Opening-up of Forests for Fire Extinguishing Purposes

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Abstract – Nacrtak

Information on the existence of forest roads as well as their quality is important not only for planning forest management activities, but also for fire management, which includes fire risk assessment and fire suppression. In the case of fire, the level of forest opening-up has a significant influence on the attendance time of fire brigades. Not sufficiently developed road network is often reflected on the elongation of fire-fighting attack and exactingness of shuttle water relay. Therefore, the level of forest opening-up is an important indicator and factor affecting the promptness of fire-fighting activities and further fire spreading, because forest roads also represent a natural barrier against fire.

A simple approach to the assessment of the level of forest opening-up has been introduced from the aspect of terrain accessibility for the available mobile fire apparatus with the use of GIS and GNSS technologies. First, the forest road network was mapped using the GNSS technology, and then the information on the quality of particular roads was collected. These data were processed in the ArcGIS 9.3 environment and as a result the geodatabase was created. It was later used to process the opening-up analysis in IDRISI Taiga environment.

The opening-up analysis was performed for the Hrabusice forest management district, located in the karst area of the Slovensky raj National Park and the available mobile fire apparatus – pumping appliance CAS 32 on Tatra 148 chassis and forest special UNIMOG on Mercedes chassis.

The objective of the opening-up analysis was to identify the zone where the terrain is accessible for mobile fire apparatus and where fire hose piping is admissible. It was based on computation of the maximum range of fire hose piping (maximum sidelong distance), road spacing and the index of forest opening-up.

The results of this analysis are valuable as a support for decision making for foresters dealing with forest protection, road planning and construction, for fire brigades in planning fire attacks, as well as for risk managers and crisis managers.

Keywords: Fire extinguishing, forest fire, GIS, GNSS, opening-up

1. Introduction – *Uvod*

The intensive exploitation of natural resources gives rise to significant claims of forest management oriented not only to sustaining and improving of wood production functions of forest, but also towards its non-production functions, such as soil protection, hydrological control, landscape architecture, health and recreation.

Forest fires are among the most harmful factors in forestry representing the highest risk for fulfilling the objectives of forest management planning.

In the period 2000–2010, there occurred 4 373 forest fires in Slovakia that destroyed about 5 831 ha of forests (JRC Scientific and Technical Report 2010). This is the reason to incorporate the effective fire protection system into a system of multi-resource forest management. The most effective fire protection is effective prevention, and if, however, a fire occurs, it is necessary to establish promptly its location and provide extinction.

The functional and efficient network of forest roads is a basic pre-requisite for a sustainable multi-resource forest management as well as for fire protection.

In steep mountainous terrain, where the use of ground-fire-fighting machinery (mobile fire apparatus) is required, the operational facilities of this machinery (mainly its working range) as well as the access to the fire place are the limiting factors (Chromek 2006).

In Slovakia, 3 types of mobile fire apparatus are commonly used: pumping appliance CAS on Tatra 148 and Tatra 815 chassis and forest special UNIMOG on Renault or Mercedes chassis.

The pumping appliance is suitable for extinguishing fires on public roads of 1st and 2nd quality class and on reinforced forest roads (in Slovakia 1L, 2L class forest roads in accordance with STN 73 6108). Due to its technical parameters, the UNIMOG is also suitable for extinguishing fires on hauling roads (with the longitudinal slope from 10 to 12%).

This paper deals with the assessment of opening-up of the area of Hrabusice forest management district for the purposes of extinguishing fires with the use of mobile fire apparatus: pumping appliance CAS 32 on Tatra 148 chassis and forest special UNIMOG on Mercedes chassis.

The choice of fire apparatus was not oriented to the latest and most powerful machine, but to the model actually used by fire brigades acting in this territory.

2. Problem – *Problem*

Effective forest fire prevention is a pre-requisite for good forest management in fire prone areas. To have a sufficiently developed road network of good quality that can be used for efficient fire-fighting is a sign of well-done fire prevention that can lead to reduction of fire vulnerability in that territory.

Planning of forest roads is commonly oriented to assigning the fundamental management activities in the forest and to reducing the costs and environmental impacts of timber logging. Nowadays, the analyses of forest opening-up are performed mainly as a part of timber logging process optimization. For this purpose the computer aided or GIS approaches are used. Numerous authors have been concerned with these problems for many years.

Tan (1999) was interested in locating forest roads by a spatial and heuristic procedure using microcomputers.

Tuček and Pacola (1999) introduced the algorithms for tractor and cableway skidding distance modelling on a raster digital terrain model in GIS environment.

Adams et al. (2003) published an approach to the modelling of steep terrain harvesting risk using GIS.

Eriksson and Rönnqvist (2003) presented a decision support system for transportation and route planning in Sweden as well as the Akarweb – web based planning system.

