# Forest fire-prevention roads as a special category of forest roads and factors that influence their distribution in space

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# FOREST FIRE-PREVENTION ROADS AS A SPECIAL CATEGORY OF FOREST ROADS AND FACTORS THAT INFLUENCE THEIR DISTRIBUTION IN SPACE

## ŠUMSKE PROTUPOŽARNE CESTE KAO POSEBNA KATEGORIJA ŠUMSKIH CESTA I ČIMBENICI KOJI UTJEČU NA NJIHOV RAZMJEŠTAJ U PROSTORU

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Forest fire-prevention roads (FFPR) are a special category of forest roads connected to the Mediterranean and Submediterranean area, i.e. to the area where forest fires represent the greatest danger of total biotic and abiotic factors harmful to the existence of forest ecosystems. Research on the most important factors which influence the spatial distribution of the network of forest fire-prevention roads of high quality, as an important factor in preventive measures against forest fires, was carried out in the management unit Senjska Draga in the area of the Forest Management, Senj. The results of the research showed that one third of the existing forest fire-prevention roads were laid with a higher longitudinal gradient than permitted. An average geometrical distance determined by a centroidal method, and by the application of the personal computer is 244.79 m, and its real equivalent is 287.15 m. Using the relative openness and the new method of bordered areas, it has been established that the researched management unit is satisfactorily open for the average geometrical distance of access to the forest area from 250 m and more. On the theoretical model, due to various influences of factors, it has been shown that forest fire-prevention roads should be designed at a distance of 300 to 600 m apart. In order to choose the most acceptable costs for forest fire-prevention roads, the computer programme COST has been created, and calculations are based on the derived mathematical expressions. Costs of excavations depend on many factors that have been analysed in detail, and according to the research of the normal transversal profile, the more economic method of building forest fire-prevention roads has been suggested.

Key words: forest fire-prevention roads, forest fires, the karst area, digital terrain model, relative openness, excavation costs

# INTRODUCTION
# UVOD

According to the data of the Public Enterprise "Croatian Forests" (1997) the area of forests on karst, i.e. forests that are on the islands and the coastal area of the Republic of Croatia, which are managed by "Croatian Forests", amounts to 873,148 ha. Wood reserves of the state seaside forests are only 46 $m^3$/ha, and the annual growth is 1.35 $m^3$/ha. The annual felling according to management plans is 387,580.00 $m^3$, but the plan cannot be fulfilled due to inaccessibility, the high costs of felling and the lack of a market for conifer trees.

The mentioned indicators, as well as others, if taken into account only from the point of view of timber mass production, could lead to the wrong conclusion, namely, that seaside forests, as they are, are not an important factor in the Croatian forestry and economy at this moment. However, if we take into account their production potential, which can be far better used and improved by intensive and professional management, and particularly if we take into account the *secondary functions* that they have, these forests represent a significant factor in Croatian forestry and in the economy in general. Apart from that, the development of tourism as a significant segment of the Croatian economy is closely connected to the existence of these forests. Without them, particularly due to their secondary functions, this area would not be what it is.

Forest fires as an abiotic destabiliser of the ecosystem of the Mediterranean, i.e. the karst area of the Republic of Croatia, have been jeopardising the vegetation of this area more and more lately. In the coastal area and on the islands of our country, forest fires represent the greatest danger in compared to any other damaging factors. Therefore, forest fires represent a problem characteristic of the Mediterranean region, a problem that has to be faced, fought against and whose solution has to be carefully planned.

According to Vajda (1974) measures of fighting against forest fires can be divided into three larger groups: *preventive measures, preparatory measures for fire extinguishing, and measures for fire extinguishing.*

We are primarily interested in the preventive measures by which, theoretically, the accurrence of all forest fires can be prevented (whose direct or indirect cause is man), and in the Republic of Croatia the proportion of total annual number of fires caused by man is 95 % (Španjol 1996).

According to Bilandžija (1988) preventive measures are: legal, educational, continuous advertising in the media, the education and organised engagement and training of the local population in activities of protection against fire, a well-organised observation-informational service, and measures which are biological (forest-growing and forest-arranging), and technical (the building and maintenance of fire-prevention straight clearings, the building and maintenance of forest fire-prevention roads and the building and maintenance of storage reservoirs and pumping sites).

In the period before Croatian independence, in former Yugoslavia, for various reasons, the organisation of protection against forest fires was not performed purposefully and successfully. The main drawbacks of the previous organisation lay in the lack of financial means, in the insufficient care taken by the state at that time and in the frequent changes in the system of organisation and in the policy of managing forestry and fire-fighting. This particularly refers to the system of carrying out preventive measures, and within these measures, there was aparticularly difficult situation with the technical component, i.e opening up Mediterranean forest areas with fire-prevention roads.

Pičman & Pentek (1996) wrote: "Forest fire-prevention roads are such forest roads that are primarily designed and built in order to prevent forest fires and in the case of the emergence of fire they have to enable conditions for its extinguishing. These are forest roads that are not called economic forest roads, as at the time of their realisation the raw base of the Mediterranean forests was uneconomical for exploitation, so the primary task of the built roads was fire-prevention."

Naturally, fire-prevention roads have other functions which arise in managing forests, so these roads can be with good reason called *multifunctional forest roads* (Pičman & Pentek, 1996).

As the Mediterranean area is the most jeopardised by forest fires and at the same time the most attractive to tourists, and as the total economy of the Republic of Croatia is particularly interested in this area, all necessary steps which will lead to the radical decrease of forest fires should be taken. One of the big steps which leads to the realisation of this aim is the optimum openness of the Mediterranean karst zone in terms of the accessibility of the jeopardised areas to intervening fire-engines.

## THE AIM OF THE RESEARCH
## CILJ ISTRAŽIVANJA

The main aims and lines of direction of this research are conceived in the following steps:

- defining and clearly distinguishing forest fire-prevention roads as a special category of forest roads,
- making a digital terrain model of the researched area,

- determining the terrain gradients and the classification of categories of gradients,
- calculating the longitudinal gradient of the existing forest fire-prevention roads and classifying of the categories of the longitudinal gradients,
- determining the optimum quantity of fire-prevention roads regarding the tactical demands of the fire-brigades while extinguishing forest fires,
- including of data received from the previous step into knowledge of foresty science about the necessary openness of forest ecosystems and about the largest allowed surface of forest roads on a forest area and finding best solutions,
- taking account of the openness of the researched area due to various average optimum geometrical and real distances of accessibility to the area in a classical way and applying the size of the relative openness of the area,
- determining the costs of excavations for forest fire-prevention roads of the proper normal transversal profile with various transversal terrain gradients, various planum widths and various categories of materials,
- the elaboration of the programme COST which can be chosen in a short time, for the most acceptable variant of forest fire-prevention roads from the point of view of the minimum excavation costs,
- using the so-called "buffer" method to determine the relative openness of the area and the efficacity of forest fire-prevention roads, and of the programme COST, in choosing the most acceptable variant of the route of the future forest fire-prevention road.

## RESEARCH PROBLEMS
## PROBLEMATIKA ISTRAŽIVANJA

Forest fire-prevention roads in the classification of forest roads in our country have not been mentioned as a separate category, so it is necessary to start by elaborating on the models of classification of forest roads in Croatia and in some other European countries, so that we can determine in which category forest fire-prevention roads can be included in line with different classification criteria. Alternatively, it can be seen whether they make up a separate category.

## THE CLASSIFICATION OF FOREST ROADS AND THEIR BASIC TECHNICAL CHARACTERISTICS
## RAZREDBA ŠUMSKIH CESTA I NJIHOVA OSNOVNA TEHNIČKA OBILJEŽJA

According to *Tehnički uvjeti za gospodarske ceste* (1989) the network of economic roads in forestry can be classified according to:

- its significance,
- traffic load (gross tons/24h),
- the configuration of the terrain,
- its size and the frequency of timber mass transport.

Regarding the frequency of use and the necessity of maintenance, according to Pičman and Pentek (1996), roads can be classified into *primary roads*, which are used during the whole year and require regular maintenance, and *secondary roads*, which are used from time to time, according to the need, so their maintenance is periodical.

In Austria, forest roads are classified according to the building standard, so Trzesniowski (1988) classifies them into: *main forest roads, subordinate forest roads, formed paths,* and *main and subordinate skid trails.* A more detailed classification within the mentioned categories has not been made.

In Slovakia, Jurik et al. (1984) offer a classification in eight categories of high quality according to technical traits within two classes.

In Germany (Dietz et al. 1984), there is a classification of forest roads according to the number of lanes, the width of a roadway, allowed load, minimum radius of horizontal curves and allowed longitudinal gradient. Taking these elements into consideration the above mentioned authors have divided forest roads into: *main forest roads, primary forest roads, secondary forest roads, tractor paths and tractor haulages.*

Potočnik in Slovenia (1996) uses as a criterion for the classification of forest roads their multifunctional use and classifies them into three categories: *category 1: symbol GI/1, category 2: symbol GI/2, category 3 where he distinguishes: GII - main export roads and GIII - subordinate forest roads.*

## THE OPENNESS OF FOREST AREA
## OTVORENOST ŠUMSKOGA PODRUČJA

According to the statements in *Tehnički uvjeti za gospodarske ceste* (1989) in the calculation of the degree of forest openness, the following is taken into account:

- a road (or a part of it) which goes through a forest - for the total length (100 %)
- a road which goes through the edge of a forest or at a distance from the edge of a forest up to 300 m, and enables loading - for 50 % of its length,
- a road which comes vertically to the edge of a forest and stays there - for a length of 500 m, and
- a navigable water current which goes through the edge of a forest and is used for loading forest assortments - for 50 % of its length.

The openness of a certain forest area by forest roads or the density of forest roads over a certain area is a quantity usually expressed in m/ha or km/1 000 ha.

The percentage relationship of the forest area which is opened by forest roads and the total surface of a gravitational area is called a relative openness, a percentage openness of forests or a degree of forest openness and is expressed as a percentage. According to such expressed openness, i.e. the accessibility of a terrain, Jurik et al. (1984) mention five basic categories of openness. They are: up to 65 % - insufficient openness, 65-70 % - barely satisfactory openness, 70-75 % - satisfactory openness, 75-80 % - higly satisfactory openness, and more than 80 % - very good openness.

Dundović (1996) determines the efficacity of a forest transport network as a percentage. Here, he uses a formula:

$$Z_s = \frac{D_{st}}{D_{sg}} \cdot 100 \tag{1}$$

where:
$Z_s$ is the efficacity of the network of transport roads, %
$D_{st.}$ is an average theoretical distance of skidding, m,
$D_{sg}$ is an average geometrical distance of skidding, m.

When a certain forest area is open, the final aim is always an optimum openness of the forest area. Various areas have determined the optimum density of the network of forest roads in various ways, but they are essentially similar - *to determine such a distance between forest roads where total costs will be minimum.*

Particularly when speaking about forest fire-prevention roads, all the factors that influence total costs have to be carefully determined. Cost factors have to be analysed in detail.

# THE OPENNESS OF FORESTS IN THE REPUBLIC OF CROATIA WITH THE EMPHASIS ON THE MEDITERRANEAN
# OTVORENOST ŠUMA U REPUBLICI HRVATSKOJ S NAGLASKOM NA MEDITERAN

Dealing with the openness of forests in the Republic of Croatia, it is necessary to start by mentioning which is the least regulated openness for certain areas due to the condition of the development of forestry in Croatia.

Table 1. The least openness of forests of a certain area of the Republic of Croatia according to *Tehnički uvjeti za gospodarske ceste* (1989)
*Tablica 1. Najmanja otvorenost šuma određenoga područja Republike Hrvatske prema Tehničkim uvjetima za gospodarske ceste (1989)*

| Forest area of the Republic of Croatia<br>*Šumsko područje Republike Hrvatske* | The least openness m/ha<br>*Najmanja otvorenost* m/ha |
|---|---|
| Lowland region<br>*Nizinsko područje* | 7.00 |
| Foothill-highland region<br>*Prigorsko-brdsko područje* | 12.00 |
| Mountain region<br>*Planinsko područje* | 15.00 |

Table 2. Planned openness of forests of the Republic of Croatia in certain areas in 2010 (Izvješće o problematici gradnje i održavanja šumskih prometnica i stanju otvorenosti šuma, 1997)
*Tablica 2. Planirana otvorenost šuma Republike Hrvatske u određenim područjima 2010. godine (Izvješće o problematici gradnje i održavanja šumskih prometnica i stanju otvorenosti šuma, 1997.)*

| Forest area of the Republic of Croatia<br>*Šumsko područje Republike Hrvatske* | Planned openness in 2010 m/ha<br>*Planirana otvorenost 2010. godine* m/ha |
|---|---|
| Lowland region<br>*Nizinsko područje* | 15 |
| Foothill region<br>*Prigorsko područje* | 20 |
| Highland and mountain region<br>*Brdsko i gorsko područje* | 25 |
| Karst region<br>*Krško područje* | 10 |

The forest management authorities of Delnice, Senj, Gospić, Buzet and Split are in the karst region. These forest management authorities manage approximately 44 % of the total area managed by the Public Enterprise "Croatian Forests".

Table 3. The quantity of roads and forest openness according to the forest management authorities on 01.01.1996.
*Tablica 3. Količina prometnica i otvorenost šuma po upravama šuma 1.1.1996. godine*

| The forest management authority *Uprava šuma* | The quantity of roads km *Količina cesta*, km | The openness in proportion to the total area m/ha *Otvorenost s obzirom na ukupnu površinu*, m/ha | The openness in proportion to overgrown area m/ha *Otvorenost s obzirom na obraslu površinu*, m/ha |
|---|---|---|---|
| Buzet | 609.40 | 9.31 | 11.45 |
| Delnice | 52.70 | 7.37 | 7.47 |
| Gospić | 566.90 | 3.07 | 3.87 |
| Senj | 940.90 | 14.41 | 37.64 |
| Split | 3,442.10 | 6.25 | 10.42 |
| Total *Ukupno* | 5,612.00 | 6.43 | 9.99 |

# THE USE OF A PERSONAL COMPUTER IN THE PLANNING, DESIGNING AND BUILDING OF FOREST ROADS
# UPORABA OSOBNOGA RAČUNALA PRI PLANIRANJU, PROJEKTIRANJU I GRADNJI ŠUMSKIH CESTA

Personal computers started to be used in forestry as a highly efficient device for designing forest roads in the 1970s. In the very beginning, personal computers were only a replacement for a classical way of making project documentation like general plans, longitudinal sections, normal sections, drawn cross-sections, cubic volume of ground masses and cost estimates. But today personal computers are used much more widely and, particularly by the application of new GIS (geographical informational system) technology and methods, comprehensive and complete solutions for opening forest areas are made.

# GEOGRAPHICAL AND GROUND INFORMATIONAL SYSTEM
# GEOGRAFSKI I ZEMLJIŠNI INFORMACIJSKI SUSTAV (GIZIS)

The geographical and ground informational system is an informational system of the whole Earth area and is intended for successful management. It includes the lithosphere, hydrosphere, biosphere and atmosphere (Brukner 1994).

The geographical and ground informational system can be divided into two separate systems: *GIS* - geographical informational system and ground informational system.

GIS is more important to us for solving tasks within forest roads, as it is directly connected with *a digital terrain model (DTM)*. Together with this name, some other names are used in practice, like *digital relief model (DMR)* or *digital elevation model (DEM)*. Regardless of the used name, the same methodology of research is used.

## DIGITAL TERRAIN MODEL (DTM)
## DIGITALNI MODEL TERENA (DTM)

The beginning of the development of the Digital Terrain Model is connected to the names Miller & Laflamme (1958) who described theoretical statements for making DTM and the wide possibilities of its use.

Stefanovič et al. (1977) described DTM as a digital account of the surface of the Earth suitable for computer processing, which consists of a set of points of that same surface determined by x, y, z co-ordinates and a suitable programme for their processing.

Generally speaking, it can be said that DTM is a set of points of a part of the surface of the Earth whose co-ordinates are organised and stored in a medium which enables computer processing. A programme which enables entry and organising, processing, analysis and a display of data is necessary for handling DTM.

