Predicting Wood Skidding Direction on Steep Terrain by DEM and Forest Road Network Extension

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Abstract – ***Nacrtak***

The study presents the procedure and functioning of the model for large-scale determination of wood skidding direction on steep slopes. The determination of wood skidding direction significantly depends on the position of the forest stand and the adjacent forest road, the characteristics of skid trail /ground/ and forest operation technology with special attention to the applied skidding means. The model evaluation of wood skidding direction is determined on the basis of forest road layout on the slope (slope, valley and ridge). The data of digital terrain model and digitalized forest road network were used as source data. The software can be modified according to specific technology needs by increasing the range and/or the level of suitability of individual wood skidding directions between two roads. The classification is presented for case study Forest Management Unit comprising 3000 ha. The application of the model discussed, as wll as its limitation and adaptation to changing technological condition and its development in the future.

Keywords: forest operation, wood skidding direction, model, forest road network, steep terrain

1. Introduction – *Uvod*

Ecology and technology are interconnected forest management issues. It is a matter of dispute whether economy belongs to the former or the latter and whether social and political issues should be discussed in connection with the basic two issues or separately. In this study, the terrain and stand conditions are origins of assessments and decision making, where forest owners and foresters seek help from modern techniques. Terrain classification is a procedure where the area is divided into homogenous units based on criteria set in advance. Different procedures and factors are applied. Forestry has accepted terrain classification as an important and logical tool for forest management, operational and silviculture planning (Löffler 1984). In this respect alpine region is a very demanding region where tractor skidding prevails, but with ever increasing alternative of cable skidding or forwarding. Operational planning provides specific guidelines for logging options in specific conditions on the basis of technological models. An essential part is the thematic map, i.e. a map showing the location of terrain characteristics which are important for forest operation (Krč 1999) and economics of managing private woodlots. The criteria for determination of technological models are related to technical, environmental, economical and social criteria, and limitations which enable and ensure the co-natural and sustainable forest resource management.

In the procedure of determination of technological models, as a base for terrain classification, the following data are used: data of topography, soil type, ground water content, stream lines layout, forest roads and skid roads layout, etc.

The selection of the technological model is highly affected by solving skidding problems (Košir 1982, Löffler 1984, Saarilahti 2002). The use of mechanized cutting has changed the relative impact of terrain characteristics on terrain classification (Berg 1992). Both parts of forest operation (cutting and skidding) are influenced by the skidding direction. There are three classes of skidding direction, depending on the terrain gradient (uphill, downhill and even). On steep slopes, the network of forest roads greatly influences the skidding direction as well as the execution of cutting (Heralt 2002, Saarilahti 2002). Skidding forms such as tractor skidding, cable skidding or forwarding add confusion to procedures of skidding direction design, where the whole design of the forest openness with skid roads and cable corridors is closely connected with environmental considerations – danger of erosion processes (Hay 1998, Pentek et al. 2004). While the skidding forms on wheels are technically no different when skidding uphill or downhill, it is a different matter when using cable cranes. Cable cranes can be gravity or all terrain; they can be classic or mobile with towers. The methods for assessing skidding direction in combination with the skidding means should, therefore, be simplified (Rowan 1996). The intention of this article was to use the existing databases but original algorithms so as to improve and to economise the determination of skidding direction as a basis for operational planning. The accuracy of such a model is of secondary importance at present and depends on the accuracy of input variables. The stress is therefore on the procedure, which should be simple and cheap.

2. Existing research methods – *Postojeće metode istraživanja*

The assessment of the specific model suitability depends mostly on skidding variants from stump to the roadside. Information technology provides many possibilities in the assessment of specific technological solutions in forest operation. There are many studies related to the optimization of the layout of new forest roads (Chung 2001, Aruga et al. 2004), and the feasibility assessment and impacts of changing the forest road density (Košir and Krč 2000).

