_S, 4_S, 5_S) as well as the comprehensively optimized forest road network (1_O, 2_O, 3_O, 4_O, 5_O). These datasets were compared within particular transport segments. For a better and broader interpretation of the final statistical assessment, they were then transformed into two datasets - one representing five current forest road networks of all five transport segments, the other consisting of five comprehensively optimized forest road networks of the five transport segments. These were then analysed in Statistika 10. The changes in the values of gradient relations were examined in forest hauling roads of five research transport segments (Smuch, Blatka, Řásník, Kostkovica, Spálená paseka); however, four of these transport segments are adjacent – they have a part of a watershed divide in common – and the fifth transport segment (Smuch) is divided by a saddle between two peaks.

Transport segment Smuch

1:12 500

Legend

▭ Transport area Smuch

— Current forest road network 1_S

— Comprehensively optimized forest road network 1_O

0   125   250   500   m
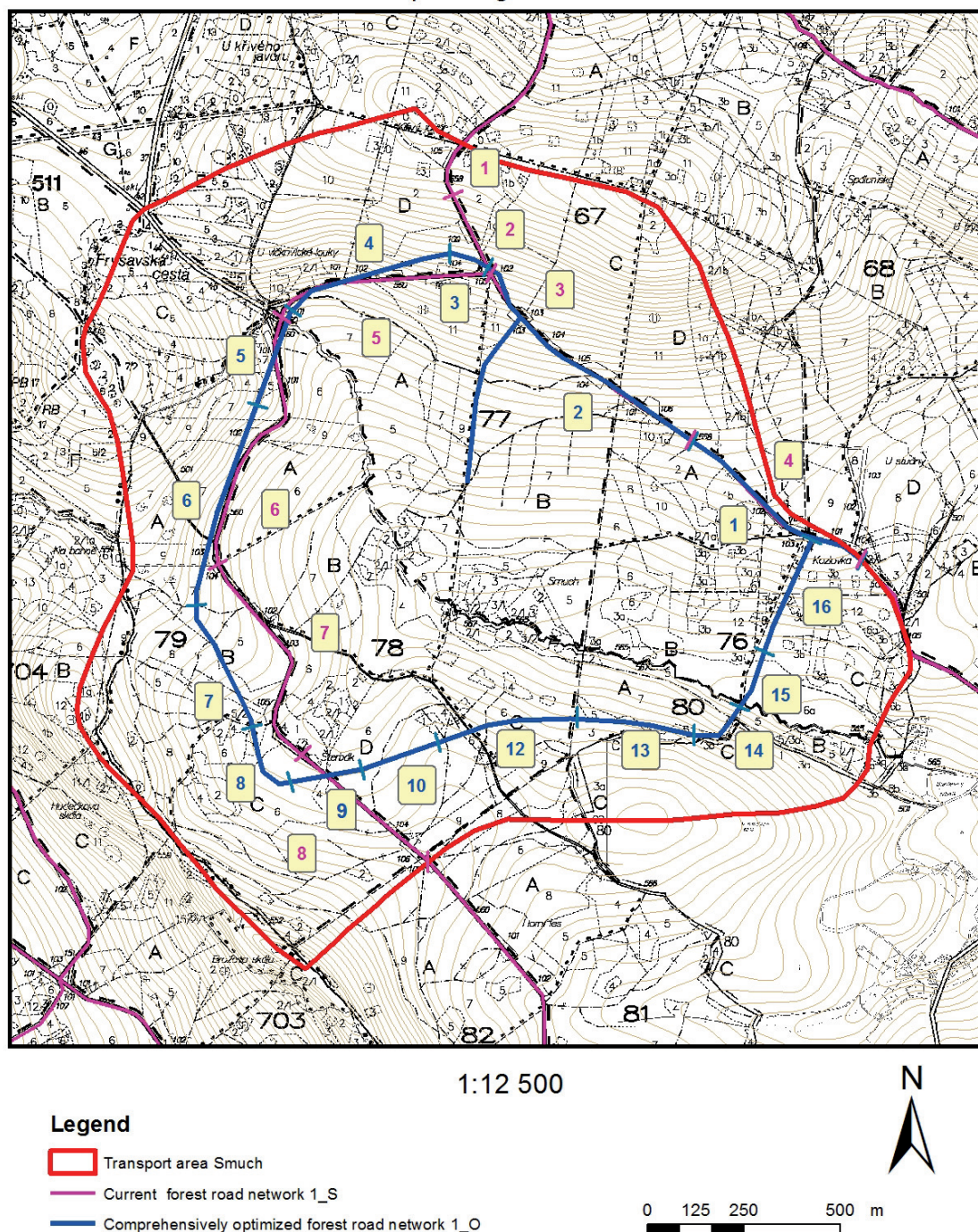
2: *An example of the current and comprehensively optimized forest road network divided into sections with the same longitudinal gradients*
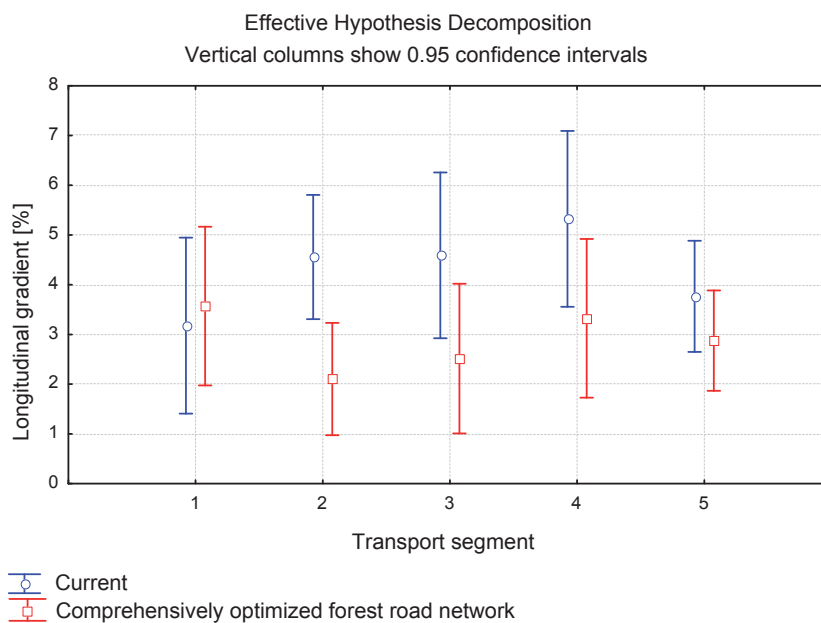
Therefore, the forest hauling roads in the entire area of study can be considered one basic set for the purposes of statistical processing. The fact that these transport segments are of the same or very similar character has been proved by the results of the statistical test of one-factor anova performed for the measured longitudinal gradients of the current and comprehensively optimized forest road network in the particular transport segments (1 – Smuch,