For the practical use of DTM, it is necessary to have special computer programmes which can be purchased individually or within GIS or CAD programme products.

## DTM AS A MEANS OF WORK IN SOLVING PROBLEMS CONNECTED WITH FOREST ROADS
## DTM KAO SREDSTVO RADA PRI RJEŠAVANJU PROBLEMA VEZANIH UZ ŠUMSKE CESTE

In opening forest areas and in the making of an optimum distribution of forest roads, Dietz et al. (1984) use a digital terrain model *(DGM - digitale Geländemodel)* as a cartographic base and a perspective account of forest terrain. They also simulate terrain circumstances with the use of a *digital terrain simulator (DGS)*. They use a topographic map with contour lines and a basic distribution of forest roads as entry data.

Shiba & Loffler (1990) use a digital terrain model (DTM) in planning the optimum spatial distribution of forest roads. They use a programme named TERDAS and do their research in the private forests "Schonsee-Drechselber" in an area of 210 ha in east Bavaria.

Shenglin (1990) uses an IBM-xt personal computer with a programme package made in the programme language FORTRAN to determine the most acceptable position of forest roads, and to determine costs by a cost-benefit method.

Knežević (1990) uses a personal computer with a peripheral unit digitiser to make an optimum distribution of forest roads in unevenly-aged forests.

Shiba (1992) uses a computer simulation of a terrain which was used in the work of Shiba & Loffler (1990) and in the same way determines four possibilities of opening, as well as establishing the optimum density of a network of forest roads.

Knežević & Sever (1992) use a personal computer to determine the optimum density of tractor haulages. As a model for data processing, they took Arnautović's formulas (1975) and they completely solved the whole problem on a personal computer.

Dürrstein (1992) considers the opening of forests with the use of a personal computer and the programme FOREST. In order to use completely the necessary electronic equipment and electronic devices in opening forests, the author starts by distinguishing two levels of forest opening.

Session (1992) calculates the minimum cost with the highest value of a network of forest roads by the use of the programme NETWORK.

Pičman (1993) determines the existing and optimum openness of the management unit Bistranska Gora by forest roads and tractor haulages using a personal computer and a peripheral unit digitizer *CalComp 9100*.

Pičman & Tomaz (1995) determine the most acceptable of four variants of the spatial distribution of tractor wood haulage ways by the use of a computer due to their longitudinal gradient of 12.5 %, 15.0 %, 17.0 % and 20.0 % in the department of the management unit Južna Garjevica.

Pičman & Pentek (1996) determine the most acceptable variant of a network of tractor haulages by the use of a personal computer taking into consideration the longitudinal gradient of tractor haulages.

The methods of determining the optimum spatial distribution of forest roads in a certain forest area by the use of personal computers and other electronic equipment represent a new approach and way of solving these problems. It can be presumed that in future, data processing will be much more precise, faster and of higher quality. Programme packages related to forest roads will offer more varied possibilities, while the account of processed data and DTM will be reliable and exact.

## FACTORS WITH A DOMINANT INFLUENCE ON THE DISTRIBUTION OF A NETWORK OF FOREST ROADS
## ČIMBENICI S DOMINANTNIM UTJECAJEM NA RASPORED MREŽE ŠUMSKIH CESTA

According to Pičman (1993) the following basic factors influence the spatial distribution and quality of built forest roads: *the morphology of microrelief (terrain), geological relationships, climatic relationship, the condition of components and forest soil survey.*

Generally speaking, factors that mostly influence the spatial distribution of a network of forest roads can be divided into the following groups: *factors that are directly connected with a forest terrain which is opened by a network of forest roads, factors of standardised technical features of a certain category of forest roads, factors of forest ingredients on the opened area, climatic factors, ecological factors, factors by which forest roads influence man, and other factors.*

## WORKING METHODS
## METODE RADA

### TERRAIN RESEARCH
### TERENSKA ISTRAŽIVANJA

After having examined a map of a management unit with all roads drawn in, forest roads are distinguished from public roads, as only forest roads are to be surveyed. They were surveyed in such a way that the gradients of grade lines were surveyed by a slope meter, while distances between breaks of grade lines were measured by a measuring tape, 30 m long. The gradients of grade lines were expressed in percentages. The total width of a forest road was surveyed at the points of break of a grade line.

## DIGITALISATION OF FOREST-MANAGEMENT MAPS
## DIGITALIZACIJA ŠUMSKO-GOSPODARSKIH KARATA

All the roads on the research area and which were not previously included on the map of the management unit Senjska Draga were first drawn onto it. A map with contour lines, with a drawn border of the management unit, with drawn borders of compartments and subcompartments, and with roadsi ncluded, was digitised with the use of a personal computer Pentium 100 MHz and 16 Mb Ram, and with the use of a digitiser CalComp 9100 for paper size A0. The digitalisation of maps was made by the programme *AutoCAD*. A digital terrain model (DTM) was obtained by the processing of the digitised map of the management unit, using the programme *ArcInfo* and the programme *Surfer*.

## THE CLASSIFICATION OF TERRAIN GRADIENTS IN VARIOUS CATEGORIES
## RAZREDBA NAGIBA TERENA U VIŠE KATEGORIJA

DTM was used as the basis for the classification of the terrain gradient in several categories. The terrain was classified according to Löffler's classification from 1991. Various categories of the terrain gradient were coloured in various colours; smaller gradients with lighter, and larger ones with darker colours.

## GRAPHICAL AND MATHEMATICAL DETERMINATION OF THE RELATIONSHIP BETWEEN THE NECESSARY EARTHWORKS AND THEIR COST FOR FOREST FIRE-PREVENTION ROADS LAID ON VARIOUS TERRAIN GRADIENTS
## GRAFIČKO I MATEMATIČKO UTVRĐIVANJE ODNOSA IZMEĐU POTREBNIH ZEMLJANIH RADOVA I CIJENE NJIHOVE IZVEDBE ZA ŠUMSKE PROTUPOŽARNE CESTE POLOŽENE NA RAZLIČITIM NAGIBIMA TERENA

If a zero-line is taken over various terrain gradients, but in the same category, the necessary quantities of excavation and embankment at the normal transversal profile will be different. The results will be shown graphically and by a mathematical expression which will show a dependence of the quantity of earthworks on the terrain gradient. By introducing the costs of the earthworks in the above mentioned relation, a cost function of the dependence of a spatial location of a forest road on the terrain gradient will be obtained.

## DETERMININATION OF AN AVERAGE GEOMETRIC AND A REAL DISTANCE OF THE APPROACH TO THE AREA BY THE USE OF THE CENTROIDAL METHOD
## ODREĐIVANJE SREDNJE GEOMETRIJSKE I STVARNE UDALJENOSTI PRISTUPA POVRŠINI PRIMJENOM TEŽIŠNE METODE

The average geometrical distances of the approach to the area are determined by the centroidal method, using a personal computer. On a digital terrain model, each geometric average of distance of the approach to the area is corrected by a factor of the vertical correction of the terrain, which is determined from the average gradient of average geometric distances of the approach to the area laid across DTM. Values from literature for certain categories of terrain were taken as a factor of the horizontal bypassing of obstacles and adapted to the existing circumstances and the primary task of forest fire-prevention roads.

## DETERMINING THE STANDARD AND RELATIVE OPENNESS OF THE RESEARCHED AREA AND THE EFFICACITY OF THE LAID NETWORK OF FOREST ROADS FOR VARIOUS VARIANTS OF THE OPTIMUM AVERAGE REAL DISTANCE OF THE APPROACH TO THE AREA
## UTVRĐIVANJE STANDARDNE I RELATIVNE OTVORENOSTI ISTRAŽIVANOGA PODRUČJA TE UČINKOVITOSTI POLOŽENE MREŽE ŠUMSKIH PROMETNICA ZA RAZLIČITE INAČICE OPTIMALNE SREDNJE STVARNE DALJINE PRISTUPA POVRŠINI

Around the existing roads, surfaces were laid which, for the chosen values of the optimum average geometric distance of the approach to the area, were on all their edges equally far from the roads. Correcting the average geometric distance of the approach to the area, the values of the average real distance of the approach to the area for the chosen optimum values were obtained. By an analysis of the differently coloured areas of the management unit, it can easily be determined which areas are not within the borders of the chosen optimum average real distance of the approach to the area. In the same way, so-called dead zones of individual forest fire-prevention roads can be observed.

## DETERMINING THE AVERAGE OPTIMUM DISTANCE OF THE APPROACH TO THE AREA ACCORDING TO THE REQUESTS OF MEMBERS OF FIRE BRIGADES AND KNOWLEDGE OF FORESTRY EXPERTS
## ODREĐIVANJE SREDNJE OPTIMALNE DALJINE PRISTUPA POVRŠINI NA TEMELJU ZAHTJEVA DJELATNIKA VATROGASNIH POSTROJBA I SPOZNAJA ŠUMARSKIH STRUČNJAKA

The basic presumption is that the unevaluated values of the generally useful functions of the forests in the karst region are large enough to cover the costs of opening these forests. From the point of view of the members of fire brigades, there are demands for a maximum optimum and minimum optimum distance between forest fire-prevention roads. These requests were corrected with the knowledge of domestic and foreign forestry experts in connection with the maximum areas allowed under the roads on 1 ha and in connection with the allowed quantities of roads in the forest ecosystem in such a way as not to endanger and not to disturb its stability and balance.

## MAKING A COMPUTER PROGRAMME "COST" DIZAJNIRANJE RAČUNALNOGA PROGRAMA "TROŠAK"

This simple programme was made in the programme language C++. The intention of the programme was to choose the most acceptable variant of forest fire-prevention roads from the point of view of the lowest cost of earthworks. Through the careful entry of basic parameters, we can obtain the cost of earthworks for all forest fire-prevention roads 1000 m long in only five minutes.

## THE RESEARCH AREA ISTRAŽIVANO PODRUČJE

### INTRODUCTION UVOD

The forest management authority Senj, i.e. Forestry Senj, manages the management unit Senjska Draga.

The total area of this management unit is 2,515.03 ha, and is divided into 43 compartments and 100 subcompartments.

### Geographic location Zemljopisni položaj

The management unit Senjska Draga is located between 44°55' and 45°00' of the northern latitude and between 14°55' and 15°05' of the eastern longitude.

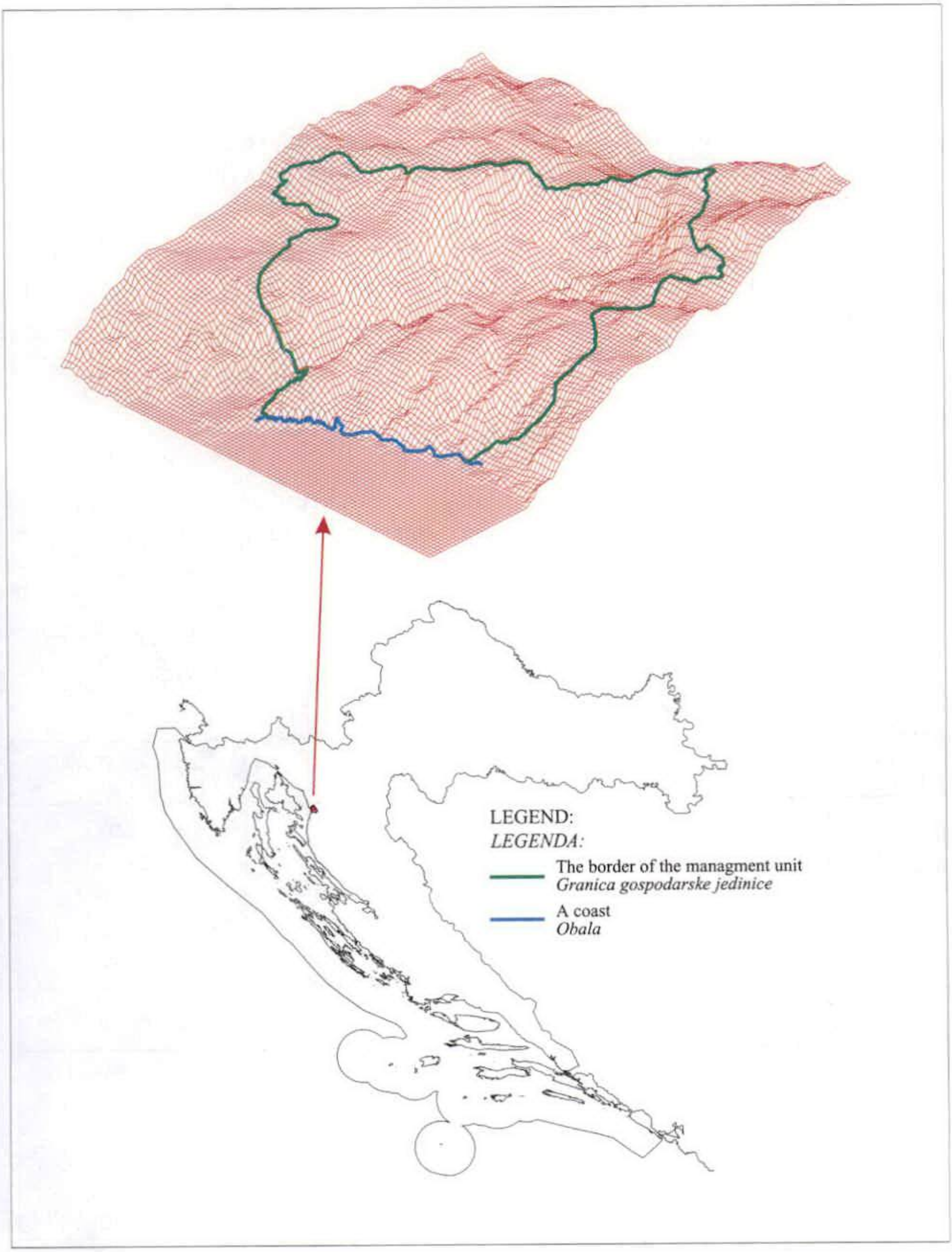
### Climatic conditions Klimatske prilike

According to Köppen's classification, the area of the management unit Senjska Draga is in the continental variant of the Mediterranean climate, of the symbol Cfsax". It is a moderately warm rainy climate, where summers are hot, with an average monthly temperature above 22 °C. A rainy period is widely distributed in a spring (from April to June) and autumn-winter maximum (October, November). The driest part of the year is in the warm season.

### Vegetative features Vegetacijska obilježja

In Senjska Draga two vegetative zones can be distinguished with the following forest zones:

Map 1. The geographic location of the management unit Senjska Draga with a 3D account of the terrain
*Karta 1. Zemljopisni položaj GJ Senjska draga s 3D prikazom terena*



1. the zone of submediterranean, xerothermophilous forests and copsewoods of hop and oriental hopbeam (link *Ostryo-Carpinion orientalis* Ht.) which spreads from the sea to an altitude of 700 m, and within it two high-altitude zones:
   - a zone of oriental hopbeam forest *(Carpinetum orientalis adriaticum* H-ić), which spreads from 0 to 300 m in altitude,
   - a zone of hop hopbeam forest *(Seslerio-Ostryetum* Ht. et H-ić) which can be found on altitudes from 300 to 700 m and includes two subassociations. In the zone of hop hopbeam forest, there are several extra-zone communities like: *Cotoneastero-Pinetum nigrae* Ht., *Luzulo-Quercetum petrae* Hill and *Luzulo-Fagetum syvaticae* Meusel.

2. the zone of moderately humid (mesophyte) forests (link *Fagion illyricum* Ht.);
   - beech forests and autumn moorgrass forests (*Seslerio-Fagetum sylvaticae* Ht.).

## Orographic relations
## Orografski odnosi

The average gradient of the terrain in the researched management unit differs widely. In the following table, categories of the terrain gradients are given according to Löffler's (1991) classification.

