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Inclusion of the ecological criterion in the design of forest road network and its effect on the parameters of forest accessing

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Forest accessing and planning of forest roads used to be based on technical and economic criteria predominantly. However, the criteria of the environment, the quality of the forest ecosystem are also being considered when designing a forest road network nowadays. The aim of this study is to test the hypothesis that the inclusion of the ecological criterion in the optimization design of a forest road network will not change the parameters of forest accessing, nor the economic costs of forest road construction, to a statistically significant degree. Parameters of the forest roads density, the mean skidding distances, the mean geometric skidding distances, the theoretical skidding distances and the efficiency of transport area access were evaluated in seven transport areas in the Czech Republic. These parameters were examined within the current condition of the roads, the optimization design of roads based on technical and economic criteria and the optimization design based on technical and economic criteria with the ecological criterion included. The results show that the proposed optimization of the current forest road network would mean obvious improvement on the road network parameters. At the same time, the values of the parameters were not different in the optimization designs without and with the ecological criterion to a statistically significant degree. This leads to the conclusion that the inclusion of the ecological criterion in the forest access optimization does not necessarily lead to higher costs.

Key words: Forest road network, ecological criterion, forest access parameters.

INTRODUCTION

The evaluation of forest roads from the economic point of view, such as low-cost designing, has the longest tradition. One of the first researchers was Matthews (1942), who designed the forest road network distribution based on minimum costs of timber skidding and transport. He used the size of harvest in a forest owner's property and the following timber skidding in relation to its time demands and costs of skidding machines; these are compared with costs of timber transport of which the total costs are then related to a hectare. An adapted version of

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his solution has been used in flat areas until today. It is important to state that the design of a forest road network is strongly affected by the shape of the terrain and its slope; this has been considered by Segabaden (1964), who refined the road spacing model taking into account that irregular stochastic networks may occur in reality and that off-road transportation follows a winded path that isnot perpendicular. To consider the first fact, he introduced a network correction factor (terrain factor) that may be estimated for a specific road network using a sample system. Heinimann (1998) proposed a road spacing model for steep slope conditions and implemented a total cost model for skidder and cable yarding system. His study analyses transportation and road geometry to specify the relationship between road density, slope gradient and road spacing. The model was implemented as a Visual Basic in Microsoft Excel software. This flexible approach makes future adaptations and changes very easy due to the modular concept. He added that the future work needs to develop production functions for the state-of-the-art technologies and improve the road building cost model. Benes (1973, 1982, 1986a, 1986b) tackled the issues of forest road constructions and forest road network optimization in the Czech environment most often. In his studies, he dealt with the factors which affect the development of the forest road network and he divided them into natural and economic factors. The optimum shape and density of a road network are mainly affected by the terrain shape and the used skidding technology. In the downs, he proposed a more intensive use of contour hauling roads and the layout of forest roads along the lines dividing tables and steep slopes, which meets the ecological and economic requirements better than roads along valley lines or ridges. He used a new criterion - forest hauling road efficiency - which is expressed as the ratio between the theoretical skidding distance and the mean geometrical skidding distance. This data is independent of the density of roads and it expresses the economy of their distribution in the area. Recently, Ghaffarian and Sobhani (2007) as well as Rafiei et al. (2009) applied designs of forest road network in flat areas of Iran based on minimization of skidding costs as well as costs of construction and use of the forest road network. They used versions for both tractor skidding and forwarding. Sessions and Boston (2006) in their paper described the optimal road spacing problem for shovel logging using a serpentine pattern on gentle terrain to minimize the sum of shovel yarding costs plus road costs from the landowner's point of view and to maximize profits from the logging contractor's point of view. Ghaffariyan et al. (2010) determined the optimal road spacing of yarding operations to help logging planners minimize logging costs. Their results show that increasing harvesting volume decreases the optimal road spacing and that increasing forest roads construction costs increases the optimal road spacing. The authors said that the load volume has a significant effect on the optimal road spacing. They pointed out that cost of road construction does not vary with road location on the terrain and it is assumed that roads can be placed anywhere on the terrain. In practice, the space among the roads is chosen based on the experience of the planner that may not be really optimal. They also noted that in their case study, that only economic criteria were considered and the roads may be economically beneficial with respect to many other management activities in sustainable forestry.

Dean (1997) commented that up to now, a design of a forest road network has been largely a manual issue. In his work, he tested some basic technologies of geographical information systems and evaluated which is the most suitable for a forest road network design. He concluded that the method called 'branch evaluation' makes designs of the distribution of forest road networks that are to 80% the same as a manual design respecting all requirements regarding timber transport in the examined area. According to Coulter et al. (2003, 2006), there are often various criteria for a design of a forest road network, especially requirements concerning the environment. The Analytic Hierarchy Process (AHP) can help as a support for a qualified decision in the case of differing requirements and a conflict of political, economic and environmental interests.