Andreson and Nelson (2004) published an optimization approach to the projecting vector-based road network based on the shortest path algorithm applicable in GIS environment.

Gumus at al. (2007) introduced a new network planning approach developed for wood-harvesting. GIS was also used for data evaluation and planning process. It was applied to Catak Forest District area.

Contreras and Chung (2007) published in their work a computer approach to finding optimal long landing location and analyzing influencing factors for ground-based timber harvesting.

Slančík at al. (2009) introduced the model for optimization of timber logging and transportation technologies regarding the ecological criteria. It was created using GIS and EMDS tools.

In 2010, Kühmaier and Stampfer introduced a GIS based evaluation model designed to select the optimal timber harvesting system. The model has been demonstrated in steep terrain in the South of Lower Austria.

The requirements related to fire extinguishing activities in the forest are not well implemented into to forest management planning. However, there are few works dealing with the problem of opening-up analyses as a simultaneous combination of requirements related to forest management and fire risk management.

Johnsson at al. (1998) published a scientific paper dealing with the problem of integration of wildfire into strategic planning for Sierra Nevada forests.

Gonzáles at al. (2005) dealt with the problem of integrating fire risk in forest management planning on landscape-level perspective in Spain.

Acuna at al. (2010) introduced an approach to the integrated spatial fire and forest management planning. They applied it in the boreal forest region of the province of Alberta in western Canada.

In Slovakia, there are also activities related to the planning and reconstruction of fire protection roads, e.g. Dvorščák and Bohmer (2006); Antalová (2010), or fire stop systems (Hlaváč at al. 2007).

In our conditions only Böhmer and Dvorščák (2006) dealt with the problem of optimization of forest opening-up for the purpose of fire extinguishing. In the optimization process they considered a pumping appliance »CAS 32« and a portable pump »PS 12«. The analysis was performed by the classic mathematical approach. In the calculation they also

included the friction losses because of different terrain slope.

The implementation of GIS methods into the analysis allows performing parallel processing of several inputs resulting in increasing time and cost efficiency in sense of reduction of exerted work, time saving and reduction of errors caused by a subjective view on the analyzed phenomenon.

3. Material and methodology – *Materijal i metodologija*

3.1 Experimental area – *Područje istraživanja*

On the basis of the results of fire danger assessment of the forests of the Slovak Republic (Majlingová 2007), the territory of Slovensky raj National Park, and hence also Hrabusice management district, is the region with the highest degree of fire danger in Slovakia. This is mainly so because of the climate conditions, forest species composition, inaccessible terrain – very low level of forest opening-up, number of tourists and people living in poverty (Majlingová 2010).

The Slovensky raj National Park is situated in the north-eastern part of the Slovenske Rudohorie Mts. near the Low Tatras Mts. Fig. 1 shows the location of the experimental area. The geological ground consists of limestone and dolomite that allow the creation of karst formations. The predominant soil types are rendzinas, pararendzinas and lithosols (80 – 90% of the area). Forest covers about 75% of the area. The most represented tree species is spruce (50%), followed by beech (30%). The climate characteristics show that the preponderance of the area belongs to a moderately cold region with an average annual temperature of 5 – 6 °C. Climate conditions together with the meteorological situation represent significant factors for fire initiation. The highest fire danger periods are the spring season (March – May) and the summer season, with the months with the highest air temperature (July and August).

This region is well-known for an abundance of canyons, ravines, caves. It is also well known because of well-developed tourism. Every year more than 300 000 visitors come here.

For fire extinguishing purposes in the experimental area, two types of mobile fire apparatus are commonly used: the pumping appliance »CAS 32« on Tatra 815 chassis and special forest mobile apparatus called »UNIMOG« on Mercedes chassis.

3.2 Basic technical parameters of the mobile fire apparatus – *Osnovni tehnički parametri korištene vatrogasne opreme*

CAS 32 Tatra 148 has an excellent driveability and quantity of extinguishing substances (6000 l). It is most commonly used in fires in inaccessible terrain (forest fires, old grasslands, etc.). Pump power output is 3200 $lmin^{-1}$ at a pressure of 0.8 Mpa. It is used to transport members of the fire brigade (1 + 2) and material as well as pressure, foaming, assistance and rescue equipment.