Table 4. Categories of the terrain gradient in the management unit Senjska Draga according to Löffler's (1991) classification of gradient (terrain data)
*Tablica 4. Kategorije nagiba terena u GJ Senjska draga prema Löfflerovoj (1991) kategorizaciji nagiba (terenski podaci)*

| Gradient groups no.<br>*Grupe nagiba*, br. | Gradient°<br>*Nagib*, ° | Area ha<br>*Površina*, ha | Percentage share %<br>*Postotni udio*, % |
|---|---|---|---|
| 1 | 0.....< 6 | 92.71 | 3.69 |
| 2 | 6.....< 11 | 566.80 | 22.54 |
| 3 | 11.....< 18 | 591.12 | 23.50 |
| 4 | 18.....< 27 | 837.22 | 33.29 |
| 5 | 27+ | 427.18 | 16.98 |
| Total<br>*Ukupno* | | 2,515.03 | 100.00 |

## Forest roads
## Šumske ceste

In the management unit Senjska Draga there are three types of roads. They are: main roads, local roads and forest roads.

Table 5. Classification of roads in the management unit Senjska Draga (Katastar prometnica JP "Hrvatske šume" 1997)
*Tablica 5. Podjela cesta u GJ Senjska draga (Katastar prometnica JP "Hrvatske šume" 1997)*

| The road type *Vrsta ceste* | Number of roads *Broj cesta*, br. | The length of roads m *Duljina cesta*, m | The superstructure *Gornji stroj* | | |
|---|---|---|---|---|---|
| | | | Asphalt *Asfalt* | Broken stone *Tucanik* | Earth *Zemlja* |
| | | | m | | |
| Main *Magistralna* | 2 | 16,000 | 16,000 | 0 | 0 |
| Regional *Regionalna* | 0 | 0 | 0 | 0 | 0 |
| Local *Lokalna* | 2 | 8,450 | 1,500 | 6,950 | 0 |
| Total *Ukupno* | 4 | 24,450 | 17,500 | 6,950 | 0 |
| Forest *Šumska* | 16 | 21,219 | 0 | 20,535 | 684 |
| Total *Ukupno* | 20 | 45,669 | 17,500 | 27,485 | 684 |
| % | 100.00 | 100.00 | 38.3 | 60.2 | 1.5 |

On the whole area of the researched management unit there are 45,669 m of roads, among which 27,485 m are those whose upper layer is made of broken stone, 17,500 m are asphalt roads, while 684 m of roads have an earth upper layer. From the mentioned data it can be seen that, due to the quality, roads with a broken stone upper layer have the greatest influence on the opening of this management unit.

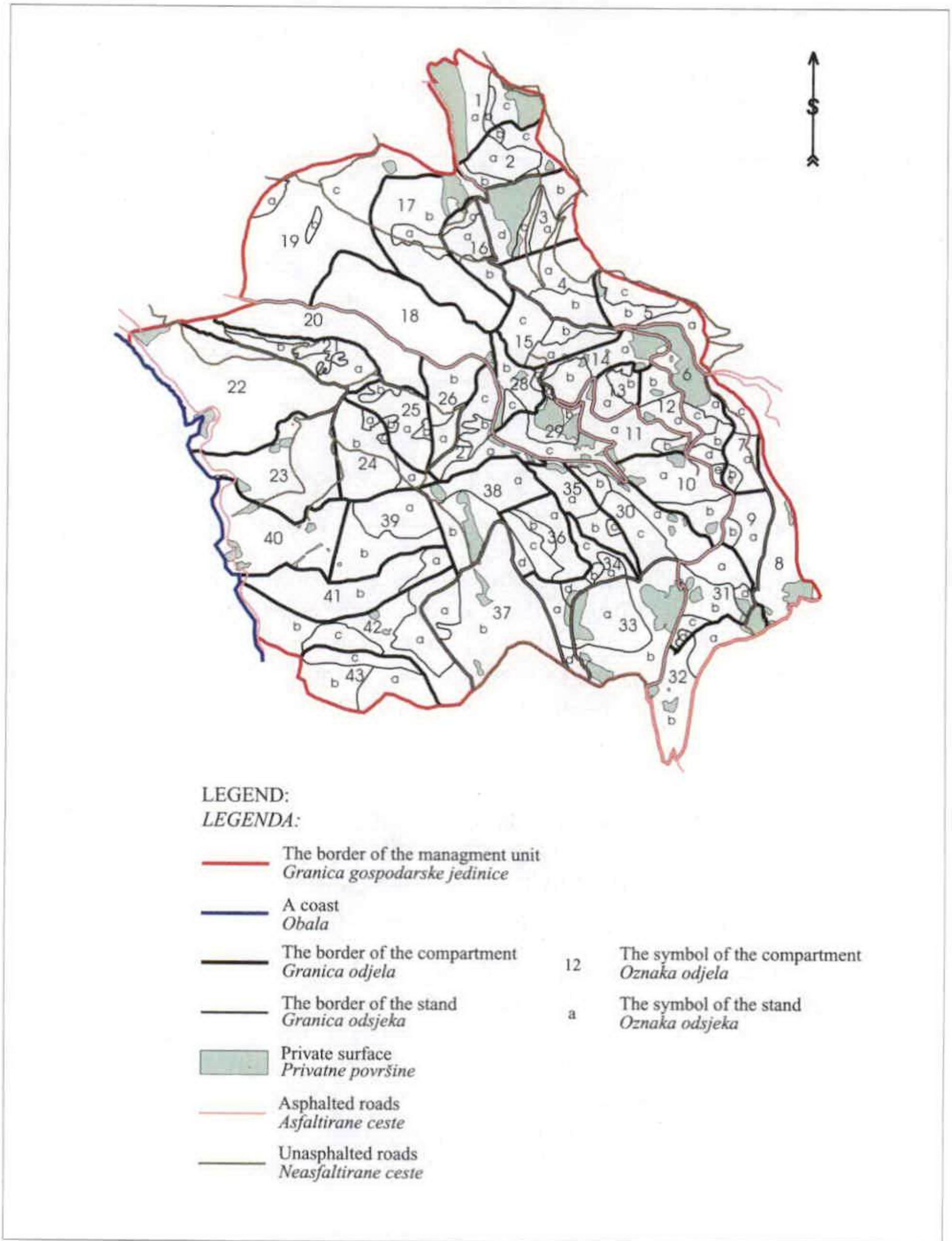
## ECOLOGICAL ECONOMIC TYPES OF FORESTS AND THE DANGER OF FOREST FIRES
## EKOLOŠKO-GOSPODARSKI TIPOVI ŠUMA I OPASNOST POJAVE ŠUMSKOGA POŽARA

According to the map of forest communities and forest soils and according to the ecological characteristics of a certain type of forest, the following ecological-economic types of forests have been distinguished and adapted to the real condition on the terrain: III-H-10, III-H-20, III-E-20, III-J-10, III-J-21.

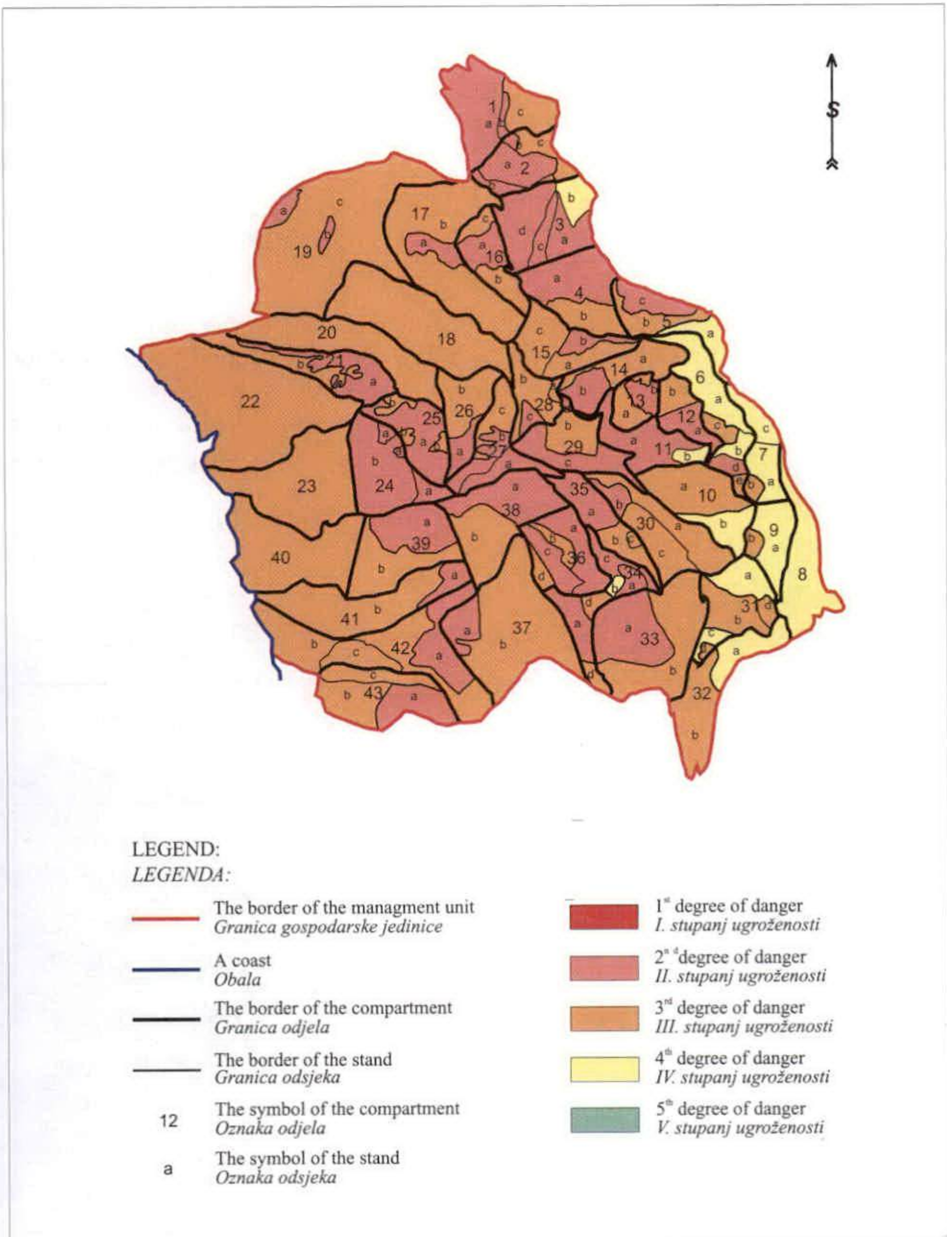
The order of endangerment of certain ecological-economic types of forests of the management unit Senjska Draga from forest fires, starting from the most endangered to the least endangered communities, is as follows: III-1-21, IIIJ-10, III-E-20, III-H-20, III-H-10.

The degree of endangerment from forest fires on the greatest part of 1,564.75 ha (62.20 %) of the area of the management unit Senjska Draga is moderate. A

Map 2. The map of the existing roads in the management unit Senjska Draga
*Karta 2. Karta postojećih cesta u gospodarskoj jedinici Senjska draga*



Map 3. Map of danger from fires in the management unit Senjska Draga
*Karta 3. Karta opasnosti od požara u GJ Senjska draga*



small danger of forest fires is characteristic of only 198.41 ha, i.e. less than 8 % of the area. However, it has to be emphasised that 751.87 ha of the total area of Senjska Draga, i.e. almost 30 %, is in a great danger of fires.

# THE RESEARCH RESULTS
# REZULTATI ISTRAŽIVANJA

## THE LONGITUDINAL GRADIENT OF FOREST FIRE-PREVENTION ROADS IN THE RESEARCHED AREA
## UZDUŽNI NAGIB ŠPPC NA ISTRAŽIVANOME PODRUČJU

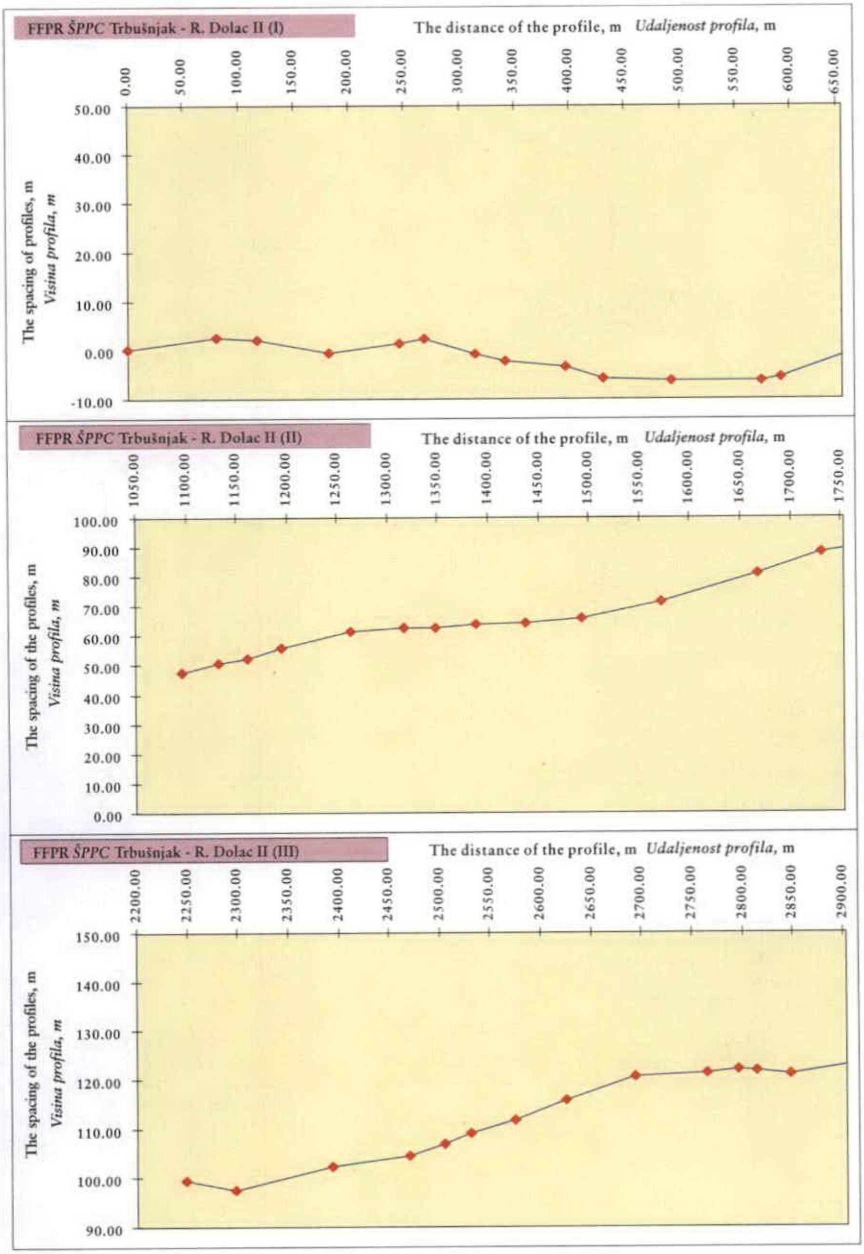
From the data measured on the terrain and according to the measured forest fire-prevention roads which are shown on Map 4, the longitudinal gradients of forest fire-prevention roads are examined. An account of a forest fire-prevention road is given in Figure 1. The position of the fraction points of a grade line, in which also a planum width is measured, is denoted on the abscissa, while a relative altitude of each fraction point is on the ordinate.

In the following tables data for all forest fire-prevention roads in the area of the management unit Senjska Draga are shown.

