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PLANNING OF FOREST ROADS IN CROATIAN MOUNTAINOUS FOREST BY THE USE OF MODERN TECHNOLOGIES

Primary forest communications (forest roads) represent the necessary infrastructure in today's intensive, integral, rational, ecologically aware forest management based on principles of constant yield, biodiversity of species and natural quality of forests. The total quantity of forest roads, their spatial distribution, as well as their prescribed technical features must be sufficient for as much as possible quality forest management with as less as possible initial and subsequent financial investment. The building and maintenance of primary forest road infrastructure network makes an important component within the total cost structure connected with the forest management. The procedure of establishing forest roads on the terrain, from the general point of view, is carried out through the following stages: planning, designing, building and maintenance. It is impossible to reach every next stage within the mentioned order without a quality completed previous stage of work. Also today, planning as a starting and initial stage of the mentioned procedure is unjustly pushed into the background. The quality planning of forest roads, i.e. making a Study of primary forest opening by applying contemporary methods, procedures and work technologies, the optimising of forest road network can be achieved, regarding various factors of optimality evaluation with the aim of achieving higher efficiency and lower length of forest roads with the lower building costs and the least possible negative influence on the whole forest ecosystem.

Keywords: forest roads, opening up of forest, mountainous forests, Geographic Information System, Global Position System, Croatia

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Планування лісових доріг у гірських лісах Хорватії із застосуванням сучасних технологій

Первинні лісові комунікації (лісові дороги) є необхідною інфраструктурою у сьогоdnішньому інтенсивному, інтегрованому, раціональному, екологічно-свідомому лісовому господарстві, що базується на принципах одержання постійного приросту, біологічного різноманіття видів і природної якості лісів. Загальна кількість лісових доріг, їх просторове поширення, а також технічні параметри повинні бути достатніми для якомога якіснішого ведення лісового господарства з найменшими фінансовими затратами.

Будівництво та утримання мережі лісових доріг є важливим компонентом загальних затрат на ведення лісового господарства. Технологічний процес створення лісових доріг включає такі стадії: планування, проектування та їх утримання. Неможливо розпочати кожен наступну стадію без якісно завершеної попередньої.

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Сьогодні планування, як початкова стадія, незаслужено відкинута на задній план. Якісне планування лісових доріг, тобто пошук та визначення місць розміщення майбутніх доріг, може бути досягнуто за умови використання сучасних методів і технологій оптимізації лісотранспортної мережі.

Ключові слова: лісові дороги, освоєння лісових масивів, гірські ліси, GIS, GPS, Хорватія.

1. Introduction

In opening forests by forest roads, i.e. in finding best possible locations of future forest roads, forest experts have been constantly balancing among economic, technical-technological, ecological and sociological-aesthetic demands put before the designers. It is very difficult to coordinate the mentioned factors and to choose, from all the relevant points of view, the best possible route of the future forest road. In the very procedure of planning forest roads, a great quantity of information should be analysed, where the help of personal computer, other contemporary technologies (GIS, GPS) and other programme packages is of extreme importance.

Many authors have dealt with forest opening and planning of forest road routes. Various authors had different ideas which resulted in a different attitude to the mentioned problem. The most significant authors are mentioned in the chronological order: *Segebaden* (1964.), *Dietz, Knigge & Löffler* (1984.), *Shiba, Ziesak & Löffler* (1990.), *Shiba* (1992), *Session* (1992.), *Dahlin & Sallnas* (1992.), *Tan* (1992.), *Lihai* (1992.), *Setyabudi* (1994.), *Krč* (1995.), *Hentschel* (1996.), *Dürrstein* (1996.), *Erdas, Acar, Karaman & Gümüş* (1997.), *Pičman & Pentek* (1998.), *Häyrinen* (1998.), *Heinimann* (1998.), *Pentek* (1998.), *Yoshimura & Kanzaki* (1998.), *Wolf* (1998.), *Sessions, Chung & Heinimann* (2001.), *Pentek* (2002.)

Having analysed the works of mentioned authors, the following approaches to the forest road network optimisation can be distinguished: a traditional (classical) planning, planning by the use of contemporary technologies and combined planning. Traditional planning has almost no supporters in the contemporary forestry since the present computerisation of all the segments of human life has also had an impact on forestry. The reason for the use of contemporary technologies in planning the optimum forest road infrastructure network is in a significant number of factors which need to be coordinated and in order to achieve this, a great amount of relevant information has to be processed.