With an increasing popularity of GIS used in the natural sciences and its increasing availability, companies developing the related applications are increasingly interested in incorporating tools for road network designs. One of these is PEGGER for road layout design for a given longitudinal slope (Rogers, 2001). Pentek et al. (2005) created the process for analysing a forest road network using instruments easily obtained with GIS. Procedures such as measures of skidding distance, skidding costs and desirable accessibility are included in the model. Relative accessibility and forest road network efficiency are two important calculated results which help the forest manager to allocate the resources to specific forest areas efficiently. 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. They used the term efficiency of forest road network and claimed to use GIS for the evaluation of forest road networks. In contrast with GIS, Pelikan and Slezingr (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 this program can be used even for detail analyses of areas. All these authors approach the issue of forest ecosystem access from the technical and economic points of view and they use the GIS to show technical elements and abiotic factors and criteria included in the decision making process. They use the GIS or AutoCAD in connection with economic requirements for the final computer design of the area access. Ammer and Loflller (1982) were among the first who dealt with the necessity to take into account ecological requirements and criteria. Using a specific example of roads in the forest they looked for a possible way of forest road construction with respect to technical, socioeconomic and ecological conditions of the specific territory. Their work contains results of long-term research. Consideration of economic, technical and ecological-requirements for the purpose of forest road network construction demands the usage of a suitable methodology for network designing. Authors state that the methodological tools for forest road designing are available but they have to be complemented by an ecological viewpoint. An inclusion of these requirements was attempted by Pentek et al. (2008, 2011). The created methodological procedures 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. Similar approach was chosen by Hosseini and Solaymani (2006). In their work, digital maps were produced and analysed by GIS and Arcview software. The maps of soil, slope and directions of slope, bedrock and volume per hectare were categorized and classified in tables to divide the research area to different units for road selecting. 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. Demir's (Demir, 2007) approach to the layout of forest access roads 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. Each step has to be taken with respect to functional planning of forest roads. Another good example of this approach is the study by 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 constructed based on the previous network plan are located in negative environmental impact areas. Potocnik 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.

As can be seen from the development of the evaluation and optimization of the forest road network, there is an obvious tendency going from the evaluation of costs to multiple criteria approaches emphasizing the impacts on all functions of forests. Besides technical and economic criteria, the society currently requires an inclusion of the ecological or environmental criterion in the decision making process. The aim of this study was to test whether an inclusion of this new criterion into the current method of forest access optimization designs would change the parameters of a forest road network and whether these changes would be statistically significant. Evaluated parameters were: density of hauling roads (HS), theoretical skidding distance (DT), the mean geometrical skidding distance ($D_{G\bar{x}}$), the mean skidding distance ($D_{S\bar{x}}$) and the efficiency of the transport area access (U).

MATERIALS AND METHODS

Typical transport areas were selected in the territory of the Czech-Moravian Upland within the property of the Forests of the Czech Republic, State Enterprise – Forest district Nove Mesto na Morave. These were transport areas called "Blatka" (331 ha), "Kostkovica" (228 ha), "Rasnik" (327 ha), "Smuch" (325 ha), and "Spalena paseka" (448 ha). Further, in the Drahany Upland within the territory of the Mendel University Forest Enterprise, these were transport areas called "Babicky potok" (424 ha) and "Utechovský potok" (375 ha) (Figure 1). In total, this makes seven representative catchment areas within uplands.

As regards access to forests, or forest roads, the used ecological criterion is based on the idea of equality of all functions produced by the forest ecosystem (Vyskot, 2003). These are the bio-productive function, function of ecological stabilization, hydric function, edaphic – soil protective function, function of social recreation, and health and hygiene function. However, the equal importance of the functions does not mean each function gains equal value within a stand. 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 real potential of forest functions is then divided based on the groups of the functions into the real potential of the bio-productive function (RPBP), the real potential of the function of ecological stabilization (RPES), the real potential of the hydric function (RPHV), the real potential of the edaphic – soil protective function (RPEP), the real potential of the function of social recreation (RPSR) and the real potential of the health and hygiene function (RPZH). They are expressed in degrees (Table 1) by the target management sets and their stand types and they are established for each stand group of the forest separately. It is also possible to establish the overall real potential of the forest ecosystem (ΣRPFL) as a sum of the real potentials of all groups of forest functions in the forest ecosystem using the following formula:

$$\Sigma RP = RPBP + RPES + RPEP + RPHV + RPSR + RPZH$$

The resulting value of the overall real potential is divided based on the functional interval 0 to 100% into six classes I to VI and each is verbally described from very low to outstanding (Table 2).

The optimization of the forest road network including the ecological criterion is based on respective 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