Mercedes–Benz UNIMOG is primarily used in the transport of extinguishing agents (2500 litres of water and 150 litres of foam) as well as members of

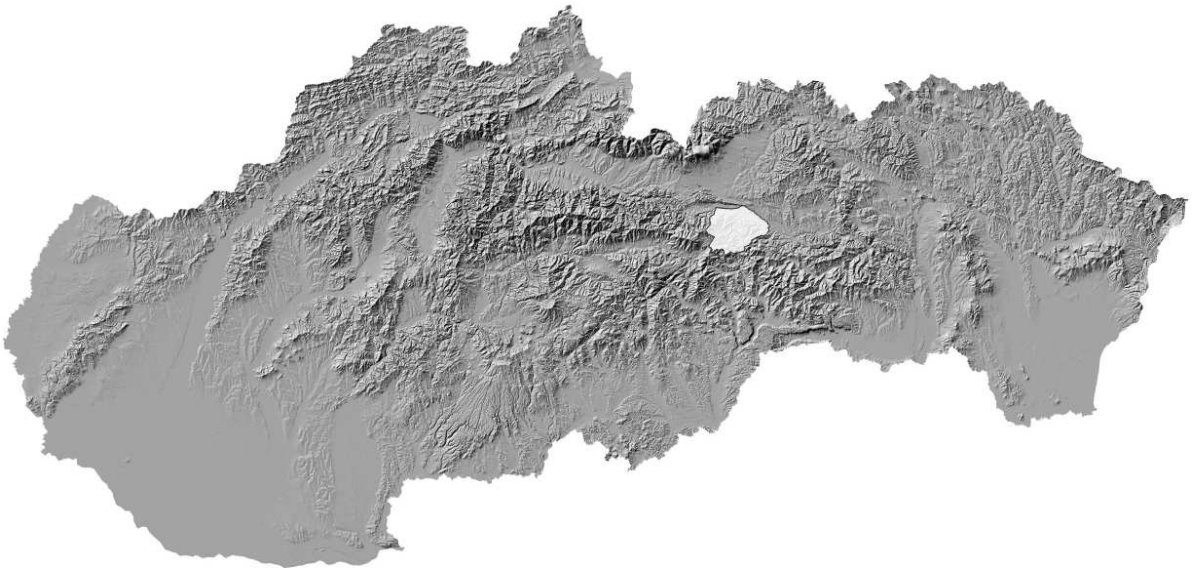

Fig. 1 Location of the experimental area
Slika 1. *Lokacija istraživanoga područja*

the fire brigade (1 + 2) and material together with the pressure, foaming, assistance and rescue equipment. This vehicle is suitable to be applied in a harsh and inaccessible terrain non-passable for another fire machine.

The technical equipment of both types of apparatus, designed to ground attack, is generally composed of 2 hoses with the diameter of 75 mm (»B« type) and the length of 20 m, 2 hoses with the diameter of 75 mm and the length of 5 m and 5 hoses with the diameter of 54 mm and the length of 20 m. Therefore the total length of the delivery fire hose piping could be up to 150 m (it is also the maximum range value).

3.3 Methodology of data collection and pre-processing in ArcGIS environment *Metodologija prikupljanja podataka i obrada u ArcGIS-u*

In the pre-processing phase, vector layer of the actual forest road network was obtained using the position measurement with the Trimble GeoXH GNSS device as well as information about its current condition obtained by terrain survey. Both sources were used to create the geodatabase that was later used in the opening-up analysis.

The position and attributes of forest road network were then corrected on the basis of the orthophotos in ArcGIS environment. The corrections were done manually by editing the position errors. Pieces of information on the road owner/user, road category, road and hauling road cover were entered into the database and changes related to specific sections of forest road network were proposed.

3.4 Methodology of forest opening-up analysis in IDRISI Taiga environment – *Analiza otvaranja šuma primjenom softverskoga paketa IDRISI Taiga*

The analysis of forest opening-up was performed in IDRISI Taiga environment using the functions of context operators, map algebra and distance analyses.