The most frequent database used for designing the models is Digital Terrain Model (DTM), which serves as a powerful means for acquiring solutions of forest openness on steep terrains. Similar issues are also addressed by research projects dealing with forest road network density, forest roads layout in relation to the environment (Newnham 1995, Tucek 1995, Yoshimura 1997) and the choice of skidding mainly means comparison between the tractor and cable skidding (Tucek 1999, Stuckelberger 2006).

Literature offers several solutions of a similar problem of how to identify watershed areas. Numerous authors have presented and described algorithms and software tools for extracting topographic structures and water catchment areas from DTM data (Mark 1983, Jenson and Dominguem 1988). The problem of identifying the water catchment is similar, but not the same as defining the wood skidding direction. The main difference between the two procedures is in the flow direction – generally, water flows only downhill while wood can be yarded in basically two (three) directions (uphill, downhill and even).

Evidently so far forest practice has placed little confidence in the results acquired by using computer simulation or taken from forest inventory databases. The data of functional classification based on past experiences have mostly been used (Rowan 1996). The consequence of this distrust is low efficiency and low rate of application of forest inventory databases, a practice which has to be changed.

3. Objectives of the study – *Cilj istraživanja*

The main goal of this research has been defining the model for terrain classification on the basis of skidding direction. In the process of classification the two main data layers (Digital Terrain Model and Digital data of forest road network) together with GIS software modules (Eastman 1997) have been used. The classification of forests into expected categories of wood skidding direction would serve as additional information source for future building, verification, validation and assessment of the models dealing with logging feasibility evaluation.

The wood skidding direction influences the efficiency and costs of logging operation. The accuracy of skidding performance assessment for certain areas can be improved, and the cost calculation can be made more reliable if the share and the location of specific wood skidding direction are known. With wood flow to a specific forest road the need for road maintenance activities in the region can be better estimated (Krč 2006). There are additional benefits connected with the assessment of forest accessibility as well as with the selection of technological models in logging operations. Newly built forest roads can significantly influence the proportion between uphill and downhill skidding area in typical Alpine conditions. The proposed algorithm can therefore also be useful as an evaluation tool, in case several choices of newly planned forest road are possible.

Secondly, there is also the question of proportion between uphill and downhill area between two roads on the slope. So far it has been assumed that ? of the space between roads should account for downhill skidding and the rest for uphill skidding. This can be true on average for moderate inclination and for tractor skidding, while in case of cable skidding just the opposite situation can be expected. The challenge of developing this procedure was also to distinguish between these two skidding options. In Alpine region, uphill skidding with cable cranes (gravity or all-terrain) is still favoured against downhill