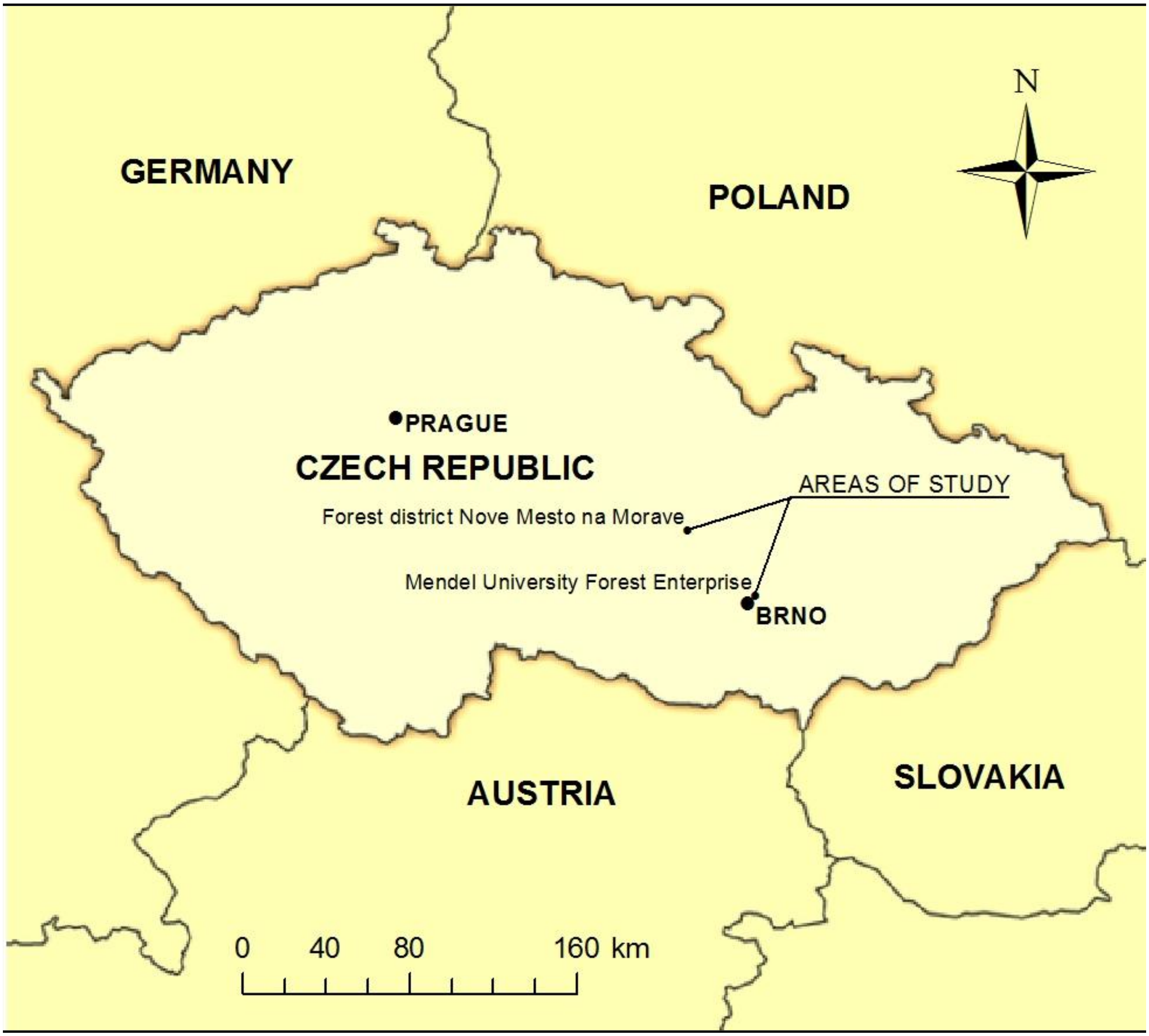

Figure 1. A location map of the study areas.

Table 1. The scale of values of real potentials of forest functions (Vyskot, 2003).

Degree of F value	Functional value interval 0 - 100%	Real potential of the function
0	< 10	Unsuitable
1	11 - 30	Very low
2	31 - 45	Low
3	46 - 55	Average
4	56 - 70	High
5	71 - 90	Very high
6	91 +	Outstanding

Table 2. Classes of the overall real potential (Vyskot, 2003).

Class ΣRP_{FL}	Value ΣF	Functional value interval 0 - 100%	The overall real potential
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