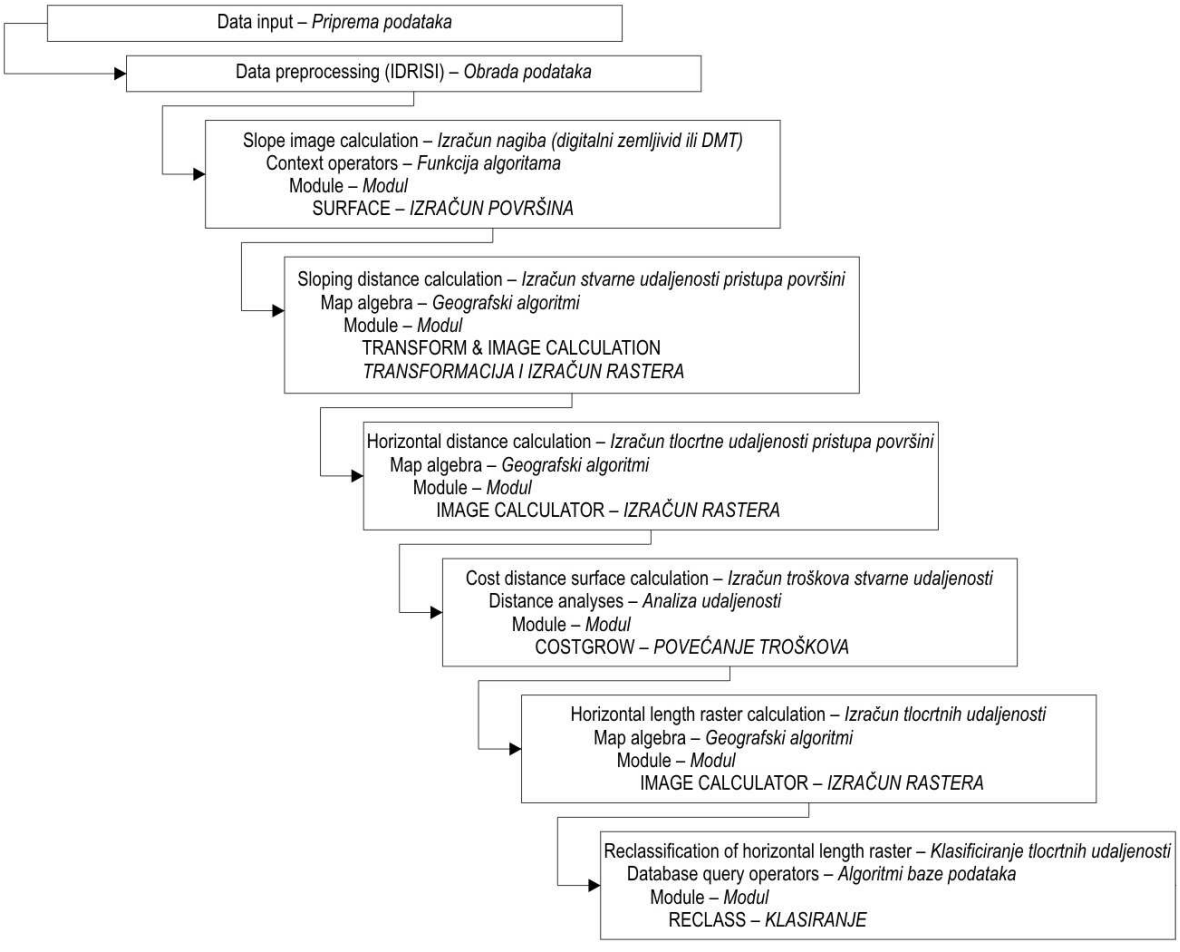

Fig. 2 Development diagram of the forest opening-up analysis
Slika 2. *Dijagram razvoja algoritma za analizu otvaranja šuma*

Due to the variability of conditions related to water relay and the direction of extinguishing (upslope or downslope), both directions of fire extinguishing were taken into consideration in the calculation. Based on the calculated maximum range values of the delivery of fire hose piping, the road spacing was calculated using the formula published in Böhmer and Dvorščák (2006). The calculated maximum range of delivery of fire hose piping also determines the zone where mobile fire apparatus can be applied for fire extinguishing.

The following data were used as the input layers to the opening-up analysis: digital relief model with the spatial resolution of 10 m, vector layer of forest unit borders and vector layer of road network representing the actual situation in spatial distribution of forest roads in the experimental area, obtained by road network mapping using the GNSS technology.

The resulting values of the analysis of forest opening-up and extraction for individual forest stands are shown in the development diagram (Fig. 2).

The first step was the data pre-processing. The digital relief model was used as a source for the slope raster calculation – module SURFACE. It was calculated in percentage. For the purposes of further analysis it was consecutively converted to the radians – module TRANSFORM. The vector representation of forest roads, distributed in the experimental area, was also converted to the raster representation (module RECLASS) – binary raster (1 – roads suitable to be used by the mobile fire apparatus, 0 – the other roads).

The next step was to calculate the cell sloping distances using map algebra tools (module Image Calculator). The input raster for this calculation was the raster of slope converted to the radians.

The calculation was performed based on the formula:

$$d_{slope} = 10/\cos a \quad (1)$$

Where:

d_{slope} sloping distance, m
10 resolution of the raster cell, m
α angle which contains the hypotenuse with an adjacent leg (or raster of slope in GIS), °

The output raster was used as a friction surface raster for the calculation of cost distances, using distance operators – module COSTGROW. In the calculation it had been considered with 2 types of analyses. The first was performed for the pumping appliance CAS 32 used for extinguishing fires from reinforced forest roads and the other for the UNIMOG which uses skidding roads except the reinforced ones.