2 – Blatka, 3 – Řásník, 4 – Kostkovica, 5 – Spálená paseka), (Fig. 4).

We examined the basic statistical characteristics of both compared datasets: arithmetic mean, modus, median, standard deviation, variance, skewness and kurtosis, and confidence interval – probability of parameter arithmetic mean occurrence at significance level $\alpha = 0.05$ – and for the reason of

No.	List1									
	1 1 S	2 1 O	3 2 S	4 2 O	5 3 S	6 3 O	7 4 S	8 4 O	9 5 S	10 5 O
1	4,3333	3,1414	1,3514	3,1627	4,5161	5,1282	7,7052	2,2727	1,1858	1,2987
2	8,9286	5,1105	4,3165	4,0795	1,3793	2,3636	3,1496	5,2469	3,8239	2,3256
3	4,4737	1,0417	1,6667	8,5417	4,0761	8,8962	1,6529	6,9604	3,8922	4,7222
4	2,6971	5,5785	1,6393	1,9048	0	5,8608	3,5052	6,3463	0,3049	2,4096
5	3,8261	3,6842	2,795	0,7407	0,4405	3,1365	0	2,5974	1,8395	1,8433
6	1,1004	1,6949	2,3077	6,6667	0,7273	8,2038	7,5359	5,9917	0,885	9,1867
7	0,758	4,235	0,1786	2,1429	6,5934	1,1494	0,3478	5,1181	1,9726	5,8
8	2,4496	0,9375	0,5556	1,1364	1,5385	3,0769	2,7027	8,0702	4,1152	0,6667
9		1,5228	2,6738	5,7143	3,3661	3,4965	1,6529		0,2463	1,5556
10		1,6432	2,8752	0,8696	3,9216		4,2945		3,1008	5,2113
11		3,0702	1,5924	5,0286	5,0485		1,6129		6,9343	4,5802
12		0,627	3,6111	2,5	2,5		0,7143		4,2827	1,3139
13		9,5238	5,2288	5,2941	4,662		2,7273		0	1,0204
14		1,9074	1,7964	10,323	1,5873		4,1096		2,7083	2,514
15		7,0175	1,0204	8,7137	6,2385		0,9302		1,7857	5,383
16		8,6721	0,0458	6,1069	2,069		2,2727		0	4,8632
17			3,7302		7,2131		5,2469		5,4054	6,068
18			0,3077		1,1111				5,618	2,1327
19			3,6364		6,2963				1,2195	4,9628
20			0,7692		0,4651				8,1818	7,4783
21			4,5752		3,8251				2,0968	
22					4,2857				0,4808	
23					0,3448				2,3077	
24					4,7826				0	

3: *The dataset with longitudinal gradients for each of the five transport segments of the current and a comprehensively optimized forest road network*

Effective Hypothesis Decomposition
Vertical columns show 0.95 confidence intervals

○ Current
□ Comprehensively optimized forest road network

4: *Graph of results of the one-factor analysis of variance of longitudinal gradients, based on the research transport segment (1 – Smuch, 2 – Blatka, 3 – Řásník, 4 – Kostkovica, 5 – Spálená paseka)*

Vertical columns show 0.95 confidence intervals
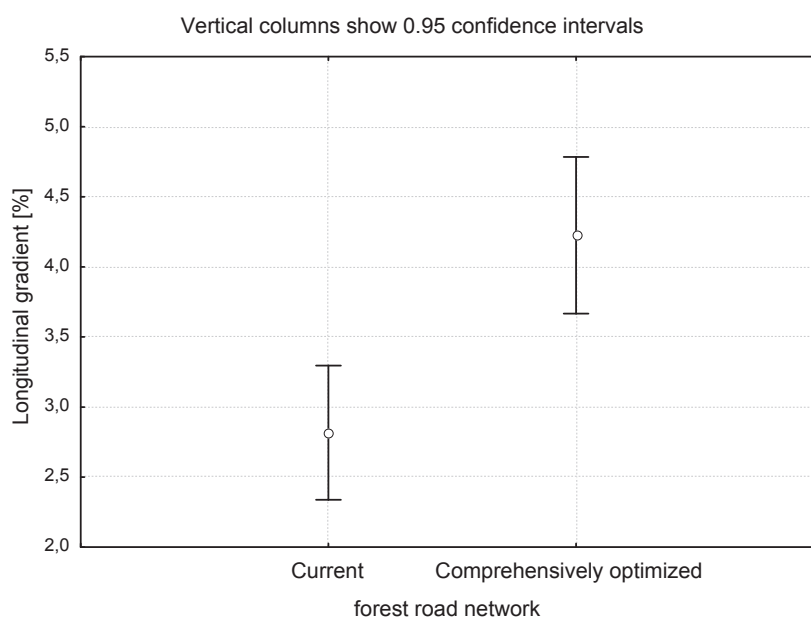
5: *Graph of results of one-factor analysis of variance of longitudinal gradients in the current and a comprehensively optimized forest road network as a whole*

selection of further statistical evaluation, test of normal distribution was carried out.