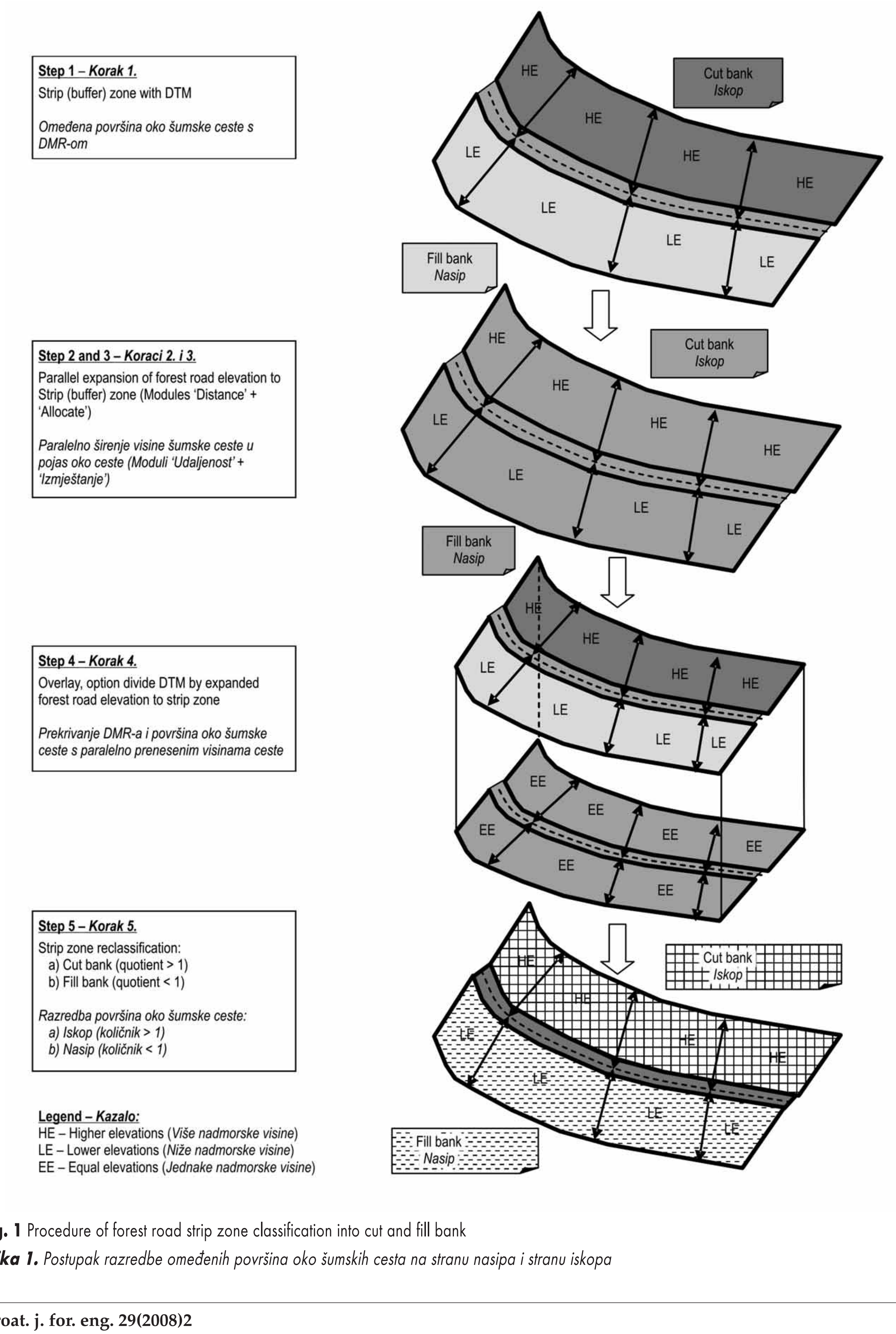

Fig. 1 Procedure of forest road strip zone classification into cut and fill bank

Slika 1. *Postupak razredbe omeđenih površina oko šumskih cesta na stranu nasipa i stranu iskopa* direction, which means that one slope road on cable terrains covers more area downwards and less upwards. This also means that in case of tractor skidding or forwarding the situation is probably just the opposite. The main objective of this article was to find a simple solution to the question what to dot, where and how.

4. Method – *Metoda rada*

The assumptions of wood skidding direction from the junction of the secondary forest communication (tractor skidding or cable skidding corridor) with forest road have been used. The following assumptions have been used for the determination of wood skidding direction:

⇒ The connections of skid trails and cable corridors on forest roadcut bank provide for downhill wood skidding direction in the catchments area;

⇒ The connections of skid trails and cable corridors on forest roadfill bank provide for uphill skidding direction.

The even wood skidding category was not included into the model for mathematical and practical reasons because even skidding on steep terrain is hardly probable.

The large-scale (depending on data and software availability) classification of wood skidding direction can be made in the following six steps (Fig. 1):

⇒ Determination of buffer zone around forest roads which can be of different width depending on specific skidding means. The determination procedure of buffer zone around forest road was conducted using GIS software (Eastman 1997). Buffer zones were created by running DISTANCE module and then by running RECLASS module on the output distance image.

⇒ Working out raster files with DTM of forest roads and DTM of adjacent buffer zones.

⇒ The assignment of forest road DTM value parallel to buffer zone. The result is a broad buffer strip with altitude equal to the adjacent forest road altitude.

⇒ Overlay the actual altitude (DTM) forest road buffer zone raster files with the altitudes parallel to road body altitude in buffer zone (overlay file from step 3 with file from step 2).