The next step was to calculate the horizontal lengths of the fire hose piping and road spacing. Providing that the road spacing is considered as the distance of its orthographic projections into the horizontal level, it was necessary to recalculate the appropriate diagonal lengths of the fire hose line onto horizontal ones according to the following equation. For that purpose the Map algebra tools (module Image Calculator) were applied.

$$d_{horiz} = d_{slope} \times \cos\left(\text{arctg}\left(\frac{s}{100}\right)\right) \quad (2)$$

Where:

d_{horiz} horizontal distance [m] (cost distance raster)
d_{slope} sloping distance, m
s slope, °

The output raster was consecutively reduced (module RECLASS) to the zone of extinguishing using the mobile fire apparatus – the area opened up for ground fire extinguishing. The maximum range of extinguishing zone was determined to 150 m due to the maximum length of delivery fire hose piping.

Road spacing was calculated from the maximum horizontal length projections of the fire hose piping for upslope and downslope ways of water transport based on the formula:

$$R = 2 \times d_{horiz} \quad (3)$$

Where:

R road spacing, m

Furthermore, range values of the fire hose piping (sloping length of fire hose piping) were established for specific forest units, using module EXTRACT as the functions of Database Query operators.

At the end the area opening-up index [%] was calculated as the ratio between accessible area [ha]/non accessible area [ha] and the whole experimental area.

4. Results and discussion – *Rezultati s raspravom*

The amount of damage caused by forest fires depends not only on the fire extent and price of wood destroyed, but much more on the consequential ecological and environmental losses. Fire extinguishing mostly depends on the area opening-up and terrain accessibility. Effective fire prevention in forest management is also based on the early fire observation, prompt fire call and especially on the terrain accessibility. In fighting forest fires, in addition to early fire call and warning, the accessibility

of localities affected by the fire is a crucial factor, followed by the provision of fire-fighting machinery and application of fire protection means. In this regard, the forest fund in Slovakia is divided into three groups: inaccessible area, hardly accessible area and easily accessible area. To improve the accessibility of mobile fire appliances, it is necessary to ensure the systematic development of the forest road network with the parameters enabling the passage of mobile fire-fighting machinery. This should be ensured by legal entities and individuals owning and managing forests (Böhmer and Dvorščák 2006).

In case of fire, the level of forest opening-up also has significant influence on the attendance time of fire brigades. Generally, the minimum time for a fire flaring is 10 minutes.

In mountainous, indented areas, the forest roads are not suitable for the use of the mobile fire apparatus. This is mainly due to their quality and technical parameters and it is reflected on the elongation of fire-fighting attack and exactingness of shuttle water relay.

Consequently, the forest opening-up level can be considered as an important indicator and factor affecting the promptness of fire fighting activities and further fire spreading, because forest roads represent a natural barrier against fire.

Partial results were then introduced leading to the calculation of opening-up index that expresses the actual state of the experimental area accessibility for the selected mobile fire apparatus.

In the calculation of the maximum length of fire hose piping, the side slope was taken into consideration, as it strongly affects the losses in fire hose piping according to the recommendation published by Böhmer and Dvorščák (2006).

The maximum length (working range) of the delivery fire hose piping was determined as 150 m, also taking into consideration the length of its particular components (technical equipment of the apparatus). The total range of the fire extinguishing zone is, therefore, between 0 – 300 m, due to two directions of extinguishing. However, this only applies in localities where the slope is not steep and the terrain conditions allow the use of the fire hose piping up to 150 m length. This is possible only in lowlands. In the mountainous terrain, the sloping distance is shorter and losses in the fire hose piping increase. Then the road spacing value of 300 m represents only a theoretical range of fire extinguishing zone. However, for the geomorphological conditions of Slovakia, the optimum road spacing is generally about 400 – 600 m.

Table 1 shows the values of maximum sloping distance established for the specific forest units in the area. They were calculated as the distance from the nearest road to the specific forest units. Only the maximum values are presented for the forest units (calculated as the distance from the road to the furthest part of a forest unit).

Table 1 Maximum sloping distance values by forest units
Tablica 1. *Maksimalne stvarne udaljenosti pristupa površini po odjelima*

Forest unit No. *Broj odjela*	Maximum sloping distance, m *Maksimalne stvarne udaljenosti pristupa površini*, m	
	CAS	UNIMOG
197	959	985
198	1653	1653
199	1686	1691
200	1512	1512
201	1954	1969
202	2182	2231
203	2481	2536
204	2846	2875
205	2887	2887
206	2486	2511
207	2718	2718
208	2925	2925
209	2808	2808
341	107	157
345	105	129
476	105	104
486	98	134

The results of the calculated sloping distance for the UNIMOG are presented in Fig. 3.

It should be pointed out here that the methodology of sloping distance calculation processing in GIS environment could also be considered as the result of this paper.

Fig. 4 presents the view on opened up forest area for the UNIMOG fire mobile apparatus. This result was produced based on the classification of forest units into categories: 1 – forest unit with the average sloping distance less or equal to 150 m and 0 – forest unit with the average sloping distance of more than 150 m. Only the forest units classified as Class 1 are suitable for fire extinguishing with the mobile fire apparatus.