Combined planning represents the ideal solution, since it presumes the interaction of contemporary technologies and forest knowledge, information achievements, expertise and experience. Well-established fact is that the best possible variant of a certain forest road can be established only to test theoretical computer models on the terrain and in practice. Apart from checking the obtained results, the input data have also to be checked, since input data, their structure and importance are the "key" to choosing the optimum solutions.

2. Problems of the research

Since the Republic of Croatia has still a big share of unopened, insufficiently opened or not quality opened forest areas, it was necessary to make a methodological study of the primary forest opening. Such a methodological study was

made in 2002 and in this paper it will be tested on two management units. With clearly defined, established and described optimisation stages, applied techniques, technologies, algorithms and work methods in each of them, the methodological study represents a kind of protocol which should be followed in contemporary forest opening and combined planning. The possibility of changing the model and the system of optimality evaluation of complex dominant influential factors, as well as of complex dominant influential factors themselves or their structures, depending on the concrete area for which a forest road network is optimised, are a guarantee of the wide use of the computer model of forest road network optimisation.

Stages of creating the comprehensive optimised forest road network have been defined as follows:

- Defining the basic function of the forest of a forest stand type and management way and designing computer database
- Analysis of the existing primary forest road infrastructure
- Determine potential routes of future forest roads
- Analysis of possible future forest roads and of achieving the aimed openness
- Optimise the network of forest roads by using a digital elevation model
- Checking the viability of a model on the terrain and provide project documentation

2.1. Zero stage of optimising

Zero stage of optimising represents a kind of a preparatory stage for further procedure of optimisation of a forest road network. Here, the basic purpose of forests, a forest stand type and the management method, have to be defined and necessary computer data base has to be worked out, designed and formed and connected with the forest management maps in a digital form.

A computer database has a value for itself since all data about a certain forest area are collected in one place and sorted in a way which suits us best; however, its real value is mostly expressed at the moment when the attributed database is connected with the spatial subcompartment unit. Having connected the computer database and subcompartments on forest management maps in a digital form in combination with GIS technology, we have obtained high-quality base for implementing various analyses, whose results are high-quality and timely decisions.

The existing forest roads have been surveyed by the use of GPS, Trimble, Geoxplorer 3, obtained data have been processed in the programme package GPS Pathfinder Office 2.80, corrected with measurements of base stations at the Zagreb cadastre office in order to eliminate mistakes and increase the precision of collected data and drawn into previously scanned maps. Measurement has been completed with the external antenna put on the vehicle with the interval of recording points of 5 seconds.

2.2. The first stage of optimising

The analysis of the existing network of primary forest road infrastructure consists of numerous operations and procedures whose basic purpose is to establish a quality, quantity and possible faults of the existing road network. Depending on obtained results of the analysis, the further development of optimising forest transport network will be determined.

At this stage of optimising we establish: the average existing real mean skidding distance, the existing costs of wood skidding, the aimed openness and the aimed real mean skidding distance, the relative openness for calculated average aimed real mean skidding distance, the efficiency of individual forest road and the whole road network and we define areas that are not opened.

2.3. Second stage of optimising

A separate computer database has been formed for each management unit. Extremely rich, complete database had to be reduced, some factors had to be joined and redefined. Reasons for decrease of input data necessary for calculation are in the basic features of all quality models: simplicity, precision, applicability and verifiability.

In designing new, working database, we have chosen a working method "from big to small". First, criteria of optimality evaluation of forest road networks have been defined, that were classified into priority levels of optimising and then, for each individual evaluation criterion, complex dominant influential factors have been determined which were joined with the simple dominant influential factors.

2.4. Third stage of optimising

At this stage of optimising of forest road network it is necessary to define the scoring limit of viability of basic square information carriers in the further optimising procedure. In other words, those basic information carriers whose number of scores is below the viability limit are eliminated from further operations, as well as those basic information carriers which have been thrown out for applying the principle of exclusivity in evaluating the certain complex dominant influential factor. Basic information carriers, whose sum of scores is higher than the necessary minimum, are kept in the optimising procedure and we carry out the third stage of forest road network optimising on them.

The obtained model of possible routes of future forest roads is adapted to the concrete situation, and using the method of bordered areas, the area of efficient bordered areas, the "dead zone" areas and the efficiency coefficient are calculated, and the possible locations of future forest roads are analysed according to the criteria of the highest influence of opening of the certain forest area. After separating routes of newly designed forest roads, they are again fitted in the existing forest road network and for the total (existing and newly designed) forest road network, the analysis procedure like in the first stage of optimising is carried out.