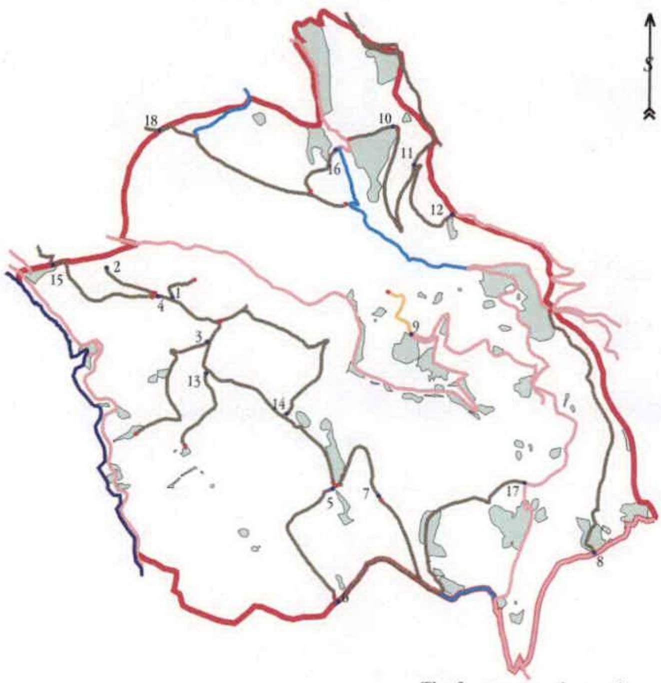
Table 6. All FFPR on the researched area
*Tablica 6. Zbirna tablica svih ŠPPC na istraživanome području*

| Ordinal number no. *Redni broj* | The name of the road *Naziv ceste* | Total number of recorded profiles *Broj snim. profila* | Total length of a road m *Ukupna duljina ceste*, m | The length of the allowed gradient m *Duljina dopušt. nagiba*, m | The length of not allowed gradient m *Duljina nedopušt. nagiba*, m | The average planum width m *Prosječna širina planuma*, m | The total area under FFPR m² *Ukupna površina pod ŠPPC*, m² |
|---|---|---|---|---|---|---|---|
| 1 | Pišarol | 9 | 496.50 | 159.80 | 336.70 | 5.96 | 2,959.14 |
| 2 | Trbušnjak | 9 | 608.25 | 608.25 | - | 5.88 | 3,576.51 |
| 3 | prema Guslicama | 38 | 1,819.10 | 778.90 | 1,040.20 | 3.93 | 7,149.06 |
| 4 | Trbušnjak-R.dolac II | 61 | 3,374.25 | 2,700.45 | 673.80 | 3.91 | 13,193.32 |
| 5 | R.dolac-Hrmotine | 24 | 1,552.55 | 1,452.75 | 99.80 | 3.97 | 6,163.62 |
| 6 | Ljubeška kosa | 21 | 1,290.90 | 885.70 | 405.20 | 4.65 | 6,002.69 |
| 7 | M.stolac-R.dolac | 22 | 1,422.00 | 1,037.45 | 384.55 | 3.99 | 5,673.68 |
| 8 | Alan-Vratnik | 49 | 3,000.20 | 1,159.65 | 1,840.55 | 4.78 | 14,340.96 |
| 9 | Gornji Lopci | 16 | 683.95 | 683.95 | - | 3.63 | 2,482.74 |
| 10 | Francikovac-Križ | 16 | 704.20 | 362.90 | 341.30 | 3.53 | 2,485.83 |
| 11 | Veljun | 9 | 484.30 | 418.70 | 65.60 | 4.31 | 2,087.33 |
| 12 | V.veljun-Petuova | 42 | 3,048.00 | 1,561.50 | 1,486.50 | 4.19 | 12,771.12 |
| 13 | Guslice-Zurci | 15 | 1,129.60 | 701.50 | 428.10 | 3.59 | 4,055.26 |
| 14 | R.dolac-Ra.draga | 23 | 2,484.00 | 1,234.00 | 1,250.00 | 3.74 | 9,290.16 |
| 15 | Trbušnjak-R.dolac I. | 21 | 1,786.80 | 913.90 | 872.90 | 3.63 | 6,486.08 |
| 16 | Francikovac-Torina | 10 | 789.10 | 789.10 | - | 3.86 | 3,045.93 |
| 17 | M.stolac-Lj. kosa | 41 | 3,495.50 | 3,133.40 | 362.10 | 3.67 | 12,828.49 |
| 18 | Kučerica-Torina | 38 | 3,194.50 | 2,321.90 | 872.60 | 4.92 | 15,716.94 |
| Total *Ukupno* | - | 464 | 31,363.70 | 20,903.80 | 10,459.90 | - | 130,308.76 |

Figure 1. The longitudinal section of the forest fire-prevention road Trbušnjak - Rončević Dolac II
*Slika 1. Uzdužni presjek ŠPPC Trbušnjak–Rončević dolac II*



Map 4. Recorded forest fire-prevention roads
*Karta 4. Snimljene šumske protupožarne ceste*




LEGEND:
*LEGENDA:*

- The border of the managent unit / *Granica gospodarske jedinice*
- A coast / *Obala*
- Public asphalted roads / *Javne asfaltirane ceste*
- Public unasphalted roads / *Javne neasfaltirane ceste*
- Forest fire-prevention roads with a superstructure / *Šumske protupožarne ceste s gornjim strojem*
- Forest fire-prevention roads without a superstructure / *Šumske protupožarne ceste bez gornjeg stroja*
- Private surfaces / *Privatne površine*
- The symbol of the beginning of measurement / *Oznaka početka mjerenja ŠPPC*
- The symbol of the end of measurement / *Oznaka kraja mjerenja ŠPPC*
- 6 The number of road / *Broj ceste*

The forest-prevention roads:
*Šumske protupožarne ceste:*

*1. Pišarol*
*2. Trbušnjak*
*3. Prema Guslicama*
*4. Trbušnjak - Rončević dolac (II)*
*5. Rončević dolac - Hrmotine*
*6. Ljubeška kosa*
*7. Mali Stolac - Rončević dolac*
*8. Alan - Vratnik*
*9. Gornji Lopci*
*10. Francikovac - Križ*
*11. Veljun*
*12. Veliki Veljun - Petuova*
*13. Guslice - Zurci*
*14. Rončević dolac - Ravna draga*
*15. Trbušnjak - Rončević dolac (I)*
*16. Francikovac - Torina*
*17. Mali Stolac - Ljubeška kosa*
*18. Kučerica - Torina*

The total length of forest fire-prevention roads is 31,363.70 m. Of the total length of forest fire-prevention roads 10,459.90 m (33.35 % of all fire-prevention roads) were laid with a higher longitudinal gradient than allowed. The total area under forest fire-prevention roads is 130,308.76 m$^2$ (13.03 ha).

Table 7. Lengths of certain categories of longitudinal gradient of forest fire-prevention roads
*Tablica 7. Duljine pojedinih kategorija uzdužnoga nagiba ŠPPC*

| The name of the road *Naziv ceste* | The length of the category of the longitudinal gradient of FFPR m *Duljina kategorije uzdužnog nagiba ŠPPC, m* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Acclivity +% *Uspon, +%* | | | | | Declivity -% *Pad, -%* | | | |
| | 13-16 | 9-12 | 5-8 | 1-4 | 0 | 1-4 | 5-8 | 9-12 | 13-16 |
| Pišarol | - | 126.20 | 54.20 | 61.20 | - | 44.40 | .- | 70.35 | 140.15 |
| Trbušnjak | - | - | - | 117.35 | - | 86.20 | 404.70 | - | - |
| prema Guslicama | - | - | - | 64.10 | - | 37.40 | 678.30 | 714.45 | 324.85 |
| Trbušnjak-R.dolac I | 71.50 | 602.30 | 941.25 | 1,061.15 | 113.00 | 476.90 | 108.15 | - | - |
| R.dolac-Hrmotine | - | 99.80 | 905.90 | 293.30 | - | 169.35 | 84.20 | - | - |
| Ljubeška Kosa | - | 52.60 | 198.00 | 389.20 | - | 46.80 | 251.20 | 254.90 | 97.70 |
| M.stolac-R.dolac | - | - | - | 91.55 | 59.10 | 264.05 | 622.75 | 384.55 | - |
| Alan-Vratnik | - | - | 120.40 | 330.60 | 18.00 | 244.80 | 446.85 | 1,746.85 | 92.80 |
| Gornji Lopci | - | - | 46.80 | 251.00 | 30.90 | 271.95 | 83.30 | - | - |
| Francikovac-Križ | 81.30 | 260.00 | 297.20 | 19.10 | - | 46.60 | - | - | - |
| Veljun | - | - | - | - | - | - | 418.70 | 65.60 | - |
| V.veljun-Petuova | - | - | - | - | - | 376.00 | 1,185.50 | 1,486.50 | - |
| Guslice-Zurci | - | - | 76.70 | - | - | 73.00 | 551.80 | 330.30 | 97.80 |
| R.dolac-Ra.draga | - | - | 250.00 | 228.90 | - | 440.10 | 315.00 | 1,250.00 | - |
| Trbušnjak-R.dolac II | - | - | - | - | - | - | - | 913.90 | 872.90 |
| Francikovac-Torina | - | - | 250.00 | - | - | 61.50 | 477.60 | - | - |
| M.stolac-Lj. kosa | - | 192.80 | 654.30 | 749.50 | 541.20 | 564.40 | 624.40 | 169.30 | - |
| Kučerica-Torina | - | 188.50 | 277.70 | 483.10 | - | 776.30 | 738.90 | 730.00 | - |
| Total *Ukupno* | 152.80 | 1,522.20 | 4,072.45 | 4,140.05 | 762.20 | 3,979.75 | 6,990.45 | 8,116.70 | 1,626.20 |

A total of 31.53 % of forest fire-prevention roads are in acclivity, among which 13.21 % of roads in the category of a longitudinal gradient 1-4 %, 12.98 % in the category 5-8 %, 4.85 % in the category of the longitudinal gradient from 9 to 12 % and 0.49 % of forest fire-prevention roads in the category of a longitudinal gradient from 13 to 16 %. 66.04 % of forest fire-prevention roads were built in declivity, mostly in the category of a longitudinal gradient of 9 to 12 % (25.88 %), slightly fewer in the category of a gradient from 5 to 8 % (22.29 %), with fewer forest fire-prevention roads in the category of a longitudinal gradient from 1 to 4 % (12.69 %) and the least, barely 5.18 % of forest fire-prevention roads, grouped in the category of a gradient of 13-16 %. In the total quantity of measured roads, 2.43 % of the forest fire-prevention roads have a longitudinal gradient which equals zero.

## DETERMINING THE AVERAGE OPTIMUM DISTANCE OF APPROACH TO A FOREST AREA OF CLASSICAL AND RELATIVE OPENNESS
## ODREĐIVANJE SREDNJE OPTIMALNE DALJINE PRISTUPA ŠUMSKOJ POVRŠINI, KLASIČNE I RELATIVNE OTVORENOSTI

Despite the fact that the intensive building of forest fire-prevention roads in the Republic of Croatia started in 1990 and that there are more than justified reasons for this, even today forest fire-prevention roads have not yet been accepted as a special category of forest roads. There are no regulated theoretical distances between FFPR, there is no recommended or optimum openness of forest fire-prevention roads, and there are no general limits for the average distance of the approach to the area. This has led to the necessity of defining and establishing certain values which should be taken into consideration in the planning, designing and building of FFPR.

After consultations with commanders of professional fire-brigades in Rijeka and voluntary fire brigades on the island of Rab regarding the tactics for extinguishing forest fires that have been used successfully for years in these areas and which are obligatory by law todayf or the whole area of the Republic of Croatia, it has been realised that the actual area which can be žcovered' in the first rush by intervening fire-engines is only an area 50 metres away from the forest fire-prevention road in all directions, while in the second rush, this service area is a maximum of 300 metres from the forest fire-prevention road in all directions.

As these are optimum values from the point of view of the fire brigade, by the use of computers, so-called "buffers" were laid around previously digitised existing roads on the research area, which extended at a uniform distance from the edges of the roads, which represented an average optimum geometrical distance of approach to the area. The variants of that parameter were 50, 100, 150, 200, 250 and 300 metres.

The obtained areas were screened and transferred into a digital terrain model on which, according to the made histogram, the average terrain gradient was determined in each variant and which was used for finding factors of vertical correction of the terrain. Each variant of the average optimum geometric distance of approach to the area was multiplied by this factor, and then divided by the factor of horizontal bypassing, which was 1.10 for the whole research area. This was done in order to obtain an average optimum real distance of approach to the area.

These expressions were used:

$$S_{PS} = \frac{S_{PG}}{k_H} \cdot k_V \tag{2}$$

$$k_H = 1.10 \tag{3}$$

$$k_V = \cos \alpha \tag{4}$$

where:

$S_{PG}$ is an average geometric optimum distance of the approach to the area, m,

$S_{PS}$ is an average real optimum distance of the approach to the area, m,

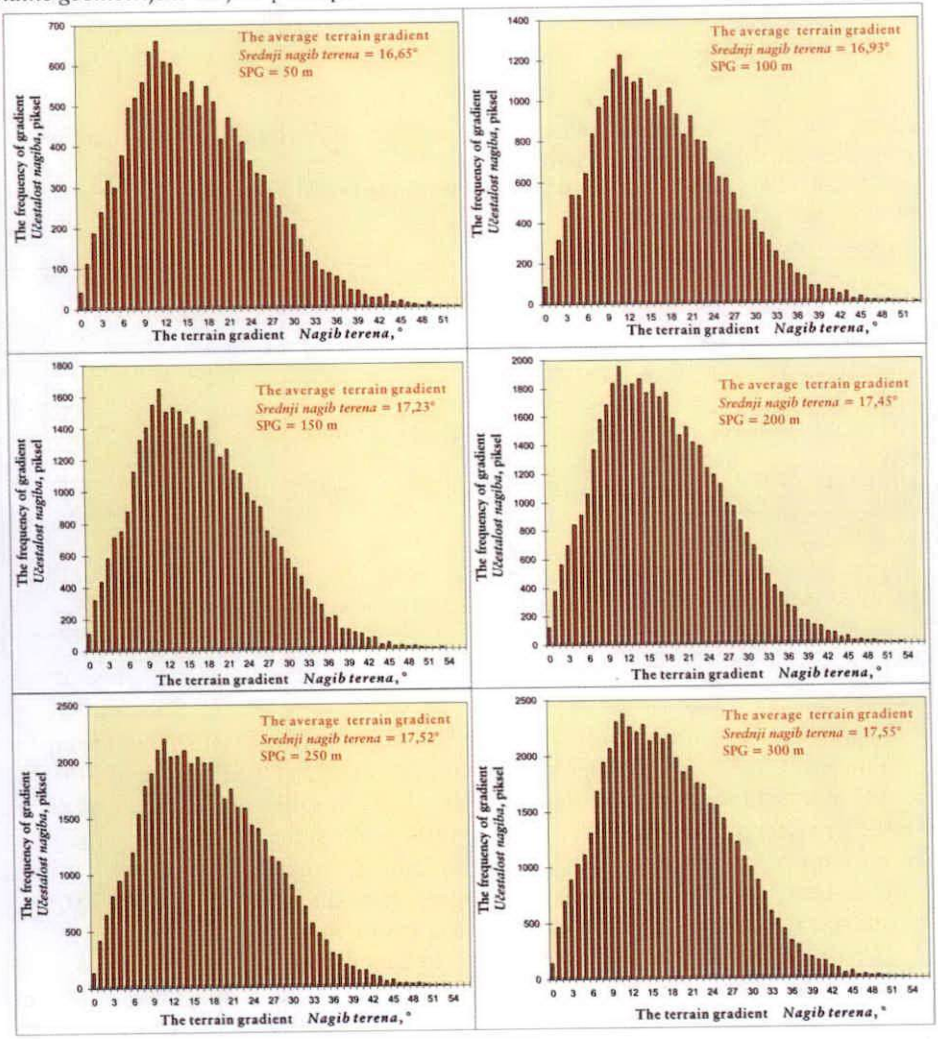
$k_H$ is a factor of horizontal bypassing,

$k_V$ is a factor of vertical correction,

$\alpha$ is an average terrain gradient °.

Figure 2. An account of the participation of various terrain gradients for areas with different variants of the average optimum geometric distance of approach

*Slika 2. Prikaz udjela različitih nagiba terena za površine s različitim inačicama srednje optimalne geometrijske daljine pristupa*



Determining an area which is open regarding the choice of an individual variant of an average approach to the area and the total area of the management unit (together with private enclaves within the areas managed by the Public Enterprise "Croatian Forests", the relative openness for each variant was obtained, according to the formula:

$$O_R = \frac{P_O}{P_U} \cdot 100 \tag{5}$$

where:

$O_R$ is the relative openness of the area, %,
$P_O$ is the open area, ha,
$P_U$ is the total area, %.