The results of opening-up analysis can be best expressed by the means of opening-up index, which shows the fact that in case of use of the CAS 32Tatra 148 the experimental area was only 26% opened-up. In case of use of the UNIMOG, the percentage rate only increased to 30.5%.

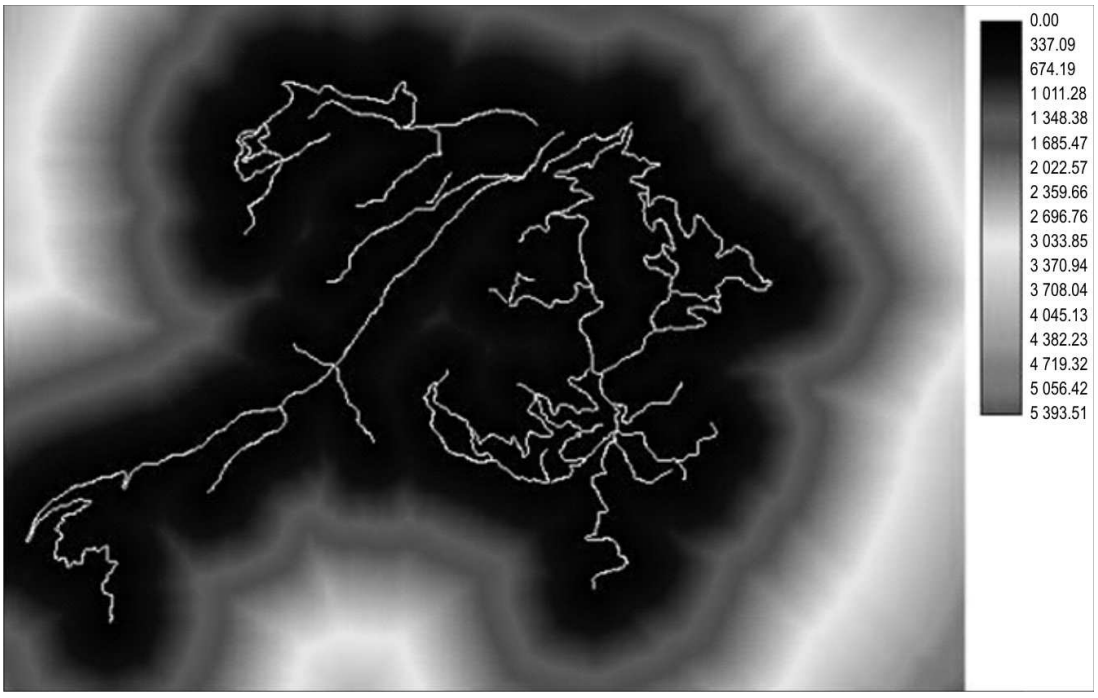

Fig. 3 Visualization of the results of the sloping distance calculation for UNIMOG, m
Slika 3. *Grafički prikaz rezultata izračunatih stvarnih udaljenosti pristupa površini za UNIMOG,* m