⇒ Reclassification of the result of overlay operation (step 4). The quotient of cut bank is greater than one while the fill bank of forest road has values (quotient) lower than one.

⇒ The roadfill and roadcut banks are used as destination areas in the process of allocation of the remaining forest area (i.e. forest stand, which is not included in forest road buffer zones). The allocation (module ALLOCATE, Eastman 1997) of the remaining area to the destination (fill and cut banks) classifies uphill skidding to roadfill bank and downhill skidding to roadcut bank.

5. Results of the case study – *Rezultati izrađene studije*

The case study object is a part of the Jelendol Forest Management Unit (FMU). The unit area covers 3,653 ha and is located on prevailingly steep terrain in the vicinity of Slovenian border with Austria. The difference of accessible forest stands had a strong influence on cutting and skidding costs and consequently on expected forest rent value. Furthermore, the skidding models frequently change due to terrain conditions on short distances. On the prevailingly steep terrain, there is a large area suitable for cable crane skidding. The altitude of FMU ranges from 750 to 2,065 m above sea level. The forest roads density is 23 m/ha; average stand growing stock is 311 m^3/ha with prevailingly coniferous trees with 80% of growing stock (Skuber 1990).

The northern part of FMU is determined as protected area taken out of wood production. All forest roads in FMU have the same exit point from the area which is located in the south west part and is at the same time the point with the lowest elevation of FMU (Fig. 2).

The three-dimensional presentation of FMU Jelendol study area has been used for verifying the skidding direction classification. The position of the individual forest road section has been evaluated with respect to the position on the slope. Three dif-