To confirm or reject the zero hypotheses about the similarity of the two compared sets, the test of one-factor analysis of variance was conducted. The results did not confirm the zero hypotheses. We can state that an inclusion of the ecological criterion in the forest road network design will bring statistically significant changes in longitudinal gradients of forest hauling roads. The mean longitudinal gradient of the current forest road network is 2.82 % and the mean longitudinal gradient of the optimized forest road network is 4.82 %. Confidence intervals of the parameter longitudinal gradient with 95 % probability range between 2.38 % and 3.26 % for the current forest road network; the range of a comprehensively optimized forest road network is 3.60–4.85 % (Fig. 5).

DISCUSSION

The first method of forest road network design was based on its economic properties solely and some authors continue using this until today (Rafiei *et al.*, 2009). A wider perspective of the issue of forest road network planning was brought by taking account of the effect of the terrain shape on the forest road placement in a forest stand (Segebaden, 1964; Beneš, 1973; Heinimann, 1998). This approach considering both, the economics and the terrain, is generally the current method of forest road network designing. However, this method needs to be complemented with a third element which is directly affected by forest road constructions and this is the forest stand itself. Therefore there is a requirement to achieve a complex way of forest road network designing that would also include environmental

approach. Although some authors (Hosseini and Solaymani, 2006; Pentek *et al.*, 2008) have tried to include ecology in the current method, they mostly minimized the negative effects on the forest terrain and did not consider the negative effect of the construction on the forest stand. The method of forest road network designing that respects high quality stands with a high value of real potential (Vyskot, 2003) and places forest roads in the stands with less functional quality creates the ecological criterion (Hrůza, 2004).

The aim of the presented study was to find out what effect an inclusion of the ecological criterion in the current method of forest road network designing will have on the most significant construction element of forest roads – the longitudinal gradient. The exploration of the effect of the ecological criterion shows that it brings statistically significant changes in the longitudinal gradient of forest hauling roads. However, when looking at the results of the exploration in more detail, it is obvious that the resulting values of the longitudinal gradients will not affect the constructional solution of a comprehensively optimized forest hauling roads, will not bring a need for a change in construction technology, and will not affect the accessibility of forest stands by timber hauling machinery.

At the same time, the environmental aspect of the proposed solution of forest road network layout needs to be emphasized. It reduces the negative impact of forest road construction on the forest ecosystem and thus positively affects the environment quality.

The shift of the values of longitudinal gradients of the comprehensively optimized forest road network upwards can even be seen positively. Although ČSN 73 6108 (1995) does not present any requirements

regarding the minimum longitudinal gradients of the particular forest road classes, according to Hanák (2002) the recommended minimum longitudinal gradients for forest hauling roads are 0.5% for roads with a bound surface and 3% for roads with an unbound surface, due to the necessary draining of forest hauling roads. The optimum longitudinal gradient is 5–7%. Longitudinal gradient of 7% is a critical limit concerning the longitudinal erosion and material wash out from the surface of roads.

The complex optimization of the forest road network thus brings us closer to the optimum longitudinal slope, without trespassing the critical limit of 7% or attacking the maximum longitudinal gradients stipulated by ČSN 73 6108 (1995) – 10% or 12% in short sections, established for the safe accessibility of forest stands by timber hauling machinery.

The results show that the complex approach to forest road network design with an included ecological criterion slightly affects one of the most significant parameter of forest roads – the longitudinal gradient. However, the changes do not affect the construction technologies and the accessibility of forest stands. The effect on the other construction parameters, e.g. the earthwork amount and the related take-up of stand area, needs to be evaluated to find out if their affect is the same.

CONCLUSION

An application of the presented method will not necessarily cause changes in the technical solution of the construction of forest hauling roads due to a change in gradient relations. The ecological criterion inclusion will not lead to a necessity to insert lateral draining structures in the road, or design roads with sealed surfaces. On the contrary, we can say that this solution will contribute to a better performance of the draining structures. In relation to the change in the longitudinal gradient due to the complex design of forest roads, the costs of forest road network construction will not increase and the maximum longitudinal gradient of forest hauling roads, from the perspective of forest accessibility for timber hauling machinery, will not be exceeded.