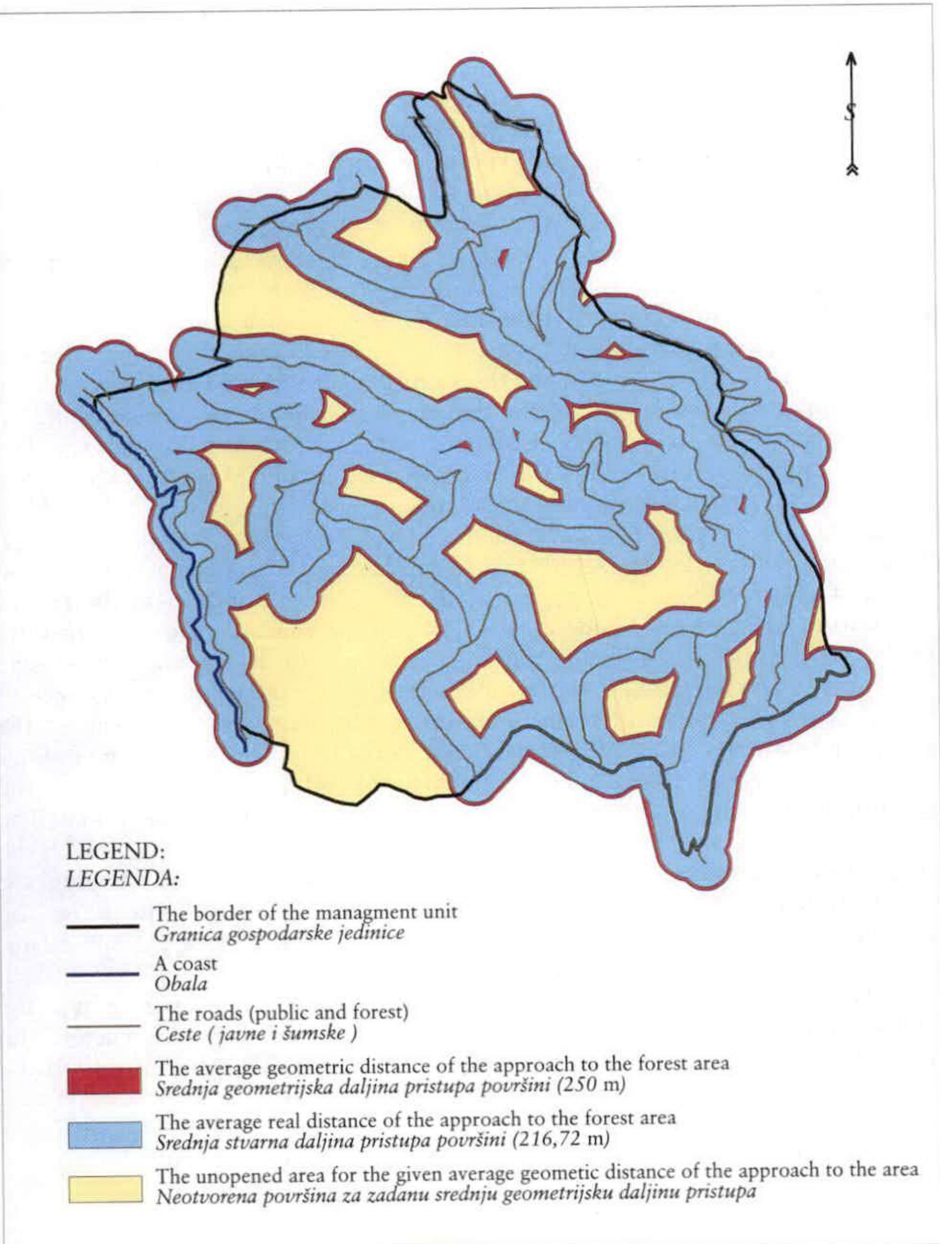
Table 8. The relative openness of the research area according to the various variants of the average real distance of approach to the area
*Tablica 8. Relativna otvorenost istraživanoga područja prema različitim inačicama srednje stvarne daljine pristupa površini*

| $S_{PG}$ m | α ° | $k_V$ | $k_H$ | $S_{PS}$ m | $P_O$ ha | $P_U$ ha | $O_R$ % | Openness *Otvorenost* (Jurik et al. 1984) |
|---|---|---|---|---|---|---|---|---|
| 50 | 16.65 | 0.95807 | 1.10 | 43.54 | 483.41 | 2,807.83 | 17.22 | unsatisfactory *nedovoljna* |
| 100 | 16.93 | 0.95666 | 1.10 | 86.97 | 912.41 | 2,807.83 | 32.50 | unsatisfactory *nedovoljna* |
| 150 | 17.23 | 0.95512 | 1.10 | 130.24 | 1,289.95 | 2,807.83 | 45.94 | unsatisfactory *nedovoljna* |
| 200 | 17.45 | 0.95398 | 1.10 | 173.45 | 1,632.32 | 2,807.83 | 58.13 | unsatisfactory *nedovoljna* |
| 250 | 17.52 | 0.95631 | 1.10 | 216.72 | 1,878.21 | 2,807.83 | 66.89 | hardly satisfactory *slabo zadovoljavajuća* |
| 300 | 17.55 | 0.95345 | 1.10 | 260.04 | 2,073.67 | 2,807.83 | 73.85 | satisfactory *zadovoljavajuća* |

Therefore, we can conclude that the openness of the area of the management unit Senjska Draga, at an average real distance of approach to the area of 300 metres, i.e. at a distance between roads of 600 metres, is satisfactory, as it is possible to intervence from one fire-prevention road on both sides. At an average real distance of approach to the area of 250 metres, the openness of the research area is hardly satisfactory. For variants of the approach to the area of 50, 100, 150 and 200 metres, the openness of the forest area is insufficient.

The described method of laying down so-called "buffers", which are equally far away everywhere from a forest fire-prevention road, i.e. roads that can be used as fire-prevention ones, is the ideal method by which the openness of a certain fo-

Map 5. An account of the method of limited areas for the average geometric distance of approach to the area of 250 m
*Karta 5. Prikaz metode "buffera" za srednju geometrijsku daljinu pristupa površini 250 m*



rest area can clearly be presented with the chosen optimum average distance of approach. In the same way, by using this method, unopened areas can be seen, which should particularly be taken into consideration in the further opening of the forest area. The "buffer" method is also efficient in the planning and further branching out of a forest fire-prevention roads network: a buffer of a specific size is laid around possible variants of routes of future forest fire-prevention roads, which are represented by a ground centre line and digitised as such. The variant of forest fire-prevention roads which opens the greatest part of the unopened forest area and at the same time includes the smallest area of the so-called dead zones, i.e. areas which, for the chosen average optimum distance of the approach to the area, are open with two or more roads, is the most efficient and the best.

The openness of the management unit Senjska Draga determined by the centroidal method was to be observed. For this purpose, by the use of a personal computer and suitable programmes, the centre of gravity of each subcompartment was found and drawn into a digitised map. The shortest distance from the centre of gravity of each subcompartment to the nearest road which can be used as a fire-prevention road was measured and defined as an average geometric distance of the approach to the area of the subcompartment. These lines of normal fire brigade intervention were drawn into the maps. In order to obtain the average real distances of the approach to the area of the subcompartment, a factor of the vertical correction of the terrain had to be found, as well as the factor of the horizontal bypassing of obstacles. The factor of the vertical terrain correction was established in such a way that the average geometric distances of the approach to the area of the subcompartment were laid across DTM and the values of the gradient were read at four points. Then, the average value in degrees was found and the cosine (cos) of that average gradient was established. The average geometric distance of the approach to the area of a subcompartment was divided by the cosine of the average gradient and multiplied by the factor of the horizontal bypassing of obstacles in order to obtain its real equivalent. A value of 1.10 was used as a factor of the horizontal bypassing of obstacles for the area of the whole management unit. The average geometric and the average real distance of the approach to the area of the whole management unit were calculated as the arithmetic mean of these values for each section, and the values of the section area were taken into consideration. The average geometric distance of the approach for the management unit Senjska Draga is 244.79 m and its real equivalent is 287.15 m.

The question is: what is the openness of the forest area expressed in m/ha for the mentioned variants of the average geometric distance of the approach to the area ? To obtain the answer, the model of the forest area of the dimension 1 200 x 1 000 m was taken and that model was opened by parallel forest fire-prevention roads on the mutually equal distance of 1 ($l = 2S_{PG}$).

The following mathematical expressions were used in the calculation:

$$l = 2\,S_{PG} \quad d = \frac{P_U}{l} \quad O = \frac{d}{P_U} \qquad (6), (7), (8)$$

where:
$S_{PG}$ is an average optimum geometric distance of the approach to the area, m,
l is the distance between roads, m,
d is the total quantity of roads on the whole area, m,
$P_U$ is the total area that is opened, ha,
O is the openness of the forest area m/ha.

The obtained results are shown in Table 9.

Table 9. The quantity of roads and the openness of forest areas depending on the chosen variant of the average real optimum distance of the approach to the area
*Tablica 9. Količina cesta i otvorenost šumskoga područja u ovisnosti o odabranoj inačici srednje stvarne optimalne daljine pristupa površini*

| $S_{PG}$ m | l m | d m | $P_U$ ha | O m/ha |
|---|---|---|---|---|
| 50 | 100 | 12 000 | 120 | 100.00 |
| 100 | 200 | 6 000 | 120 | 50.00 |
| 150 | 300 | 4 000 | 120 | 33.33 |
| 200 | 400 | 3 000 | 120 | 25.00 |
| 250 | 500 | 2 400 | 120 | 20.00 |
| 300 | 600 | 2 000 | 120 | 16.67 |

According to the criterion of the openness of the forest area and according to knowledge on openness in the leading world forest countries, it can be concluded that an openness of 100.00 m/ha, which was obtained for the average optimum real distance of approach to an area of 50 m, cannot be considered, at least for building forest fire-prevention roads. An openness of 50 m/ha which was obtained for the variant $S_{PG}$ = 100 m, is also very high and can hardly be justified in practice.

Therefore, according to the criterion of the openness of the forest area by forest fire-prevention roads, it is possible to open forest areas endangered by fires from an average optimum geometric distance of approach from 150 meters and above.

One of the criteria for determining the largest quantity of roads permitted in a particular ecosystem without disturbing its balance and without exceeding the allowed limits of dangers from damage caused by erosion is also the amount of the forest area under forest roads. This can be obtained by dividing the forest area under roads by the total area which is to be opened and expressed as a percentage. According to Pičman (1994), that quantity for forest roads is 3 %. The area under forest fire-prevention roads is calculated for various variants of the average optimum real distance of the approach on the previously used theoretical forest area. The various planum widths of forest fire-prevention roads were used as entries.

Table 10. The relation of the forest area under forest fire-prevention roads with various variants SPG and various planum widths

*Tablica 10. Odnos šumske površine pod šumskim protupožarnim cestama kod različitih inačica $S_{PG}$ i različite širine planuma*

| | The average geometric distance of the approach to the area<br>*Srednja optimalna geometrijska daljina pristupa površini* | | | | | |
|---|---|---|---|---|---|---|
| | 50 | 100 | 150 | 200 | 250 | 300 |
| | m | | | | | |
| The planum width<br>*Širina planuma* | The area under forest fire-prevention roads<br>*Površina pod šumskim protupožarnim cestama* | | | | | |
| m | % | | | | | |
| 3.00 | 3.00 | 1.50 | 1.00 | 0.75 | 0.60 | 0.50 |
| 3.50 | 3.50 | 1.75 | 1.17 | 0.88 | 0.70 | 0.58 |
| 4.00 | 4.00 | 2.00 | 1.33 | 1.00 | 0.80 | 0.67 |
| 4.50 | 4.50 | 2.25 | 1.50 | 1.13 | 0.90 | 0.75 |
| 5.00 | 5.00 | 2.50 | 1.67 | 1.25 | 1.00 | 0.83 |

According to the factor of the percentage share of the area under forest roads, in the total surface of the area that is to be opened, the obtained results are in accordance with previous considerations. The network of forest fire-prevention roads in which the mutual distance of roads is 100 m, even with the minimum planum width of 3.00 m, reaches the maximum values of 3 % of the area under forest roads. Such a network of forest roads, although being considered the optimum by members of fire-brigades, is absolutely unacceptable from the forestry point of view and untenable in forest ecosystems. The area values under forest roads for a road distance of 200 m are acceptable, but are close to the allowed upper maximum. As we are dealing with fire-prevention roads in karst areas where there are great dangers of erosion and where vegetation, as the basic factor which prevents erosion, is not rich and not exuberant, it is better to plan and design networks of forest roads with larger distances which will also decrease the area under forest fire-prevention roads.

## DETERMINING AREAS AND VOLUMES OF EXCAVATIONS AND EMBANKMENT IN FFPRS OF THE NORMAL TRANSVERSAL PROFILE DESIGNED ON VARIOUS TRANSVERSAL TERRAIN GRADIENTS
## ODREĐIVANJE POVRŠINE I VOLUMENA ISKOPA I NASIPA KOD ŠPPC NORMALNOGA POPREČNOGA PROFILA PROJEKTIRANIH NA RAZLIČITIM POPREČNIM NAGIBIMA TERENA

The final cost of execution is very important when choosing a particular variant of a FFPR. The main source of expenses are the costs of earthwork which can be influenced in planning the future route of a fire-prevention road. The position of a FFPR was presented by ground centre lines of various gradients, depending on the terrain gradient. The characteristic of each ground centre line is that the level of the grade line in the axis of the future road is equal to the level of the terrain at points obtained by designing ground centre lines on the digitised map (points which are on contour lines).

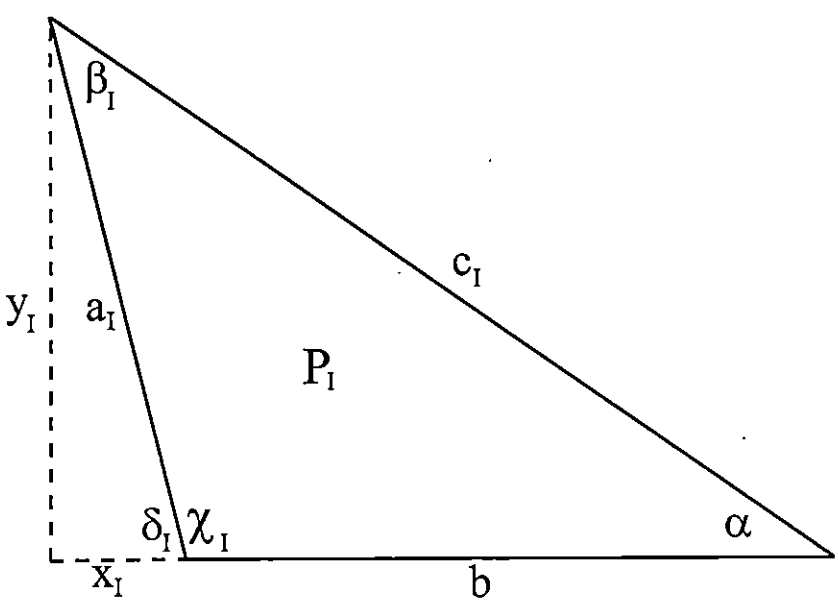
As the normal transversal profile of a forest fire-prevention road is known and a ground centre line which approximates the future situation on the terrain is laid, it is possible to determine in a very short period parallel costs of more variants of future routes of forest fire-prevention roads. The presumption is that the terrain gradient vertical on the ground centre line is constant for the whole planum width of the FFPR, which is 4.00 m.

While deriving mathematical expressions to calculate surfaces of excavation and embankment, which are necessary to obtain the volume of earthwork, and finally to obtain the approximate costs of the earthwork, we will use triangles of the surface $P_I$ (the surface of the excavation) and $P_N$ (the surface of the embankment).