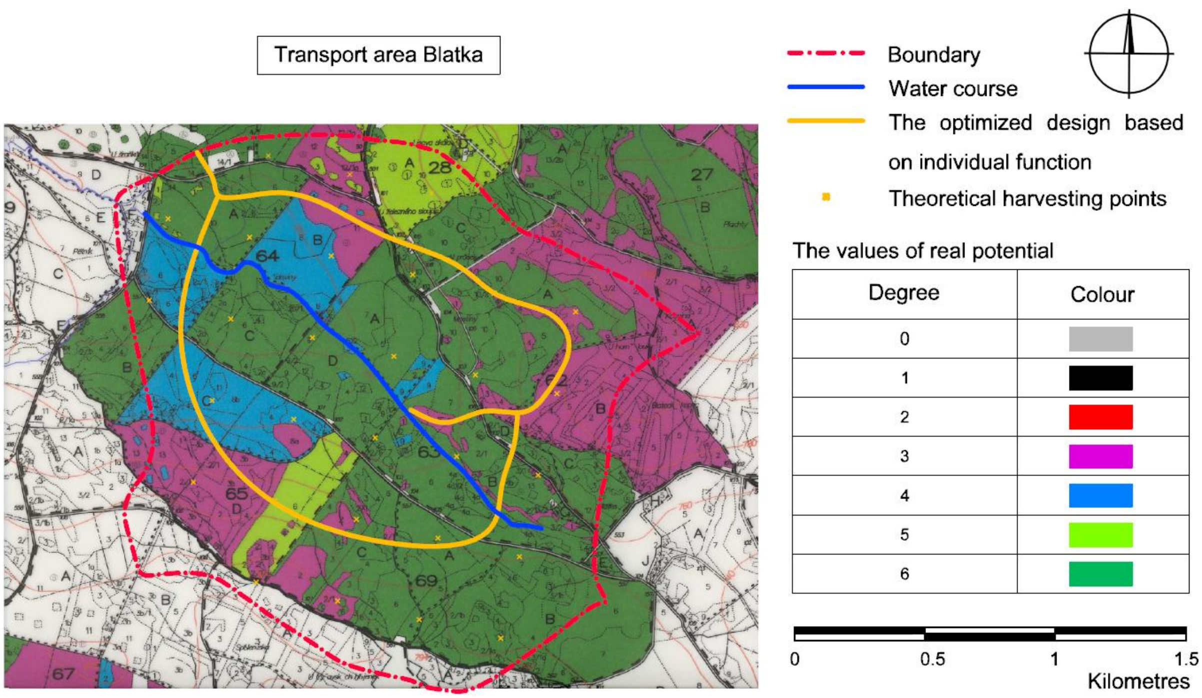

Figure 2. An example of optimized design based on bio-productive function in transport area Blatka.

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 designs of forest road network were prepared for seven selected transport areas where Benes (1986a) researched the dependence of morphological quantities of the terrain shape on the degree of difficulty of accessing the area. Based on the technical and economic criteria, he made a design of the optimized road network and presented model examples. His graphical proposals were transferred to AutoCAD program as vector lines and used for the evaluation of the solution based on technical and economic criteria only. Then the real potential of the individual forest functions was calculated: real potentials of the bio-productive function function of ecological stabilization, hydric function, edaphic – soil protective function, function of social recreation, and health and hygiene function and also the overall real potential based on Vyskot (2003), and their values were expressed graphically. The value degrees of the real potentials of the individual forest functions and classes of the overall real potential were colour coded for the creation of maps serving as fundamental data for the design.

At first stage, raster maps of the real potential values were created for each forest function separately. The maps were made in the TOPOL computer program. Forestry maps were used to mark the values of real potentials of the functions for individual stand groups of forest stands. The created maps for individual functions were used as the underlying raster layer of the selected transport areas for the evaluation of the access parameter in AutoCAD, where the design of forest road network optimization with the included ecological criterion, that is, respecting the individual forest functions, was started (Figure 2). Each design was based on the technical and economic solution and at the same time respected the stands with a high value of the real potential. The design and construction of the forest road network made in this procedure would not disturb the stands that provide the overall stability of the accessed area (use of the map raster of the function of ecological stabilization). The risk of possible erosion caused by harvest would be reduced (use of the map raster of the edaphic – soil protective function) as well as the hydric function disturbance (use of the map raster of the hydric function). Using the map rasters of the function of social recreation and the health and hygiene function, the stands with a high value of the real potential of these functions would

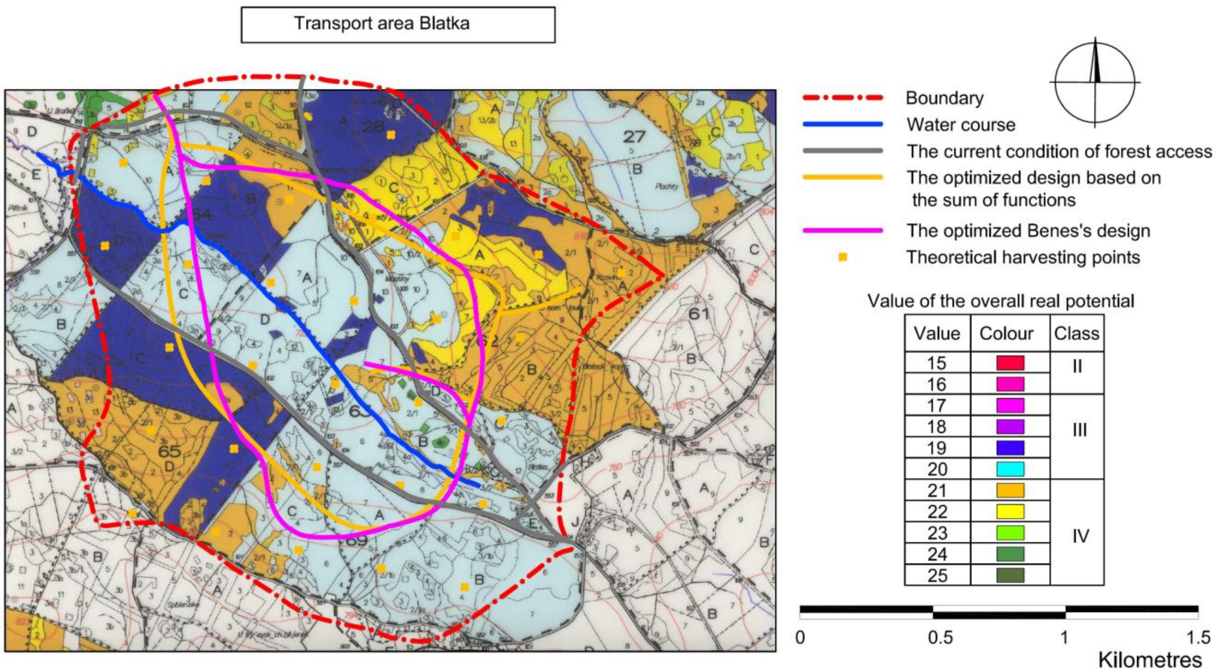

Figure 3. An example of optimized design based on the sum of functions in transport area Blatka.

remain untouched. In this way, six vector layers of forest road network design with an included ecological criterion were created.