2.5. The fourth stage of optimising

The result of the third stage of optimising forest road network is the most optimum forest road network regarding its position; those information carriers were chosen as locations of the newly designed forest roads for which it was determined to be of the highest quality, by various methods and systems of optimality evaluation, from complex dominant influential factors to criteria and priority levels to comprehensive optimisation. Layered maps in a digital form were used as the base, on which we have used GIS technology of data and information analyses, using already existing or own methods. All results of optimising refer to the one-dimensional distribution of forest road network, while a height component of a forest road route development has not been taken into account until now. It is the task of this stage of optimising.

2.6. The fifth stage of optimising

Designed computer models have to be checked on the terrain in order to estimate their quality and prove the viability and applicability in practice.

3. Research area

The research was carried out in two mountain management units: the management unit Lisina and the management unit Veprinačke forests of the Forest Administration Buzet. From the orographic point of view, it is the area broken with steep slopes, wreaths, smaller terraces and plateaus where we can find karst valleys. This area is characterised by a karst relief and a complex geological relation of limestone and dolomite. As a result of that, in this area there are numerous grounds typical for the mountainous area of limestone-dolomite rocks. According to Köppen's classification of the researched management unit, they lie in the climate zone of Cfsax" type – transitional type of climate with hot summers and due to its specific position and orographic conditions in forming climate conditions, there is an exchange of sea and continental hinterland (the Slovenian Alps).

Both management units are situated in the area of seaside beech (*Seslerio Fagetum*/Ht. 1950./M. Wraber 1960./). That climatogenic community stretches above the submediterranean vegetation, i.e. above the area of hornbeam forest (*Ostryo Carpinetum*). In the area of the management unit Lisina and the management unit Veprinačke forests, the seaside beech forest community is divided into two subassociations: seaside beech forest typical (*Seslerio Fagetum subass. typicum*/Ht. 1950.) and seaside beech forest with bitter cresses (*Seslerio Fagetum subass. cardaminetosum*/Pelcer 1982.).

In forest exploitation, skidders are used in the second stage of work, therefore, in skidding round wood. Such an orientation presumes good secondary forest opening by tractor roads which, due to the terrain configuration and developed orography, have to be built. A half-tree length method is used in felling and processing works. Basic characteristics of works of forest opening and exploitation are: steep and indented mountain terrain, richness and diversity of karst relief phenomena, shallow grounds and rocky basis and heavy building material categories. Mentioned characteristics indicate the need of good primary and secondary forest opening due to the decrease of costs of timber transport. The annual cut quality in both management units is very good and a significant beech quantity (white beech) ends at the international bid (Italian market), where it achieves much higher prices than the bid price.

4. The aim of the research and working methods

The main aim of the research is to show that by contemporary working methods (GIS, GPS, etc.) at the stage of forest road planning, better results can be obtained than by classical methods. We also wanted to point to the necessity of making the Study of primary forest opening with the aim of rationalisation of forest opening and the increase of efficiency of the primary forest road infrastructure network.

In this, we have used methods, procedures, technologies and formulas which were defined in details and explained for each substage of six main stages within the methodological study of forest opening.

5. Result of the research

Analysis results of the existing primary forest road infrastructure network have shown that further opening of not opened areas should be carried out. After determining potential routes of future forest roads and the analysis of chosen possible locations of future forest roads and achieving the aimed openness in the area of the management unit Lisina and the management unit Veprinačke forests, which were considered in opening as an integral area, we designed six forest roads. One road is completely in the management unit Lisina, three roads completely pass through the management unit Veprinačke forests, while two forest roads pass through both management units.

Table 1. Summary table of forest road infrastructure opening analysis according to forest opening variants in the management unit Lisina ($P=1\,524.44$ ha)

	Zero condition of openness	Present condition of openness	Present improved condition of openness	1. variant of opening zero condition	2. variant of opening zero condition	3. variant of opening zero condition
Forest road (FR) length, km	0.00	21.48	23.99	17.20	15.28	17.63
Public road (PR) length, km	14.68	14.68	14.68	14.68	14.68	14.68
Total road length, km	14.68	36.16	38.67	31.88	29.96	32.31
Openness (forest roads) km/1000 ha	0.00	14.09	15.74	11.28	10.02	11.56
Openness (public roads) km/1000 ha	9.63	9.63	9.63	9.63	9.63	9.63
Openness (forest + public roads) km/1000 ha	9.63	23.72	25.37	20.91	19.65	21.19
Relative openness (forest + public roads), %	41.20	82.35	87.68	87.43	88.81	88.98
Category of relative openness	1	4	5	5	5	5
Efficiency coefficient (forest roads), %	–	38.58	39.30	56.65	54.38	57.11
Existing mean skidding distance, m	821	341	275	257	296	251
Annual cost of wood skidding, EUR	49967	24196	22716	21831	23789	21510
Annual cost of FR building, EUR	0	16920	18900	13546	12035	13891
Annual cost of FR maintenance, EUR	0	13118	14653	10502	9331	10770
Total cost of wood transport, EUR	49967	54234	56269	45879	45155	46171