SUMMARY

Technical elements, such as a forest road network, are inseparable parts of forest ecosystems. The current approach to the layout of a forest road network is largely based on technical and economic solutions and does not include an approach related to the forest ecosystem itself, which should be taken into account in the form of an ecological criterion. The aim of this study was to find out whether an inclusion of the ecological criterion in the current method for the layout of a forest road network will affect the longitudinal gradient and due to technology of forest road surfacing or accessibility of forest stands by timber hauling machinery. The inclusion of the ecological criterion is based on respecting forest stands with a high value of the real potential of forest functions within the accessed area so that these stands could be disrupted as little as possible and the real potential of forest functions would not be reduced considerably in consequence of construction and use of the forest road network. The forest road network is therefore designed in the stands with a low value of the real potential.

We can state that an inclusion of the ecological criterion in the forest road network design will bring statistically significant changes in longitudinal gradients of forest hauling roads. The mean longitudinal gradient of the current forest road network is 2.8% and the mean longitudinal gradient of the optimized forest road network is 4.82%. Confidence intervals of the parameter longitudinal gradient with 95% probability range between 2.38% and 3.26% for the current forest road network; the range of a comprehensively optimized forest road network is 3.60–4.85%.

However, when looking at the results of the exploration in more detail, it is obvious that the resulting values of the longitudinal gradients will not bring a need for a change in construction technology, and will not affect the accessibility of forest stands by timber hauling machinery. The ecological criterion inclusion will not lead to a necessity to insert additional draining structures in the road, or design roads with bound surfaces. On the contrary, we can say that this solution will contribute to a better performance of the draining structures. In relation to the change in the longitudinal gradient due to the respecting forest stands with high potential functional value, will not increase the costs of forest road network construction.

REFERENCES

BENEŠ, J., 1973: Vliv tvaru terénu na dopravní zpřístupnění lesa. *Lesnictví*, 19, 6: 479–492. ISSN 1212-4834.

BENEŠ, J., 1982: Eroze způsobená výstavbou lesních cest a dopravou po nich. *Lesnictví*, 28, 7: 539–554. ISSN 1212-4834.

BENEŠ, J., 1986a: Optimalizace lesní dopravní sítě. *Lesnictví*, 32, 12: 1089–1114. ISSN 1212-4834.

BENEŠ, J., 1986b: *Předpoklady zpřístupnění lesa*. Brno: VŠZ, 66 s.

ČSN 73 6108, 1995: *Lesní dopravní síť*. Praha: Český normalizační institut, 28 s.

DEMIR, M., 2007: Impacts, management and functional planning criterion of forest road network system in Turkey. *Transport. Res. A-Pol.*, 41, 1: 56–68. ISSN 0965-8564.

GHAFFARIAN, M. R., SOBHANI, H., 2007: Optimization of an existing forest road network using Network 2000. *Croatian Journal of Forest Engineering*, 28, 2: 185–193. ISSN 1845-5719.

GHAFFARIYAN, M. R., STAMPFER, K., SESSIONS, J., 2010: Optimal road spacing of cable yarding using a tower yarder in Southern Austria. *European Journal of Forest Research*, 129, 3: 409–416. ISSN 1612-4677. ISSN 1612-4669.

GUMUS, S., ACAR, H. H., TOKALY, D., 2008: Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. *Environ. Monit. Assess.*, 142, 1–3: 109–116. ISSN 0167-6369.

HAYATI, E., MAJNOUNIAN, B., ABDI, E., 2012: Qualitative evaluation and optimization of forest road network to minimize total costs and environmental impacts. *IForest.*, 5, 3: 121–125. ISSN 1971-7458.

HEINIMANN, H. R., 1998: A Computer Model to Differentiate Skidder and Cable-Yarder Based Road Network Concepts on Steep Slopes. *J. For. Res.*, 3, 1: 1–9. ISSN 1341-6979.