The angle a is the terrain gradient angle which can be read from the digital terrain model. The quantity b is calculated from the total planum width of forest fire-prevention roads:

$$b = \frac{P}{2} \tag{9}$$

Figure 3. An account of the basic components for the calculation of the excavation surface
*Slika 3. Prikaz osnovnih sastavnica za izračun površine iskopa*



From the planned straight clearing gradient marked with m, a smaller angle between the straight clearing gradient and the horizontal ($\delta_I$) will be calculated:

$$\delta_I = arctg(m) \tag{10}$$

From Figure 3 we can see that the following relation is valid:

$$\chi_I + \delta_I = 180° \Rightarrow \chi_I = 180° - \delta_I \tag{11}$$

The following mathematical expressions are also valid:

$$\frac{\sin\alpha}{a_I} = \frac{\sin\beta_I}{b} \Rightarrow a_I = \frac{\sin a \cdot b}{\sin\beta_I} \tag{12}$$

$$P_I = \frac{a_I \cdot b}{2} \cdot \sin\chi_I \tag{13}$$

where:
$\alpha$ is a terrain gradient angle vertical on the ground centre line, °,
$\beta_I$ is an angle between the straight clearing gradient and the terrain, °,
$x_I$ is a bigger angle between the straight clearing gradient and the horizontal, °,
$\delta_I$ is a smaller angle between the straight clearing gradient and the horizontal, °,
P is a planum width, m,
b is half of the planum width, m,
m is a designed straight clearing gradient,
$a_I$ is the length of the excavation gradient, m,
$P_I$ is the excavation surface, $m^2$.

The procedure of derivation of necessary patterns for the calculation of the embankment surface is the same as in the derivation of formulas for the calculation of the excavation surface. The obtained formulas differ only in the indexes next to the symbols and quantities. The final expressions are:

$$b = \frac{P}{2} \tag{14}$$

$$\delta_N = arctg(n) \tag{15}$$

$$\chi_N = 180 - \delta_N \tag{16}$$

$$\beta_N = 180 - \alpha - \chi_N \tag{17}$$

$$\frac{\sin\alpha}{a_N} = \frac{\sin\beta_N}{b} = \frac{\sin\chi_N}{c_N} \Rightarrow a_N = \frac{\sin\alpha \cdot b}{\sin\beta_N} \tag{18}$$

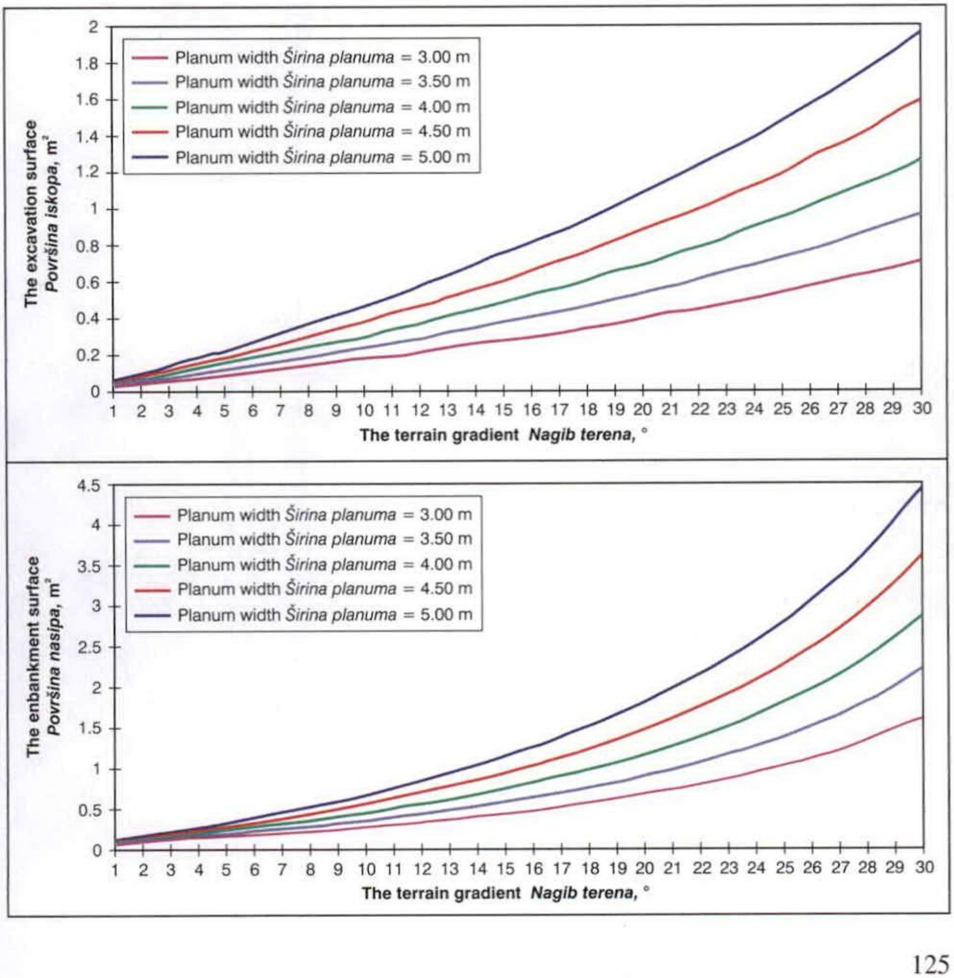
$$P_N = \frac{a_N \cdot b}{2} \cdot \sin \chi_N \tag{19}$$

The excavation surfaces as well as the embankment surfaces for a FFPR of a constant planum width increase proportionally to the increase of the transversal terrain gradient.

From Figure 4 the lack of earth for building an embankment for a FFPR is obviously in relation to the existing earth excavated in making a straight clearing

Figure 4. A graphical account of the dependence of the excavation and embankment surface on the characteristic transversal profile of a FFPR at various transversal terrain gradients and planum widths

*Slika 4. Grafički prikaz ovisnosti površine iskopa i nasipa na karakterističnom poprečnom profilu ŠPPC pri različitom poprečnom nagibu terena i širini planuma*



with the increase in the transversal terrain gradient and with the increase in the planum width. This means that the lack of material for embankment building should be solved in the most economic way.

An idea on how to solve this problem lies in the use of building technology of the so-called side compensation of earth masses.

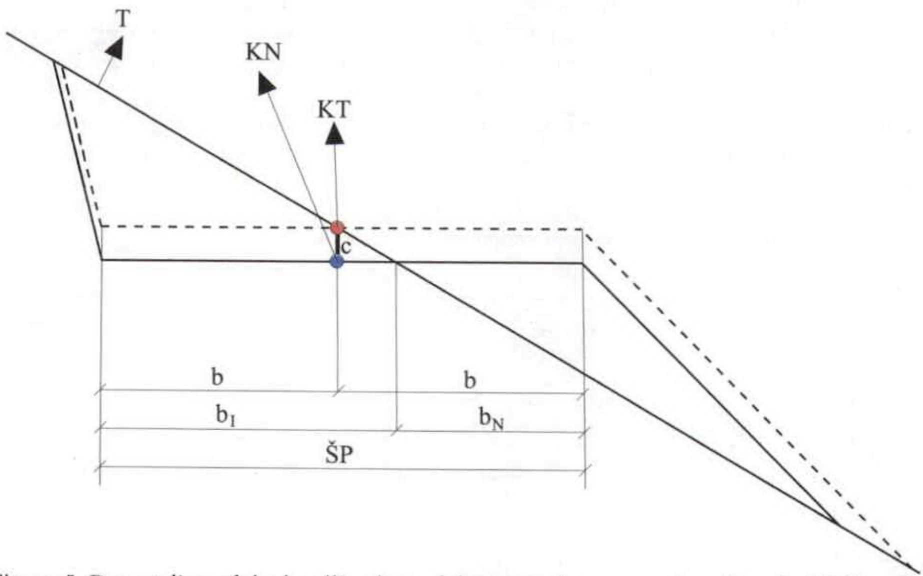



Figure 5. Descending of the levelling line of the normal transversal profile of a FFPR under the terrain level
*Slika 5. Spuštanje kote nivelete normalnoga poprečnoga profila ŠPPC ispod kote terena*

where:
*gdje je:*

- ŠP is planum width, m; *širina planuma,* m
- b is half planum width, m; *pola širine planuma,* m
- $b_I$ is planum width in the excavation for which the surface of excavation is the same as the surface of the embankment, m; *širina planuma u iskopu za koju je površina iskopa jednaka površini nasipa,* m
- $b_N$ is planum width of the embankment for which the excavation surface is the same as the embankment surface, m; *širina planuma u nasipu za koju je površina iskopa jednaka površini nasipa,* m
- c is the difference between the terrain level and the levelling line, m; *razlika između kote terena i kote nivelete*, m
- KT is terrain level, m; *kota terena,* m
- KN is levelling line, m; *kota nivelete*, m
- T is terrain; *teren*

Two changes which appear in moving the levelling line under the terrain level should be noted. They are important for further work: the excavation surface is equal to the embankment surface and the relation of the planum width in the straight clearing and the embankment is no longer 1:1. For this reason it was necessary to find a new ratio of the planum width of the FFPR in the excavation and the embankment.

Excavation and embankment surfaces are expressed depending on $b_I$ and $B_N$ and depending on the transversal terrain gradient:

$$P_I = \frac{\sin \chi_I \cdot b_I^2 \cdot \sin \alpha}{2 \cdot \sin \beta_I} \qquad P_N = \frac{\sin \chi_N \cdot b_N^2 \cdot \sin \alpha}{2 \cdot \sin \beta_N} \qquad (20), (21)$$

For the planned excavation gradient m = 4:1 and the planned embankment gradient n = 1:1, we will get:

$$P_I = \frac{0.970 \cdot b_I^2 \cdot \sin \alpha}{2 \cdot \sin (75.95 - \alpha)} \qquad P_N = \frac{0.707 \cdot b_N^2 \cdot \sin \alpha}{2 \cdot \sin (45 - \alpha)} \qquad (22), (23)$$

As there is a case of side compensation, this should be:

$$P_I = P_N \Rightarrow \frac{b_I}{b_N} = \sqrt{\frac{0.707 \cdot \sin (75.95 - \alpha)}{0.970 \cdot \sin (45 - \alpha)}} \qquad (24)$$

If we mark the expression under the root with k and if we know the total planum width, it follows:

$$b_I + b_N = P \qquad \mathrm{b_N} = \frac{P}{k+1} \qquad (25), (26)$$

Solving two equations with two unknowns ($b_I$ and $b_N$), we can easily calculate the planum width in the straight clearing and the planum width in the excavation. The difference between the terrain level and the levelling line ( c ) will be calculated by the expression:

$$\mathrm{tg}\, \alpha = \frac{c}{b_I - b} \Rightarrow c = \mathrm{tg}\, \alpha \cdot (b_I - b) \qquad (27)$$

When we know the excavation and the embankment surfaces which are equal for each segment of the ground centre line and are determined in the middle of the segment, it is possible to determine the volume of the earthwork of the excavation and the embankment for each segment of the ground centre line, as each segment of the ground centre line is of the same length, by these expressions:

$$V_I = P_I \cdot l \qquad V_N = P_N \cdot l \tag{28), (29}$$

while for the whole FFPR, the volume of necessary excavations and embankments will be calculated according to the formulas:

$$V_{IUK.} = \sum_{i=1}^{n} V_{I_i} \qquad V_{NUK.} = \sum_{i=1}^{n} V_{N_i} \tag{30), (31}$$

and if we want to find out the total cost of the execution of excavations and embankments on the FFPR, the following patterns will be used:

$$T_{IUK.} = V_{IUK.} \cdot C_I \quad T_{NUK.} = V_{NUK.} \cdot C_N \tag{32), (33}$$

where:

$V_I$ is an excavation volume of each segment of the ground centre line, $m^3$,
$V_N$ is an embankment volume of each segment of the ground centre line, $m^3$,
$P_I$ is the excavation surface calculated on the half segment of the ground centre line, $m^2$,
$P_N$ is the embankment surface calculated on the half segment of the ground centre line, $m^2$,
$l$ is the length of segments of the ground centre line, m,
$V_{IUK}$ is the total volume of the excavation earthwork for the whole forest fire-prevention road, $m^3$,
$V_{NUK}$ is the total volume of the embankment earthwork for the whole forest fire-prevention road, $m^3$,
$i$ is the ordinal number of the ground centre line segment,
$T_{IUK}$ are total costs of excavation earthwork for the whole forest fire-prevention road, kn
$T_{NUK}$ are total costs of the embankment earthwork for the whole forest fire-prevention road, kn
$C_I$ is the execution price of 1 $m^3$ of the excavation, kn,
$C_N$ is the execution price of 1 $m^3$ of the embankment, kn.

## CALCULATION OF THE COSTS OF EARTHWORK OF A FFPR FOR THE VARIABLE QUANTITIES OF THE PLANUM WIDTH, TRANSVERSAL TERRAIN GRADIENT AND CATEGORIES OF THE MATERIAL
## IZRAČUN TROŠKOVA ZEMLJANIH RADOVA ŠPPC ZA PROMJENJIVE VELIČINE ŠIRINE PLANUMA, POPREČNOG NAGIBA TERENA I KATEGORIJE MATERIJALA

The transversal terrain gradient of 0° to 45° has been divided into categories of a 5° width. In this way the quantities 2.5°, 7.5°, 12.5°, 17.5°,…, 37.5° and 42.5° are obtained, which represent a particular category of the transversal terrain gra-

Table 11. The relation of the excavation costs in building a FFPR 1 000 m long, depending on the terrain gradient and the planum width for material of the III category
*Tablica 11. Odnos troškova zemljanih radova pri izvedbi ŠPPC duljine 1 000* m, *ovisno o nagibu terena i širini planuma za materijal III. kategorije*