From data in the table 1 we can conclude that at the present state of openness and the first opening variant, the openness by forest roads has increased from 14.09 km/1000 ha to 15.74 km/1000 ha and the total openness by forest and public roads increased from 23.72 km/1000 ha to 25.37 km/1000 ha. The relative openness was increased by 5.33 % (from 82.35 % to 87.43 %). The efficiency of the total forest road network (the existing and future ones) is 39.30 %. The average existing mean skidding distance is 275 m and in comparison with the present condition (341 m) is smaller by 66 m. Total costs of wood transport have increased a bit (by 2035 EUR/year), however, they have to be observed in the context of calculating the cost of timber skidding (they represent a direct cost of work of a logging tractor LKT 81T without the cost of a driver and a chocker setter). It was all achieved by 2.51 km of new forest roads.

Table 2. Summary table of forest road infrastructure opening analysis according to forest opening variants in the management unit Veprinačke forest (P=1 950.87 ha)

	Zero condition of openness	Present condition of openness	Present improved condition of openness	1. variant of opening zero condition	2. variant of opening zero condition	3. variant of opening zero condition
Forest road (FR) length, km	0.00	17.71	21.89	20.90	24.77	21.52
Public road (PR) length, km	16.94	16.94	16.94	16.94	16.94	16.94
Total road length, km	16.94	34.65	38.83	37.84	41.71	38.46
Openness (forest roads) km/1000 ha	0.00	9.08	11.22	10.71	12.70	11.03
Openness (public roads) km/1000 ha	8.68	8.68	8.68	8.68	8.68	8.68
Openness (forest + public roads) km/1000 ha	8.68	17.76	19.90	19.39	21.38	19.71
Relative openness (forest + public roads), %	42.94	76.92	86.47	90.78	90.90	91.35
Category of relative openness	1	4	5	5	5	5
Efficiency coefficient (forest roads), %	–	46.70	47.19	52.46	51.71	52.42
Existing mean skidding distance, m	798	344	317	289	281	292
Annual cost of wood skidding, EUR	58329	31271	29804	27975	27488	28175
Annual cost of FR building, EUR	0	13951	17246	16469	19512	16958
Annual cost of FR maintenance, EUR	0	10816	13371	12769	15127	13147
Total cost of wood transport, EUR	58329	56038	60421	57213	62127	58280

In the management unit Veprinačke forests in the improved present condition of openness with the total of 4.18 km of new forest roads and the total of 21.89 km of forest roads (existing), we have obtained the openness by forest roads of 11.22 km/1000 ha, by forest and public roads of 19.90 km/1000 ha and the existing mean skidding distance of 317 m (by 27 m less than the present). Costs of timber transport have increased by 4383 EUR/year due to the previously mentioned reasons, but the relative openness reached the category of excellent openness with 86.74 %, with the efficiency coefficient of the forest road network of 47.19 %.

It has to be emphasised that better results than the present ones were obtained by a computer model of forest opening in the present condition, while simulating the zero condition, better results were obtained than those currently present in the management unit Lisina and the management unit Veprinačke forests, but also better than the results obtained by improving the present condition of openness. In this way, the unquestionable quality and use of the applied model has been determined. Also, apart from the systematic approach to the forest opening, it should be insisted on studies of forest opening for bigger areas and a model of the chosen route of future forest roads should be followed as much as possible in designing.

6. Conclusions

The computer base of attributive and spatial data of the researched area, in combination with GIS and adequate programme packages (ArcGIS), provides a very good solution, by which it is possible to analyse a great quantity of input data

and create quality base for making timely and valid decisions. Once formed computer database is dynamic and can be used in all segments of forestry, managing a forest ecosystem and area in general.