At the second stage, we examined whether it would be possible to test only one map – the overall real potential of the forest ecosystem representing all individual functions - for routing and optimization of the forest road network. For this there would have to be the condition that the assessed parameters of the access design cannot change to a statistically significant degree when compared with the parameters of the designs based on the individual functions. The sums of real potentials of individual functions of each stand group in our study range between 15 and 25. As the classes of the overall real potential have a large range of values and the values are concentrated mainly in classes II, III, IV, we used a more detailed distinction. Each value, not a class, of the overall real potential of a stand group was assigned with a colour. Thus we created a graphic map of the total sum of the values of real potential with a more detailed 10-degree differentiation, which seems to be more suitable for the overall design of the transport area roads. In regard to the modification of the scale of the overall real potential classes, the created graphical map of the total sum of the real potential values was marked as the sum of function real potential values. Thus another optimized road network with an included ecological criterion respecting all functions together was designed in the map of the total sum of real potential values (Figure 3).For the comparison of the current and the optimized networks in the form of the size of parameter changes, an independent vector layer of the current forest road network was created. The data on the current access to selected areas were gained from the survey of forest access conducted during the creation of the Regional Forest Development Plans (UHUL, 2000). Thus nine vector layers were created for each transport area.

The next step was a calculation of the parameters and their statistical processing for the optimized designs of forest accessing with an included ecological criterion based on respecting the individual forest functions, the design representing all functions together and their comparison with the optimized Benes's design as well as the current condition. The calculation of individual parameters, the density of hauling roads (H_S), the theoretical skidding distance (D_T), the mean geometrical skidding distance ($D_{G\bar{x}}$), the mean skidding distance ($D_{S\bar{x}}$) and efficiency of the transport area access (U) was performed using the method by Benes (1986a). The method uses a 10 h network of theoretical harvesting points for the calculation of parameters.

Basic characteristics of the statistic set were found during the statistical processing. These are the average, variation, standard deviation, asymmetry, skewness and occurrence probability of a parameter. The lower and upper limits of the interval where the parameter occurs with 95% probability were established. All tests of parameter occurrence were performed at a level of significance α=0.05. Further, an analysis of statistical data (medium value and interval of occurrence) was performed for each access parameter to evaluate the difference of the resulting values of the basic statistical processing of individual parameters. The purpose of the analysis was to find out whether the changes in the assessed parameters of the current condition, Benes's optimized design and the optimized designs with an included ecological criterion, that is, the design respecting the forest functions and the sum of real potentials, are statistically significant. This analysis also shows whether it is possible to use the raster map of the sum of real potentials as the only layer for the optimized forest road network design respecting forest functions in the landscape or whether these changes are statistically significant and the increased costs of forest road network construction and timber transport will have to be taken into account.

RESULTS AND DISCUSSION

Nine designs of area accessed and their parameters were analysed for each of the seven transport areas. The current condition of forest access (S), Benes's optimized design (B), six optimized designs with an included ecological criterion with respective individual forest functions (bio-productive (BP), ecological stabilization (ES), edaphic – soil protective (EP), hydric (HV), social recreation (SR) and health and hygiene (ZH)), and the optimized design with an included ecological criterion created in the map representing all forest functions together (for the sum of real potential values (sum)) were analysed.

For the assessment, the following parameters were examined in each of the design of access in each transport area: density of hauling roads (H_S), theoretical skidding distance (D_T), the mean geometrical skidding distance ($D_{G\bar{x}}$), the mean skidding distance ($D_{S\bar{x}}$) and the efficiency of transport area access (U). The results are presented in Table 3.

The results were statistically processed in ADSTAT 2.0. In total, seven transport areas were processed, that is why the parameters gain seven values. As this range is quite small (n=7, it was necessary to examine whether the sets meet the basic prerequisites for a standard statistical analysis. Test of normal distribution was performed together with the test of outliers. The normal distribution was tested in ADSTAT 2.0 using d´Agostin's test and the outliers were tested by the method of modified inner bounds.

Basic characteristics of the statistical set were calculated for the parameter values that met the condition of normal distribution: the average, standard deviation, variance, asymmetry and skewness, the interval of parameter occurrence at level of significance α=0.05. Statistically significant deviations from the normal distribution occurred in two cases only: in the parameter of the road network density (Hs) for the evaluation of the current condition (S) and in the parameter of the geometrical skidding distance (Dg) for the design respecting the function of social recreation (SR). The basic characteristics of these sets were established using Box-Cox power transformation in ADSTAT 2.0. The presented graphs (Figures 4 to 8) show how the middle values (the average) and the size of the interval with possible 95% probability parameter value occurrence change for individual parameters.