| The terrain gradient °<br>*Nagib terena, °* | 2.5 | 7.5 | 12.5 | 17.5 | 22.5 | 27.5 | 32.5 | 37.5 | 42.5 |
|---|---|---|---|---|---|---|---|---|---|
| The planum width = 3.00 m *Širina planuma* = 3.00 m | | | | | | | | | |
| The excavation volume, m³<br>*Volumen iskopa*, m³ | 40 | 140 | 250 | 400 | 590 | 850 | 1,230 | 1,850 | 3,180 |
| The excavation cost, kn<br>*Cijena iskopa*, kn | 149 | 521 | 930 | 1,488 | 2,195 | 3,162 | 4,576 | 6,882 | 11,830 |
| The embankment volume, m³<br>*Volumen nasipa*, m³ | 40 | 140 | 250 | 400 | 590 | 850 | 1,230 | 1,850 | 3,180 |
| The cost of embankment building, kn<br>*Cijena izradbe nasipa*, kn | 170 | 596 | 1,065 | 1,704 | 2,513 | 3,621 | 5,240 | 7,881 | 13,547 |
| The earthwork cost, kn<br>*Cijena zemljanih radova*, kn | 3,409 | 4,207 | 5,085 | 6,282 | 7,798 | 9,873 | 12,906 | 17,853 | 28,467 |
| The planum width = 3.50 m *Širina planuma* = 3.50 m | | | | | | | | | |
| The excavation volume, m³<br>*Volumen iskopa*, m³ | 60 | 190 | 350 | 550 | 810 | 1,160 | 1,680 | 2,520 | 4,330 |
| The excavation cost, kn<br>*Cijena iskopa*, kn | 223 | 707 | 1,302 | 2,046 | 3,013 | 4,315 | 6,250 | 9,374 | 16,108 |
| The embankment volume, m³<br>*Volumen nasipa*, m³ | 60 | 190 | 350 | 550 | 810 | 1,160 | 1,680 | 2,520 | 4,330 |
| The cost of embankment building, kn<br>*Cijena izradbe nasipa*, kn | 256 | 809 | 1,491 | 2,343 | 3,451 | 4,942 | 7,157 | 10,735 | 18,446 |
| The earthwork cost, kn<br>*Cijena zemljanih radova*, kn | 4,084 | 5,121 | 6,398 | 7,994 | 10,069 | 12,862 | 17,012 | 23,714 | 38,159 |
| The planum width = 4.00 m *Širina planuma* = 4.00 m | | | | | | | | | |
| The excavation volume, m³<br>*Volumen iskopa*, m³ | 70 | 240 | 450 | 710 | 1,050 | 1,520 | 2,190 | 3,290 | 5,660 |
| The excavation cost, kn<br>*Cijena iskopa*, kn | 260 | 893 | 1,674 | 2,641 | 3,906 | 5,654 | 8,147 | 12,239 | 21,055 |
| The embankment volume, m³<br>*Volumen nasipa*, m³ | 70 | 240 | 450 | 710 | 1,050 | 1,520 | 2,190 | 3,290 | 5,660 |
| The cost of embankment building, kn<br>*Cijena izradbe nasipa*, kn | 298 | 1,022 | 1,917 | 3,025 | 4,473 | 6,475 | 9,329 | 14,015 | 24,112 |
| The earthwork cost, kn<br>*Cijena zemljanih radova*, kn | 4,678 | 6,035 | 7,711 | 9,786 | 12,499 | 16,249 | 21,596 | 30,374 | 49,287 |
| The planum width = 4.50 m *Širina planuma* = 4.50 m | | | | | | | | | |
| The excavation volume, m³<br>*Volumen iskopa*, m³ | 90 | 310 | 570 | 900 | 1,330 | 1,920 | 2,770 | 4,160 | 7,160 |
| The excavation cost, kn<br>*Cijena iskopa*, kn | 335 | 1,153 | 2,120 | 3,348 | 4,948 | 7,142 | 10,304 | 15,475 | 26,635 |
| The embankment volume, m³<br>*Volumen nasipa*, m³ | 90 | 310 | 570 | 900 | 1,330 | 1,920 | 2,770 | 4,160 | 7,160 |
| The cost of embankment building, kn<br>*Cijena izradbe nasipa*, kn | 383 | 1,321 | 2,428 | 3,834 | 5,666 | 8,179 | 11,800 | 17,722 | 30,502 |
| The earthwork cost, kn<br>*Cijena zemljanih radova*, kn | 5,353 | 7,109 | 9,183 | 11,817 | 15,249 | 19,956 | 26,739 | 37,332 | 61,772 |
| The planum width = 5.00 m *Širina planuma* = 5.00 m | | | | | | | | | |
| The excavation volume, m³<br>*Volumen iskopa*, m³ | 120 | 380 | 710 | 1,120 | 1,650 | 2,370 | 3,420 | 5,140 | 8,840 |
| The excavation cost, kn<br>*Cijena iskopa*, kn | 446 | 1,414 | 2,641 | 4,166 | 6,138 | 8,816 | 12,722 | 19,121 | 32,885 |
| The embankment volume, m³<br>*Volumen nasipa*, m³ | 120 | 380 | 710 | 1,120 | 1,650 | 2,370 | 3,420 | 5,140 | 8,840 |
| The cost of embankment building, kn<br>*Cijena izradbe nasipa*, kn | 511 | 1,619 | 3,025 | 4,771 | 7,029 | 10,096 | 14,569 | 21,896 | 37,658 |
| The earthwork cost, kn<br>*Cijena zemljanih radova*, kn | 6,107 | 8,183 | 10,816 | 14,087 | 18,317 | 24,062 | 32,441 | 46,167 | 75,693 |

dient. According to the previously derived mathematical expressions, the cost of the excavation, the total cost of the embankment construction and the total cost of the earthwork of forest fire-prevention roads 1 000 m long were calculated as final quantities, at various transversal terrain gradients, for the normal transversal profile of a forest fire-prevention road and according to the cost estimates of the works of the Public Enterprise "Croatian Forests".

The surface of the normal transversal profile of forest fire-prevention roads in which the grade line level under the terrain level for the value c in which the excavation surface is equal to the embankment surface was taken into consideration. The obtained surfaces were multiplied by 1 000 m to get the excavation and the embankment volumes. The excavation volume was multiplied by the cost of a particular type of work in the III category of the material, the prices were added and the total cost of earthwork was obtained.

The cost of earthwork for forest fire-prevention roads increases with the increase in planum width and with the increase in transversal terrain gradients. Also, the cost of earthwork increases with less acceptable terrain categories on which the work is executed. If we observe the cost movement for earthwork of a planum width of 4,00 m and if we compare it to the cost of earthwork for a terrain gradient of 42.5°, we will get interesting results shown in Table 12.

Table 12. A comparison of the quantity of FFPRs with a planum width of 4.00 m which can be executed with the same financial investment, but with different transversal terrain gradients

*Tablica 12. Usporedba količine ŠPPC sa širinom planuma 4,00 m koje se mogu izvesti uz ista financijska ulaganja, ali pri različitim poprečnim nagibima terena*

| Transversal terrain gradient<br>*Poprečni nagib terena*, ° | The earthwork cost for 1,000 m of FFPR<br>*Cijena zemljanih radova za 1 000 m ŠPPC*<br>kn | The length of FFPR which can be build for 49,287 kn<br>*Duljina ŠPPC koje se mogu izvesti za 49 287* kn<br>m |
|---|---|---|
| 2.5 | 4,678 | 10,536 |
| 7.5 | 6,035 | 8,167 |
| 12.5 | 7,711 | 6,392 |
| 17.5 | 9,786 | 5,036 |
| 22.5 | 12,449 | 3,959 |
| 27.5 | 16,249 | 3,033 |
| 32.5 | 21,996 | 2,241 |
| 37.5 | 30,374 | 1,623 |
| 42.5 | 49,287 | 1,000 |

Table 13. A comparison of the length of FFPRs which can be built with the same financial investment in the same transversal terrain gradient and with materials of different categories

*Tablica 13. Usporedba duljine ŠPPC koje se mogu izgraditi uz jednaka financijska ulaganja pri jednakim poprečnim nagibima terena i materijalu različitih kategorija*

| | Material of III cat. *Materijal III. kat.* | | Material of IV. cat. *Materijal IV. kat.* | | Material of V. cat *Materijal V. kat.* |
|---|---|---|---|---|---|
| A transversal terrain gradient *Popr. nagib terena* | The cost of earthwork for 1000 m of FFPR *Cijena zemljanih radova za 1000 m ŠPPC* | The length of FFPR that can be made for the cost of earthwork of material of V category *Duljina ŠPPC koja se može izvesti za cijenu zemljanih radova materijala V. kat.* | The cost of earthwork for 1000 m of FFPR *Cijena zemljanih radova za 1000 m ŠPPC* | The length of FFPR that can be made for the cost of earthwork of material of V category *Duljina ŠPPC koja se može izvesti za cijenu zemljanih radova materijala V. kat.* | The cost of earthwork for 1000 m of FFPR *Cijena zemljanih radova za 1000 m ŠPPC* |
| ° | kn | m | kn | m | kn |
| 2.5 | 4,678 | 1,763 | 6,421 | 1,284 | 8,245 |
| 7.5 | 6,035 | 3,026 | 12,011 | 1,521 | 18,263 |
| 12.5 | 7,711 | 3,973 | 18,916 | 1,620 | 30,639 |
| 17.5 | 9,786 | 4,697 | 27,465 | 1,673 | 45,961 |
| 22.5 | 12,449 | 5,301 | 38,664 | 1,707 | 65,997 |
| 27.5 | 16,249 | 5,766 | 54,097 | 1,732 | 93,693 |
| 32.5 | 21,996 | 6,055 | 76,127 | 1,749 | 133,176 |
| 37.5 | 30,374 | 6,519 | 112,295 | 1,763 | 197,999 |
| 42.5 | 49,287 | 6,851 | 190,221 | 1,775 | 337,664 |

Therefore, whenever it is possible, those terrains whose transversal gradient is lower should be chosen as a route for forest fire-prevention roads, as then there are smaller surfaces of excavation and embankments on the normal transversal profile. Consequently, the lower the volumes of excavation and embankments for each segment of the forest fire-prevention road, the lower the total costs of earthwork for the whole fire-prevention road.

Naturally, all other factors of a spatially well-laid network of forest fire-prevention roads should also be taken into consideration.

With an increase in the transversal terrain gradient, differences in the number of kilometres that can be built for the same construction costs also increases, starting from the III to IV and V category of materials with which the work is done. Also, there are bigger differences between the possible quantity of FFPRs in the II and the III categories than in the III and the IV categories of materials.

## THE CALCULATION OF THE COSTS OF EARTHWORK OF THE VARIANTS OF FFPRs, SIMULATED BY THE GROUND CENTRE LINE AND USING THE PROGRAMME "COST" AS ONE OF THE CRITERIA FOR CHOOSING THE MOST ACCEPTABLE VARIANT
## IZRAČUN TROŠKOVA ZEMLJANIH RADOVA INAČICA ŠPPC, SIMULIRANIH NULTOM LINIJOM I UPORABOM PROGRAMA "TROŠAK", KAO JEDAN OD KRITERIJA ODABIRA NAJPOVOLJNIJE INAČICE

According to the previously mentioned theoretical presumptions and derived mathematical expressions, a simple computer programme called COST was written in the programme language C++. The programme calculates the cost of earthwork for forest fire-prevention roads, i.e. costs which are under the direct influence of the transversal terrain gradient, i.e. the terrain configuration. By the entry of the basic components of the normal transversal profile of forest fire-prevention roads such as planum width, planned straight clearing gradient, and planned embankment gradient, and by the entry of the transversal terrain gradient in degrees and excavation costs, the costs of building the embankment and the costs of planum planning, it is possible to obtain the total cost of earthwork for each particular segment of the ground centre line in a very short time. At this stage of planning, a forest fire-prevention line is approximately presented by the ground centre line, and the data which are entered are average values for each segment of the ground centre line or values measured in the middle of the segment. Total costs for the whole FFPR are obtained by adding the costs for each segment.

By comparing the total costs of earthwork for more variants of forest fire-prevention roads, it is possible to obtain in a very short time data according to which we can choose the most acceptable variant, taking into consideration other factors.

## FINAL CONSIDERATIONS
## ZAKLJUČNA RAZMATRANJA

According to the research that was carried out and the obtained results, the following conclusions can be drawn:

Forest fire-prevention roads are a special category of forest roads.

Due to other criteria, further classification should be made within the category of forest fire-prevention roads.

In the management unit Senjska Draga a total length of forest fire-prevention roads of 31,363.70 m has been established. Of this, a total of 10,459.90 m (33.35 %) was laid with a bigger longitudinal gradient than allowed, while on 20,903.80 m (66.65 %) of forest fire-prevention roads, the longitudinal gradient was within the limits of that allowed (up to 8 %). The total surface under FFPRs is 130,308.76 $m^2$ (13.03 ha).

The average geometric distance of the centroid of the section determined by the centroid method is 244.79 m, while the average real distance of the centroid of the section is 287.15 m.

Due to the relative openness of the research area, which was determined by laying down so-called buffers around the existing network of forest roads, the research area is satisfactorily opened for the average optimum geometric distance of the approach to the surface of 250 m, i.e. for the average optimum real distance of the approach to the surface of 216.72 m, and for the average optimum geometric distance of the approach to the surface of 300 m, i.e. for the average optimum real distance of the approach to the surface of 260.04 m.

The planning of future forest fire-prevention roads which have to fit into the existing network can efficiently be done on DTM by laying down the buffer around the existing forest fire-prevention roads and by examining various variants of future FFPRs in order to choose the most acceptable one.

The factor of the vertical correction of the terrain, by which the average optimum geometric distance of the approach to the surface is corrected, to obtain the average optimum real distance of the approach to the surface, can be quickly and precisely determined on the DTM, as well as the average terrain gradient in each section.

The cost of the earthwork of forest fire-prevention roads is proportionally related to the transversal terrain gradient (the terrain gradient vertically on the FFPR), provided that all other elements of the normal transversal profile of a forest fire-prevention road are constant and that the cost of earthwork is the same for the whole route of the road.

At the presently valid regulated normal transversal profile of a FFPR, it is necessary, in order to minimalize the costs of building roads, to move the level of the grade line under the level of the terrain for the particular value c, where the surface of the road in a straight clearing is the same to the surface of the road on the embankment.

Whenever possible, so-called side compensation should be used in building forest fire-prevention roads, since in this way more roads can be built with the same financial investment.

The computer programme "COST" gives us the possibility of a fast calculation of total costs of earthwork for particular digitised ground centre lines, which present different variants of forest fire-prevention roads. In combination with the efficacity of each variant determined by laying down a buffer at a distance of the average real distance of the approach to the surface from forest fire-prevention roads, we gain an opportunity to choose the most acceptable variant of the future forest fire-prevention road, naturally taking into consideration other factors that influence that choice.

It has been determined that forest fire-prevention roads should be built at a minimum distance of 300 m to a maximum distance of 600 m apart, i.e. that the average real distance of the approach to the surface should be from 150 m to 300 m, depending on the degree of danger of forest fire.

The buffer method can be successfully used in an analysis of the existing network of forest fire-prevention roads, its advantages and weaknesses, and in determining the relative openness of an area for the required average optimum distance of approach to the surface. In combination with the programme COST, this method is a useful tool to improve the network quality of forest fire-prevention roads, i.e. in planning future FFPRs and in choosing the most acceptable variant and establishing its efficacity.

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# ŠUMSKE PROTUPOŽARNE CESTE KAO POSEBNA KATEGORIJA ŠUMSKIH CESTA I ČIMBENICI KOJI UTJEČU NA NJIHOV RAZMJEŠTAJ U PROSTORU

## SAŽETAK

Šumske protupožarne ceste (ŠPPC) jesu posebna kategorija šumskih cesta koja je vezana uz mediteransko i submediteransko područje, odnosno uz krško područje Republike Hrvatske. S obzirom na specifičnosti područja u kojem se planiraju, projektiraju i izvode, a samim time i s obzirom na svoju primarnu zadaću, odnosno na tehnička obilježja, ŠPPC se značajno razlikuju od šumskih gospodarskih cesta (ŠGC).

Primarna je zadaća ŠPPC preventivna zaštita od šumskih požara, koji su kao ekološki destabilizator ekosustava u primorskim šumama najveća opasnost od svih abiotskih i biotskih štetnih čimbenika. Isto tako ova kategorija šumskih cesta mora u slučaju izbijanja požara pružiti najpovoljnije uvjete za njegovo suzbijanje. Iz navedenih razloga prišlo se istraživanju čimbenika koji utječu na prostorni raspored

mreže šumskih protupožarnih cesta s ciljem da se uz što manja financijska ulaganja izgradi što veća količina cesta uz zadovoljenje propisanih zahtjeva za kakvoćom.

Istraživanja su provedena na području UŠ Senj, Šumarije Senj, u gospodarskoj jedinici Senjska draga. Osim terenskih izmjera postojećih cesta na istraživanom području uporabljen je i postupak digitalizacije šumskogospodarskih karata, izrađen je i digitalni model terena (DTM). Na digitaliziranim i obrađenim podlogama razvijena je metoda tzv. "buffera"– omeđenih površina, predložena je tehnologija ekonomičnije izgradnje ŠPPC s obzirom na čimbenike koji imaju izravan utjecaj na troškove zemljanih radova, te je u tu svrhu dizajniran jednostavan kompjuterski program koji izabire troškovno najpovoljniju inačicu šumske ceste.

Iz podataka izmjerenih na terenu, a prema karti izmjerenih šumskih protupožarnih cesta (karta 4) redom su raščlanjeni uzdužni nagibi protupožarnih cesta. Slikovni prikaz jedne ŠPPC dan je na slici 1. Na apscisi je označena stacionaža točaka loma nivelete, u kojima je ujedno mjerena širina planuma, dok je na ordinati relativna nadmorska visina svake točke loma.

U tablicama 6 i 7 prikazani su sumarni podaci za sve ŠPPC na području GJ Senjska draga.