The inventory of forest communications (forest roads and skid trails and strip roads) by the use of GPS and the use of return method, taking into account the correction of differential mistake on the terrain of imaged data, represents a very fast and quite precise method by which it is possible to map imaged roads to maps in a scale 1:5000. Once determined catalogue of forest communications enables exact and detailed insight into the existing resources of a certain forest area, the analysis of the existing condition of the primary and secondary forest openness and noticing of possible needs, faults and lacks, planning and control of costs of maintaining forest roads and repairs of strip roads, etc.

The criteria of evaluating the optimality are economic and technical-technological, in the first priority level of optimisation and the environmental-ecological in the second priority level of optimisation. The criteria of the optimality evaluation of the first priority optimisation level influence the general route of future forest roads, while criteria of the second priority optimisation level influence the local placement of certain parts of routes of the future forest roads. Each criterion of optimality evaluation of the forest road network consists of a certain number of complex dominant influential factors. As their name suggests, these are factors which, for the researched environment and general conditions that we meet there, have the most significant meaning in evaluating optimality per the individual evaluation criterion. Each complex dominant influential factor consists of the certain number of simple dominant influential factors. For various areas of the application of the computer model of a forest road network optimisation it is possible to create own evaluation criteria and priority levels of optimisations and complex dominant influential factors and their structure, as well as evaluation models and systems of each of them.

Testing of the theoretical computer model of forest road network optimisation in practice, on the terrain, was carried out for the present condition of openness and for the first opening variant, since only this guaranteed that there are not already built roads on locations of future forest roads. Deviations by a computer model of certain routes and their projection on the terrain from the axle polygon of designed forest roads were within acceptable limits and did not deviate much from the general route trend. The greatest influence on moving the designed forest road route from the one determined by the model, had unmapped rock complexes, karst forms, existing strip roads and imprecisely mapped borders of private areas. The greatest influence on the relocation of the designed route of the forest road from the one determined by the model, had unmapped rock complexes of the surface of even more than half a hectare, karst forms which have not been put into Basic State Maps, existing strip roads, whose routes we tried to follow because of lower building costs, borders of private areas which had not been precisely mapped and do not correspond to the situation on the terrain. It has to be mentioned that opened areas, i.e. unopened areas of the researched area, represented the most difficult terrains (that's why they remained unopened), and the whole researched area is characterised by great indentedness of the relief and steep slopes, karst forms and

rocky building categories of the material, which finally results in extremely difficult and complicated conditions for carrying out the procedure of forest opening.

For obtaining even better results in forest opening and in choosing the possible forest road routes as close to designed forest roads as possible, we suggest to map compact complexes of rocks of the surface area above 0,25 ha, to precisely survey and map boundaries of private areas, to survey skid trails and strip roads and draw them into maps, for subcompartments, to describe the relief rockiness and scalar features.

Made designed project documents of designed forest roads confirm the correspondence of their features with features prescribed by technical conditions for economic roads by which the possibility of performance is undoubtedly confirmed. Cost calculation shows its fitting into the calculation of the planned price.

Methodological study of forest opening is the first step in this area in Croatia, and as such, is subject to improvements and changes; therefore, further research is necessary which will go in this direction. The applicability of the forest opening methodological study will increase by the automatisisation of the optimisation procedure, for which the preconditions were made by making an optimising flow Figure per optimisation stages.

It is necessary to make similar methodological study for secondary forest opening which, like those for primary opening, should be an integral part of the Management plan of certain forest area.

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AN OFF-ROAD ROUTING USING GIS-ANALYSIS

The paper describe concept for the GIS based terrain trafficability modelling and the optimization of an off-road route. The concept of the generation of the cost surface is based on machine, tyre, terrain and weather objects. Different cost surface alternatives can be generated according to changing information in objects. The analysis of soil bearing capacity is based on plasticity theory. A regular cost surface analysis was used to determine the optimal off-road route between two points. In addition, the five per cent corridor around the least-cost route was generated. It has been shown that useful parameters can be found for national level digital maps for supporting the off-road analysis.

Keywords: Off-road routing, vehicle mobility, terrain trafficability, GIS, cost surface analysis

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Планування маршрутів руху лісових машин на базі ГІС-аналізу

Описано концепцію моделювання опорної прохідності лісових машин та оптимізацію маршрутів їх руху на базі ГІС-технологій. Оцінювання несучої здатності ґрунту базується на теорії пластичності. Для визначення оптимального маршруту лісової машини виконувався вартісний аналіз з використанням даних про лісову машину, її шини, місцевість та погодні умови. Крім того, навколо напрямку оптимального маршруту генерувався 5 %-ий коридор найменшої вартості використання лісо-

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