The graphs show that the middle value and size of parameter intervals are mainly different in the current condition, especially parameters: the mean geometrical skidding distance ($D_{G\bar{x}}$), the mean skidding distance ($D_{S\bar{x}}$) and the efficiency of access (U). The middle values and the sizes of interval of individual parameters of Benes's design, designs with an included ecological criterion respecting the individual forest functions and the total sum of the values of real potentials do not differ considerably. This leads us to the assumption that Benes's design, the designs based on individual functions and the design based on the total sum of real potentials are quite homogeneous and thus applicable with the same or very similar effect. This assumption and the question if these differences are statistically significant were tested in the further statistical processing and analysis. Should the assumption be confirmed, we could use Benes's criteria and the map of the sum of real potentials as one data layer for the design of forest road network optimization with an included ecological criterion respecting forest functions.

To evaluate the mutual differences among the individual values of parameters, one-factor analysis of variance was performed. The differences of individual characteristics of the current condition, Benes's design, designs based on individual functions and the design based on the sum of real potentials were evaluated. As the condition of normal distribution was met, it was possible to use the parametric one-factor analysis of variance.

The parameters with a statistically significant difference were found were tested by multiple comparisons. The results confirmed that the statistically significant differences are caused by the values of the parameters of the current condition of the forest road network. Thus it can be concluded that an optimization of the forest road network brings statistically significant changes when compared with the current condition and that the current condition of evaluated areas does not meet the requirement of the optimal forest road network distribution.

The optimized designs improve the access efficiency and shorten the skidding distances, while maintaining the same density of the forest road network.The optimized Benes's design, the optimized designs based on individual functions and the optimized design based on the sum of real potentials form a homogeneous group and we can set a common mean parameter value and occurrence interval with 95% probability for them.

The statistically processed and analysed results show that the middle value deviation of all examined parameters of designs respecting forest functions has been minimal since Benes's design and is not statistically significant. It means there is no considerable deviation of values of the functions.

The inclusion of the ecological criterion in the design of transport area access optimization does not cause statistically significant changes in the values of individual parameters when compared with the optimized Benes's design, which is based on technical-ecological criteria only. Moreover, there are no statistically significant differences in parameters of designs based on individual functions. This finding shows that a single map, a map showing the sum of function real potential values, can be used as a basis for a design of a forest road network with an included ecological criterion.

The study shows that the layout of access optimization is not considerably changed when respecting the forest functions. The changes only concern the routing of hauling roads directed to the ridges where there is a turning area and they do not form an interconnected accessing unit.

The designing of forest access roads can be supplemented by an ecological criterion that is based on

Table 3. The resulting values of parameters in selected transport areas.

Parameter	S	B	Bp	Es	Ep	Hv	Sr	Zh	Sum
H_S (m/ha)									
Babicky p.	19.8	24.5	24.3	23.6	23.5	24.3	24.2	24.7	23.7
Blatka	17.1	16.1	15.5	16.5	16.1	16.4	15.2	16.5	16.7
Kostkovica	18.3	16.9	15.5	16.3	15.7	15.9	16.1	16.4	16.2
Rasnik	18.2	16.1	16.4	15.9	16.1	15.6	14.3	16.1	16.1
Smuch	13.6	16.9	17.2	16.0	16.9	16.9	17.4	16.9	16.8
Spal. paseka	14.7	21.4	19.9	21.1	21.4	21.2	19.5	21.4	20.2
Utechovsky p.	37.4	28.7	24.8	25.1	28.9	28.7	27.1	25.3	25.8
D_T (m)									
Babicky p.	126	102	103	106	106	103	104	101	106
Blatka	146	155	161	152	155	152	165	151	150
Kostkovica	136	148	161	154	159	158	155	153	155
Rasnik	137	156	152	157	156	160	175	156	156
Smuch	184	148	146	157	148	148	144	148	149
Spal. paseka	170	117	125	119	117	118	128	117	123
Utechovsky p.	67	87	101	100	86	87	92	99	97
$D_{G\bar{x}}$ (m)									
Babicky p.	251	147	148	151	153	151	152	148	152
Blatka	244	175	178	175	173	177	179	175	182
Kostkovica	304	179	212	170	181	183	169	179	170
Rasnik	197	186	204	190	186	195	230	186	215
Smuch	286	177	187	187	176	177	175	177	180
Spal. paseka	307	135	149	146	135	135	151	135	145
Utechovsky p.	170	137	155	156	139	138	140	146	153
$D_{S\bar{x}}$ (m)									
Babicky p.	327	188	201	197	193	206	211	198	194
Blatka	276	274	235	281	292	286	254	292	255
Kostkovica	373	242	248	237	255	297	274	242	266
Rasnik	253	245	278	285	292	301	352	292	280
Smuch	381	227	218	218	210	234	220	227	221
Spal. paseka	333	189	209	206	189	209	205	189	188
Utechovsky p.	225	169	178	182	167	164	167	162	180
U (%)									
Babicky p.	50.3	69.6	69.2	70.2	69.6	68.3	68.1	68.2	69.5
Blatka	59.8	88.8	90.3	86.7	89.8	86.1	92.1	86.4	82.3
Kostkovica	44.8	82.7	76.0	90.3	88.0	86.2	91.9	85.2	91.0
Rasnik	69.6	83.7	74.7	82.6	83.7	82.1	75.9	83.7	72.4
Smuch	64.5	83.8	77.9	83.8	84.3	83.8	82.2	83.8	82.6
Spal. paseka	55.5	86.9	84.2	81.1	86.9	87.4	84.7	86.9	85.2
Utechovsky p.	39.3	63.6	65.1	63.8	62.1	63.1	65.9	67.7	63.3

the real potentials of all forest functions. The results show that in the selected transport areas the density or the length of forest roads does not change to a statistically significant degree and that the increase in the mean skidding distance from the area of harvest to the hauling place is only minimal. The worries that respecting the functions of forests, in our case represented by the ecological criterion, within designs will substantially increase the costs of forest road network construction as its length and the skidding distances will be expanded