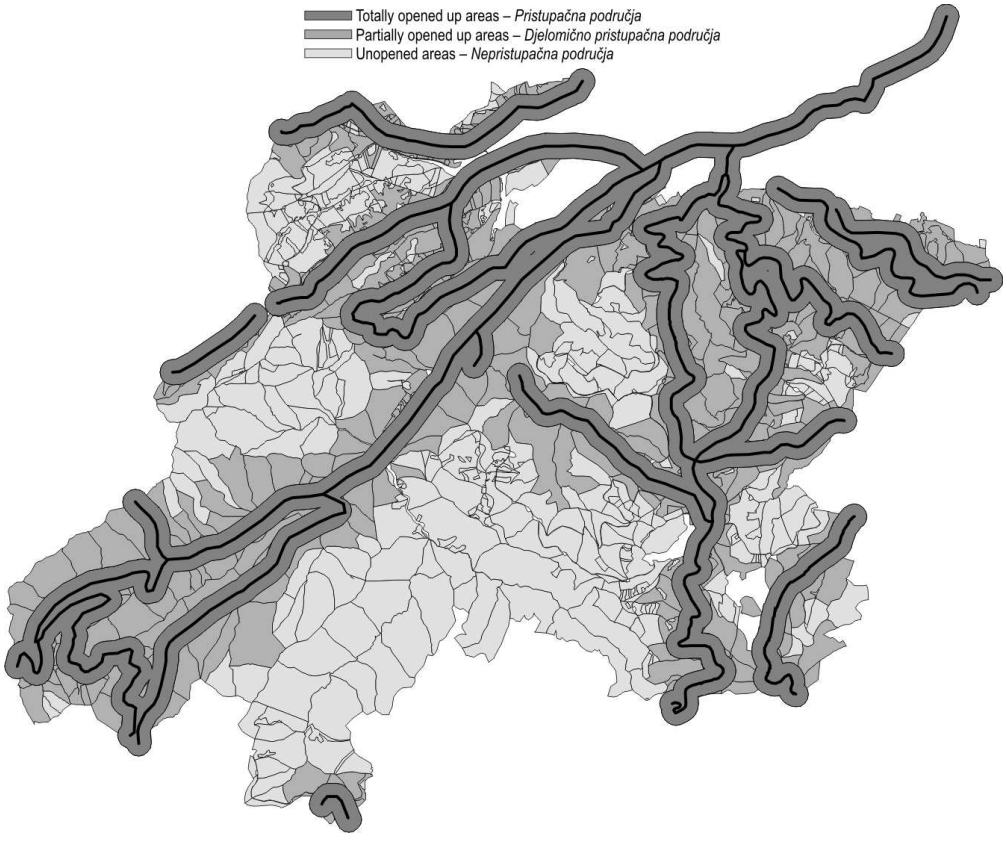

Fig. 4 Visualization of the results of forest opening-up analysis for UNIMOG
Slika 4. *Prikaz analize otvaranja šuma za UNIMOG*

Table 2 Survey of current opening-up in the experimental area
Tablica 2. *Postojeća pristupačnost terena u istraživanom području*

	CAS 32		UNIMOG	
	Extent – *Površina*, ha	Relative rate – *Relativni udio*, %	Extent – *Površina*, ha	Relative rate – *Relativni udio*, %
Total area – *Ukupno*	5528.23	100	5528.23	100
Accessible area – *Pristupačno područje*	1437.34	26	1686.11	30.05
Inaccessible area – *Nepristupačno područje*	4090.89	74	3842.12	69.5

The present level of forest opening-up of the Hrabusice forest management district is shown in Table 2.

The results presented here refer to the low level of the area opening-up. This is mainly caused by the geomorphohological conditions of the experimental area. This is one of the most significant reasons why this area is the region with the highest number of forest fires and with the largest extent of the area burnt. It also implies the need to apply the aerial attack in case of fire. However this technology is more expensive and does not allow keeping a continuous shuttle water relay at the fire site as the mobile fire apparatus does.

5. Conclusions – *Zaključci*

The Slovensky raj National Park is known for its steep terrain, and numerous karst forms as gulches, ravines and canyons. However, it is also well known because of the fire occurrence in the area. The forest fires that occurred in the past affected large areas and it took several days to extinguish them. Six people burnt during extinguishing a fire that occurred in this area in 2000. Therefore, mainly because of the high fire risk in this area, it is necessary to provide the opening-up of this area.

Due to operational tactics, it is generally known that in the Slovensky raj National Park the aerial attacks were mainly used for extinguishing fires. The results presented in this paper confirm the need for their use based on the low level of the area opening-up. For this reason the mobile fire apparatus could only be used for fire extinguishing in areas that are properly opened up by reinforced forest roads of good quality.

The advantage of the area opening-up analysis and evaluation method based on GIS is the fact that it allows processing of the analysis for any area in a relatively short time and at low costs, which allows efficient decision making on fire extinguishing tactics. The other advantage is GIS capability to also process and combine information about factors that could not be assessed in the terrain, e.g. because of smoke curtain.

Acknowledgment – *Zahvala*

This work was supported by the Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic under the contracts No. VEGA 1/0714/10 andVEGA 1/0313/09.

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Sažetak

Otvaranje šuma radi zaštite od požara

Podatak o količini i prostornom razmještaju šumske prometne infrastrukture važan je podatak ne samo za potrebe gospodarenja šumama već i za planiranje prevencije i zaštite šuma od požara. U slučaju šumskoga požara podatak o prostornom razmještaju šumske prometne infrastrukture ima velik utjecaj na vrijeme dolaska vatrogasne postrojbe na mjesto požara. Nedovoljno razvijena mreža šumskih cesta često se odražava na produljenje protupožarne obrane, a samim time i veće štete nastale požarom. Stoga je podatak o relativnoj otvorenosti šuma važan pokazatelj koji utječe na brzinu protupožarne zaštite i brzinu širenja požara jer je šumska prometna infrastruktura ujedno i prirodna barijera koja sprečava širenje požara.