Željelo se vidjeti i kolika je otvorenost GJ Senjska draga utvrđena težišnom metodom. U tu je svrhu, primjenom osobnoga računala i odgovarajućih programa, pronađeno težište svakoga odsjeka i ucrtano u digitaliziranu kartu. Najkraća udaljenost od težišta svakoga odsjeka pa do najbliže ceste, koja se može rabiti kao protupožarna, izmjerena je i definirana kao srednja geometrijska daljina pristupa površini odsjeka. Te su linije srednje vatrogasne intervencije ucrtane u karte. Da bismo dobili srednje stvarne daljine pristupa površini odsjeka, trebalo je pronaći čimbenik vertikalne korekcije terena i čimbenik horizontalnoga zaobilaženja prepreka. Čimbenik vertikalne korekcije terena određen je tako da su srednje geometrijske daljine pristupa površini odsjeka položene preko DTM-a i očitane vrijednosti nagiba u četiri međusobno jednako udaljene točke. Zatim je pronađena srednja vrijednost u stupnjevima i određen kosinus (cos) toga srednjega nagiba. Srednja geometrijska daljina pristupa površini odsjeka podijeljena je kosinusom srednjega nagiba i pomnožena čimbenikom horizontalnoga zaobilaženja prepreka da bi se dobila njezina stvarna istoznačnica. Kao čimbenik horizontalnoga zaobilaženja prepreka, za područje cijele gospodarske jedinice, uzeta je vrijednost od 1,10. Srednja geometrijska i srednja stvarna daljina pristupa površini cijele gospodarske jedinice izračunate su kao aritmetičke sredine tih vrijednosti za svaki odsjek, a kao težine su poslužile vrijednosti površine odsjeka. Srednja geometrijska daljina pristupa za GJ Senjska draga je 244,79 m, a njezina stvarna istoznačnica – 287,15 m.

Danas ne postoje propisani teoretski razmaci između ŠPPC, nema preporučene ili optimalne otvorenosti ŠPPC, a nema ni okvirnih granica u kojima bi se trebala kretati srednja daljina pristupa površini. To je dovelo do potrebe definiranja i utvrđivanja određenih vrijednosti kojima bi trebalo težiti pri planiranju, projektiranju i izgradnji šumskih protupožarnih cesta. U konzultacijama sa zapovjednicima profesionalnih vatrogasnih postrojba u Rijeci i dobrovoljnih vatrogasnih postrojba na otoku Rabu, s obzirom na taktiku gašenja šumskih požara koja se na tim prostorima godinama uspješno primjenjuje, a danas je i zakonom propisana za cijelu Republiku Hrvatsku, došlo se do spoznaja da je stvarna površina koja se pri gašenju šumskih požara u prvoj navali može "pokriti" interventnim vatrogasnim vozilima samo površina 50 metara udaljena od šumske protupožarne ceste, u svim smjerovima, dok je u drugoj navali ta površina maksimalno do 300 metara od šumske protupožarne ceste, u svim smjerovima.

S obzirom na to da su to optimalne vrijednosti s vatrogasnoga stajališta, primjenom računala, oko prethodno digitaliziranih postojećih cesta na istraživanomu području položene su primjenom računala površine, tzv. "bufferi", koji su svagdje na svojemu rubu bili udaljeni od ceste za određeni isti iznos, koji je predstavljao srednju optimalnu geometrijsku daljinu pristupa površini. Inačice toga parametra iznosile su 50, 100, 150, 200, 250 i 300 metara.

Dobivene su površine rasterizirane i prebačene na digitalni model terena na kojemu je, na osnovi izrađenoga histograma, određen prosječni nagib terena u svakoj inačici, koji je poslužio za pronalaženje čimbenika vertikalne korekcije terena. Tim je čimbenikom pomnožena svaka inačica srednje optimalne geometrijske daljine pristupa površini, a zatim podijeljena čimbenikom horizontalnoga zaobilaženja, koji je za čitavo istraživano područje iznosio 1,10. To je učinjeno da bi se dobila srednja optimalna stvarna daljina pristupa površini. Pri tome su upotrijebljene formule (2), (3), (4).

Određivanjem površine koja je otvorena s obzirom na odabir pojedine inačice srednje daljine pristupa površini i ukupne površine GJ (zajedno s privatnim enklavama unutar površina kojima gospodari JP "Hrvatske šume"), dobivena je relativna otvorenost za svaku inačicu prema formuli (5). Rezultati ocjene relativne otvorenosti za odabrane vrijednosti srednje daljine pristupa površini prikazani su u tablici 8.

Možemo zaključiti da otvorenost GJ Senjska draga pri srednjoj stvarnoj daljini pristupa površini od 300 metara zadovoljava, jer je s jedne protupožarne ceste moguće intervenirati na obje strane. Pri srednjoj stvarnoj daljini pristupa površini od 250 metara otvorenost istraživanoga područja slabo zadovoljava. Za inačice pristupa površini od 50, 100, 150 i 200 metara otvorenost je šumskoga područja nedovoljna.

Opisana metoda polaganja tzv. "buffera", koji su na svome rubu svugdje jednako udaljeni od ŠPPC, idealna je metoda kojom se vrlo zorno može predočiti otvorena površina određenoga šumskoga područja s odabranom optimalnom srednjom daljinom pristupa. Primjenom ove metode uočavaju se i neotvorena područja, o kojima posebice treba voditi računa pri daljnjem otvaranju šumskoga područja. Metoda je "buffera" također učinkovita pri planiranju i pri daljnjem grananju mreže ŠPPC: oko mogućih inačica trasa budućih ŠPPC, koje su predstavljene nultom linijom i kao takve digitalizirane, položi se "buffer" određene veličine. Inačica ŠPPC koja otvara najveći dio neotvorenoga šumskoga područja, a istodobno obuhvaća najmanju površinu tzv. mrtvih zona, odnosno područja koja su za odabranu srednju optimalnu daljinu pristupa površini otvorena s dvije ili više cesta, najučinkovitija je i nameće se kao najbolja. Metoda "buffera" za srednju geometrijsku daljinu pristupa površini od 250 m prikazana je na karti 5.

Postavlja se pitanje: kolika je otvorenost šumskoga područja iskazana u m/ha za navedene inačice srednje geometrijske daljine pristupa površini ? Da bi se dobio odgovor, uzet je model šumske površine dimenzija 1200 x 1000 m i taj je model otvoren paralelnim šumskim protupožarnim cestama na međusobno jednakoj udaljenosti l ($l = 2S_{PG}$). Pri izračunu su primijenjene matematičke formule(6), (7), (8), a rezultati su dani u tablici 9.

Prema kriteriju otvorenosti šumskoga područja i prema spoznajama o otvorenosti u vodećim svjetskim šumarskim zemljama može se zaključiti da otvorenost od 100,00 m/ha, koja je dobivena za srednju optimalnu stvarnu daljinu pristupa površini od 50 m, ne dolazi o obzir, barem što se tiče izgradnje šumskih protupožarnih cesta. Otvorenost od 50 m/ha, koja je dobivena kod inačice $S_{PG}$=100 m, također je vrlo visoka i u praksi jedva da može naći opravdanje. Dakle, šumskim protupožarnim cestama, prema kriteriju otvorenosti šumske površine, moguće je otvarati šumska područja ugrožena požarima od srednje optimalne geometrijske daljine pristupa od 150 metara pa naviše.

Jedan od kriterija za utvrđivanje najveće dopuštene količine prometnica u određenom ekosustavu, a da se njegova ravnoteža ne poremeti i da opasnosti od šteta uzrokovanih erozijom ne prijeđu dopuštene granice, jest i površina šumskoga područja pod šumskim prometnicama. Za šumske ceste, prema Pičmanu (1994), ta veličina iznosi 3 %. Za različite inačice srednje optimalne stvarne daljine pristupa izračunata je površina pod šumskim protupožarnim cestama na prije rabljenoj teoretskoj šumskoj površini dimenzija 1 200 x 1 000 m. Kao ulazi uzete su i različite širine planuma šumskih protupožarnih cesta, a izračunate vrijednosti su u tablici 10.

Prema čimbeniku postotnoga udjela površine pod šumskim cestama, u ukupnoj površini područja koje se otvara, dobiveni su rezultati u skladu s prijašnjim promišljanjima. Mreža šumskih protupožarnih cesta u kojoj je međusoban razmak cesta 100 m, čak i kod minimalne širine planuma od 3,00 m, doseže maksimalne vrijednosti od 3 % površine pod šumskim cestama. Kao takva, ova je mreža šumskih cesta, iako najoptimalnija sa stajališta vatrogasnih djelatnika, potpuno neprihvatljiva sa šumarskoga gledišta i neodrživa u šumskim ekosustavima. Vrijednosti površine pod šumskim cestama za razmak cesta od 200 m, u prihvatljivim su granicama, ali se približavaju gornjem dopuštenom maksimumu. Kako se radi o protupožarnim cestama u krškim područjima, gdje su opasnosti od erozije velike, a vegetacija kao osnovni čimbenik koji sprječava nastajanje erozije nije bogata i nije bujna, to je bolje planirati i projektirati mreže šumskih prometnica s većim razmakom, a samim time i površina pod ŠPPC bit će manja.

Pri izboru određene inačice šumske protupožarne ceste veliku ulogu ima konačna cijena izvedbe. Stoga je napravljena raščlamba normalnoga poprečnoga profila ŠPPC. Troškovi zemljanih radova predstavljaju glavni izvor troškova na koje se pri planiranju buduće trase protupožarne ceste može utjecati. Položaj protupožarnih cesta prikazan je nultim linijama različitoga nagiba, ovisno o nagibu terena. Budući da je poznat normalni poprečni profil šumske protupožarne ceste i da je položena nulta linija koja aproksimira buduću situaciju na terenu, moguće je, u vrlo kratkom vremenu, odrediti i usporedne cijene više inačica budućih trasa šumskih protupožarnih cesta. Pretpostavka je da je nagib terena okomit na nultu liniju stalan za čitavu širinu planuma ŠPPC, koja iznosi 4,00 m.

Pri izvođenju matematičkih izraza za izračun površina iskopa i nasipa, koji su nam potrebni za dobivanje volumena zemljanih radova i, u konačnici, za dobivanje približnih troškova zemljanih radova, uporabit ćemo trokute površina $P_I$ (površina iskopa) i $P_N$ (površina nasipa). Krajnji rezultat matematičkih izvoda su formule (13) i (19).

Površine iskopa i površine nasipa za šumsku protupožarnu cestu stalne širine planuma povećavaju se proporcionalno povećanju poprečnoga nagiba terena. Iz slike 4 uočljivo je povećanje manjka zemlje za izradbu nasipa u odnosu na raspoloživu zemlju iskopanu pri izvedbi zasjeka s povećanjem poprečnoga nagiba terena i povećanjem širine planuma. To znači da bi manjak materijala za izradbu nasipa trebalo riješiti na najekonomičniji način. Ideja o tome kako riješiti ovaj problem bila je u primjeni tehnologije gradnje tzv. bočnom kompenzacijom zemljanih masa.

Na slici 5 prikazani su potrebni preduvjeti za primjenu predložene tehnologije gradnje.

Treba primijetiti dvije promjene što nastaju pri pomicanju kote nivelete ispod kote terena, a koje su važne za daljnji tijek rada: površina iskopa jednaka je površini nasipa i odnos širine planuma u zasjeku i u nasipu više nije 1:1. Zato je bilo nužno pronaći novi omjer širina planuma ŠPPC u iskopu i u nasipu. Površine iskopa i nasipa iskazane su u ovisnosti o $b_I$ i $B_N$, te su u ovisnosti o poprečnome nagibu terena dane matematičkim izrazima (20) i (21) za planiranu kosinu iskopa m = 4:1, te za planiranu kosinu nasipa n = 1:1 izrazima (22) i (23). Budući da je riječ o bočnoj kompenzaciji, mora biti $P_I = P_N$ (24), i konačno rješavanjem dviju jednadžba s dvije nepoznanice (25) i (26) jednostavno ćemo izračunati širinu planuma u zasjeku i širinu planuma u nasipu. Razliku kote terena i kote nivelete (c) izračunat ćemo pomoću izraza (27).

Kad znamo površine iskopa i nasipa koje vrijede za svaki segment nulte linije, a određuju se na sredini segmenta, moguće je, budući da je svaki segment nulte linije jednake duljine, odrediti i volumen zemljanih radova iskopa i nasipa za svaki segment nulte linije (28) i (29), dok će se za čitavu protupožarnu cestu volumen potrebnih iskopa i nasipa izračunati prema formulama (30) i (31), a želimo li doći do ukupnoga troška izvedbe iskopa i nasipa na protupožarnoj cesti, uporabit ćemo formule (32) i (33).

Htjelo se ispitati ponašanje troškova zemljanih radova pri mijenjanju određenih utjecajnih čimbenika, prije svega širine planuma, poprečnoga nagiba terena i kategorije materijala u kojem se radovi izvode.

Poprečni nagib terena od 0° do 45° podijeljen je u kategorije širine 5°. Tako su dobivene vrijednosti 2,5°, 7,5°, 12,5°, 17,5°,...., 37,5° i 42,5°, koje predstavljaju pojedinu kategoriju poprečnoga nagiba terena. Prema prije izvedenim matematičkim izrazima izračunate su kao konačne veličine ukupna cijena iskopa, ukupna cijena izradbe nasipa i cjelokupna cijena zemljanih radova ŠPPC duljine 1 000 m kod različitih poprečnih nagiba terena, za normalni poprečni profil šumske protupožarne ceste i prema troškovniku radova JP "Hrvatske šume" (tablica 11).

Cijena zemljanih radova kod ŠPPC raste s povećanjem širine planuma i s povećanjem poprečnih nagiba terena. Isto tako, cijena je zemljanih radova viša što je nepovoljnija kategorija zemljišta u kojoj se radovi izvode. Promotrimo li kretanje cijene zemljanih radova za širinu planuma od 4,00 m, te ako cijenu zemljanih radova za poprečni nagib terena od 42,5° uzmemo za usporedbu, dobit ćemo zanimljive rezultate prikazane u tablici 12.

Kad god smo, dakle, u mogućnosti, za trasu ŠPPC treba birati one terene kod kojih je poprečni nagib što manji, jer nas tada čekaju manje površine iskopa i nasipa na normalnom poprečnom profilu, manji će biti volumeni iskopa i nasipa za svaki segment ŠPPC, a, analogno tomu, manji će biti i ukupni troškovi zemljanih radova za cijelu protupožarnu cestu. Razumije se da u obzir treba uzeti i ostale čimbenike prostorno dobro položene mreže ŠPPC.

Broj kilometara koje je moguće izvesti uz jednake troškove gradnje, opada idući od III. preko IV. do V. kategorije materijala u kojem se radovi izvode. Također su veće razlike između moguće količine ŠPPC u II. i III. nego u III. i IV. kategoriji materijala (tablica 13).

Na temelju prije navedenih teoretskih postavki i izvedenih matematičkih izraza napisan je jednostavan računalni program nazvan TROŠAK u programskom jeziku C++. Program izračunava troškove zemljanih radova ŠPPC, dakle troškove koji su pod izravnim utjecajem poprečnoga nagiba terena odnosno konfiguracije terena. Unosom osnovnih sastavnica normalnoga poprečnoga profila ŠPPC, kao što su širina planuma, planirani nagib kosine zasjeka, planirani nagib kosine nasipa, te unosom poprečnoga nagiba terena u stupnjevima i troškova iskopa, troškova izradbe nasipa i troškova planiranja planuma, moguće je u kratkome vremenu dobiti ukupnu cijenu zemljanih radova za svaki pojedini segment nulte linije. ŠPPC je u ovoj fazi planiranja približno predstavljena nultom linijom, a podaci koji se unose jesu srednje vrijednosti za svaki segment nulte linije ili vrijednosti izmjerene na sredini segmenta. Ukupni se troškovi za čitavu ŠPPC dobiju zbrajanjem troškova za svaki segment.

Usporedbom ukupnoga troška zemljanih radova više inačica ŠPPC vrlo se brzo mogu dobiti podaci na osnovi kojih, dakako, uz uvažavanje ostalih čimbenika, možemo odabrati najpovoljniju inačicu.

Ključne riječi: šumske protupožarne ceste, šumski požari, krško područje, digitalni model terena, relativna otvorenost, troškovi zemljanih radova