HOSSEINI, S. A., SOLAYMANI, K., 2006: Investigation of effective factors for path tracing using GIS in Kheyroud Forest (Iran-Mazandaran Province). *Pakistan Journal of Biological Sciences*, 9, 11: 2055–2061. ISSN 1028-8880.

HRŮZA, P., 2004: *Návrh optimalizace lesní cestní sítě s ohledem na funkce lesa v krajině.* Brno: Mendelova zemědělská a lesnická univerzita v Brně, 119 s. Disertační práce.

HANÁK, K., 2002: *Zpřístupňování lesa. Vybrané statě I.* Brno: Mendelova zemědělská a lesnická univerzita v Brně, 154 s. ISBN 80-7157-639-5.

MACKŮ, J., 1996: *Oblastní plány rozvoje lesů – Metodika.* Brandýs nad Labem: Ústav pro hospodářskou úpravu lesů, 85 s.

MATTHEWS, D. M., 1942: *Cost control in the logging industry.* New York: McGraw-Hill Book Company, 374 p.

MESSINGEROVÁ, V., TAJBOŠ, J., 2006: Technological and Environmental Parameters of Helicopter Timber Extraction in Slovakia. *Croatian Journal of Forest Engineering*, 27, 2: 123–133. ISSN 1845-5719.

PELIKÁN, P., ŠLEZINGR, M., 2011: Methodology for the establishment of physical and geometric properties of a drainage basin. *Acta univ. agric. et silvic. Mendel. Brunen.*, 59, 6: 265–270. ISSN 1211-8516.

PENTEK, T., PICMAN, D., POTOCNIK, I., DVORSCAK, P., NEVECEREL, H., 2005: Analysis of an existing forest road network. *Croatian Journal of Forest Engineering*, 26, 1: 39–50. ISSN 1845-5719.

PENTEK, T., PORSINSKY, T., SUSNJAR, M., 2008: Environmentally sound harvesting technologies in commercial forests in the area of Northern Velebit – Functional terrain classification. *Periodicum biologorum*, 29, 2: 127–135. ISSN 0031-5362.

PENTEK, T., PICMAN, D., NEVECEREL, H., 2011: Primary Forest Opening of Different Relief Areas in the Republic of Croatia. *Croatian Journal of Forest Engineering*, 32, 1: 401–416. ISSN 1845-5719.

POTOČNIK, I., PENTEK, T., PIČMAN, D., 2008: Filling in the clearance of a forest road cross-section in beech forest. *Croatian Journal of Forest Engineering,* 29, 1: 53–62. ISSN 1845-5719.

PRYIMACHUK, I., 2010: *Long term forest management planning in Ukraine – A case study.* Alnarp: Swedisch Univerzity of Agricultural Sciences, 32 p. Master Thesis No. 155.

RAFIEI, A.A, LOTFALIAN, M., HOSSEINI, S.A., PARSAKHOO, A., 2009: Determining the optimum road density for ground skidding system in Dalak Kheyl forest-Hyrcanian zone. *World Appl. Sci. J.*, 7: 263–270. ISSN 1818-4952.

SEGEBADEN, G.V., 1964: *Studies of cross-country transport distance and road net extension.* Stockholm: Svenska Skogsvardsföreningen, 67 p.

SESSIONS, J., BOSTON, K., 2006: Optimization of Road Spacing for Log Length Shovel Logging on Gentle Terrain. *International Journal of Forest Engineering*, 17, 1: 67–75. ISSN 0843-5243.

ÚHUL, 2009: *Oblastní plány rozvoje lesů* [online]. [cit. 2012-08-8]. Retrieved from: <http://www.uhul.cz/oprl/pruvodce.php>.

VYSKOT, I., 2003: *Quantification and Evaluation of Forest Functions on the Example of the Czech Republic.* Praha: Ministerstvo životního prostředí, 194 s. ISBN 80-7212-265-7.

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