*Šumski su požari u Slovačkoj najveća prijetnja šumama i šumskomu zemljištu te su jedan od glavnih čimbenika koji utječu na (ne)ispunjavanje ciljeva zadanih osnovom gospodarenja. Od 2000. do 2010. godine zabilježena su 4373 šumska požara u Slovačkoj koji su opustošili oko 5831 ha šuma i šumskoga zemljišta (*JRC Scientific and Technical Report 2010*).*

Pri planiranju mreže šumske prometne infrastrukture do sada je najčešće glavni cilj bio zadovoljiti zahtjeve gospodarenja šuma, a pri tome se najviše računa vodilo o smanjenju troškova pri sječi i izradi te privlačenju drvnih sortimenata. Iz toga su razloga analize otvaranja šumskih područja rađene uglavnom kao dio optimizacije pridobivanja drva, a zahtjevi vezani uz protupožarnu zaštitu donekle su uzimani u obzir ili uopće nisu.

U ovom je radu predstavljen jednostavan pristup određivanja relativne otvorenosti šuma iz aspekta pristupačnosti terena za dostupna vatrogasna vozila koristeći tehnologiju GIS i GNSS. Šumska prometna infrastruktura snimljena je pomoću tehnologije GSNN te su tako dobiveni podaci o kvaliteti i učinkovitosti šumskih cesta. U računalnom programu ArcGIS 9.3 snimljeni podaci su obrađeni i kao rezultat napravljena je baza podataka koja je poslije korištena za analizu otvaranja istraživanoga područja u softverskom paketu IDRISIS Taiga uz primjenu funkcije algoritama, digitalne zemljovide i analize udaljenosti. Zbog varijabilnosti terenskih uvjeta i smjera gašenja požara u obzir i izračun uzeta su oba smjera gašenja požara (uz nagib i niz nagib).

Analiza otvaranja izvedena je za gospodarsku jedinicu »Hrabusice« koja ima najveći indeks opasnosti od požara u Slovačkoj te je smještena u krškom području Nacionalnoga parka »Slovensky raj«. Indeks opasnosti od požara za navedeno područje vrlo je velik zbog klimatskih uvjeta, sastava šumskih vrsta (udio smreke 50 %, bukve 30 % i ostale vrste 20 %), nepristupačnosti terena (vrlo niske relativne otvorenosti), velikoga broja turista (godišnje više od

300 000 posjetitelja). Najveća opasnost od šumskih požara javlja se u proljeće (ožujak – svibanj) te u ljetnim mjesecima za vrijeme najviših temperaturnih vrijednosti (srpanj – kolovoz). Navedena je analiza napravljena za vatrogasna vozila Tarta 148 i Mercedesov Unimog opremljenih vatrogasnom opremom.

Cilj je rada bio analizirati relativnu otvorenost istraživanoga područja te definirati nepristupačna područja za vatrogasna vozila Tarta 148 i Mercedesov Unimog opremljenih vatrogasnom opremom. Pristupačnost područja izračunata je na temelju maksimalnoga dometa protupožarnoga crijeva, udaljenosti između šumskih cesta i indeksa otvaranja šuma.

Efektivna zaštita od požara u gospodarenju šumama temeljena je na ranom otkrivanju šumskih požara, brzom dojavljivanju vatrogasnim postrojbama, pristupačnosti terena i mogućnosti korištenja različitih tehnika gašenja požara. Što se tiče pristupačnosti terena u Slovačkoj, on je podijeljen u tri grupe: nepristupačan, teško pristupačan i lako pristupačan teren. Da bi se poboljšala pristupačnost terena kada se radi o šumskim požarima, prijeko je potrebno osigurati planirani razvoj mreže šumske prometne infrastrukture koja će moći podnijeti prometno opterećenje i omogućiti nesmetan i siguran prolazak protupožarnih kamiona.

Najviša je duljina protupožarnoga crijeva 150 m, uzimajući u obzir i duljinu pojedinih njegovih dijelova (tehničke opreme). Dakle, ukupni je raspon zone za gašenje požara između 0 i 300 m, s obzirom na to da se gasiti može u oba smjera. Takav način izračuna vrijedi samo za nizine (neznatan poprečni nagib terena) gdje terenski uvjeti omogućuju da raspon zone za gašenje požara iznosi 300 m.

Na brdovitom i planinskom terenu zbog poprečnih nagiba terena i gubitaka u cjevovodu najviši raspon zone za gašenje požara od 300 m samo je teorijska vrijednost. Zbog toga i razmaci između cesta od 300 m, na takvim područjima, nisu dostatni za potpunu zaštitu. U Slovačkoj optimalni razmak između šumske prometne infrastrukture na brdskim i planinskim terenima iznosi između 400 i 600 m.

Ovim su radom dobivene vrijedne spoznaje kao potpora pri donošenju odluka za zaštitu šuma, pri planiranju novih šumskih prometnica te za vatrogasne postrojbe pri planiranju adekvatne i učinkovite zaštite šuma od požara.

Ključne riječi: gašenje požara, šumski požar, GIS, GNSS, otvaranje šuma

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Received (*Primljeno*): December 13, 2010
Accepted (*Prihvaćeno*): March 28, 2011