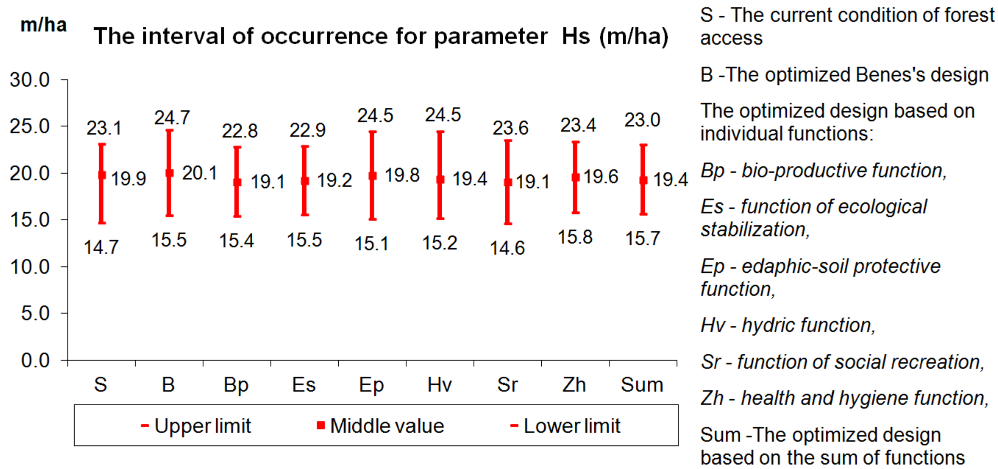

Figure 4. Graph of the middle value and occurrence interval with the level of significance α=0.05 for the density of hauling roads.

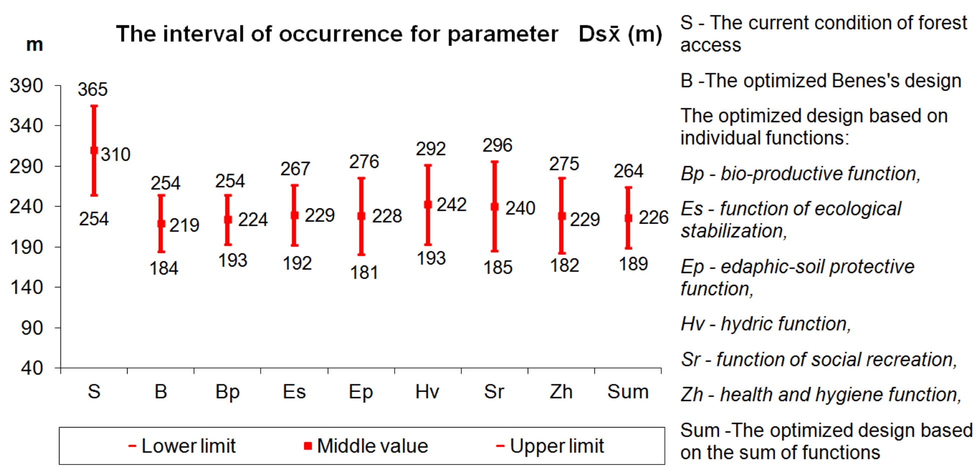

Figure 5. Graph of the middle value and occurrence interval with the level of significance α=0.05 for the mean skidding distance.

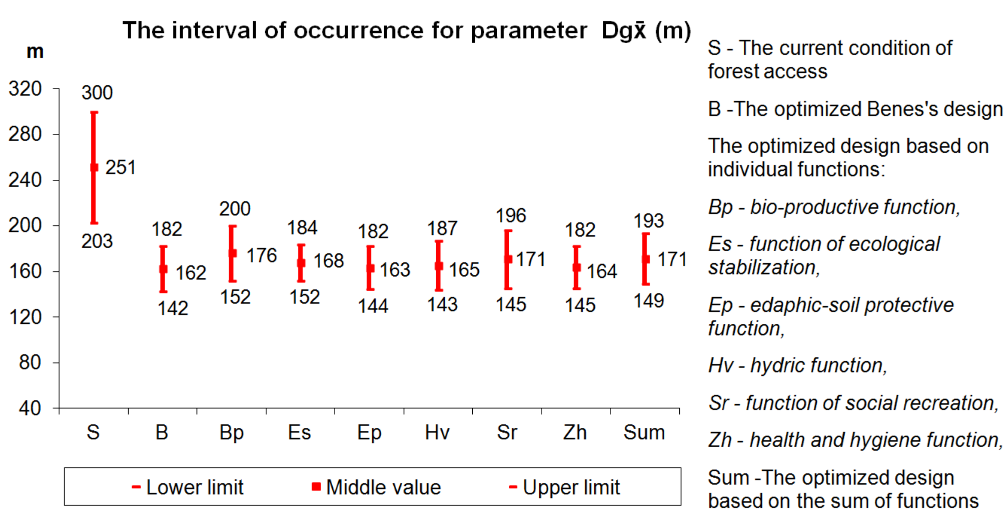

Figure 6. Graph of the middle value and occurrence interval with the level of significance α=0.05 for the mean geometrical skidding distance.

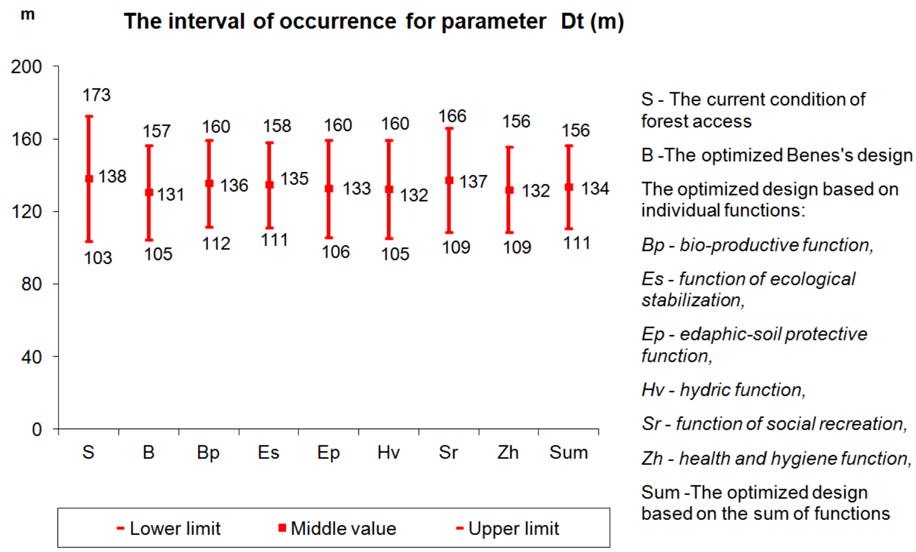

Figure 7. Graph of the middle value and occurrence interval with the level of significance α=0.05 for the theoretical skidding distance.

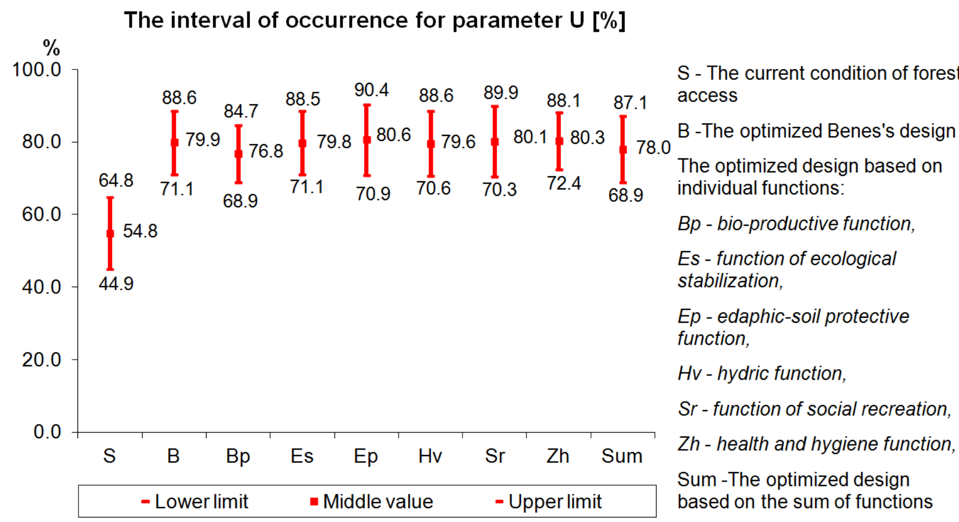

Figure 8. Graph of the middle value and occurrence interval with the level of significance α=0.05 for the efficiency of access.

proved to be unsubstantiated. These results support the results of a study in which Becker (1998) presented the issue whether it is economically wise to reoptimize the current road network. His reoptimization consists of the reduction of the road network density with the current length of skidding distance being maintained and the transformation of a part of skid roads into hauling roads. The author recommended combining two methods; (1) reoptimize the road network; and (2) introduce the differentiated maintenance system. The costs of re-optimization will be made up for by the reduced costs of the road network maintenance in the long term. These data show that optimization can be implemented with a long-term perspective without additional costs. In this case, it would be appropriate to use the mentioned method of respecting all forest functions as the financial costs would not be increased and, at the same time, the final design would be a complex solution to transport area access that would include the ecological criterion in forest access issues.

Conclusion

Based on this study, the former technical and economic approach can be changed into technical-economic-ecological approach which contributes to the reduction of the environment-related negative effects of forest road network construction. Moreover, the study has proven that the parameters of the forest road network did not change. This allows us to presume that an inclusion of an ecological criterion does not increase costs of forest road network layout. Considering all the effects included in the solutions to forest access issues, a long-term aim is to put the technical, economic and ecological requirements in harmony and to minimize the negative effects of a forest road network.

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