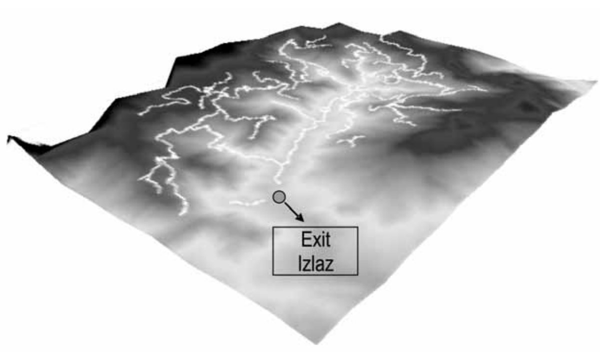

Fig. 2 Digital Terrain Model of FMU Jelendol with forest roads

Slika 2. *DMR gospodarske jedinice Jelendol s ucrtanom mrežom šumskih cesta*

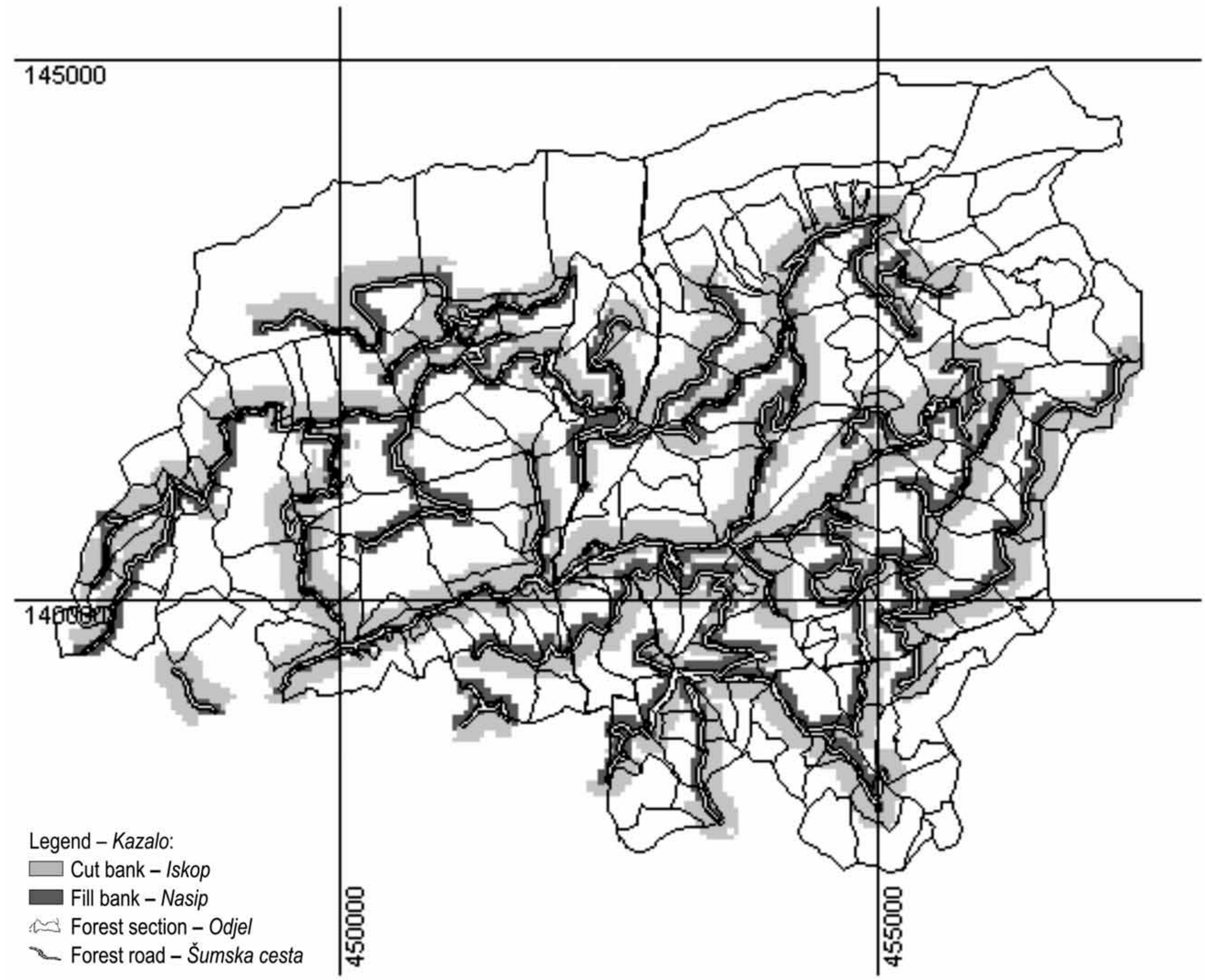

Fig. 3 Extraction of roadcut and roadfill banks used as target features for classification of wood skidding direction

Slika 3. *Razredba smjera privlačenja drva temeljem položaja pomoćnih stovarišta uz šumsku cestu (na strani nasipa ili na strani iskopa)*

ferent positions of forest road section on the slope have been determined:

⇒ Valley (forest road section only has a roadcut bank),

⇒ Slope located (forest road section has – both roadcut and roadfill banks) and

⇒ Ridge located (forest road section has roadfill banks on both sides, Fig. 3).

In the procedure of allocating stands to roadcut and roadfill banks, specific friction influencing the skidding direction has been applied. Frictions by definition (Eastman 1997) means inhibit movement through space. The following important influential friction factors, affecting wood skidding operation, have been considered: existence of skid trails, ridge points (lines), terrain slope and other topographical, traffic and ground features with significant influence on wood skidding. Same factors act in positive (skid rails), other in negative friction (ridge points) regarding wood skidding.

Determination of specific topographic elements using DTM has already been worked out by many studies and algorithms (Jenson et al. 1988, Krč 2006). It is possible to modify (i.e. increase or decrease) the share of specific skidding direction on the slope terrain between two roads. The modification is done by scaling the buffer zone of roadcut or roadfill banks. A broader bank zone promotes corresponding skidding direction, while a narrow bank zone influences in the opposite direction.

The result of classification of FMU Jelendol into predicted classes of skidding direction is shown in Fig. 4. The evaluation of classification has been made by analyzing the share of raster cells in the file repre-

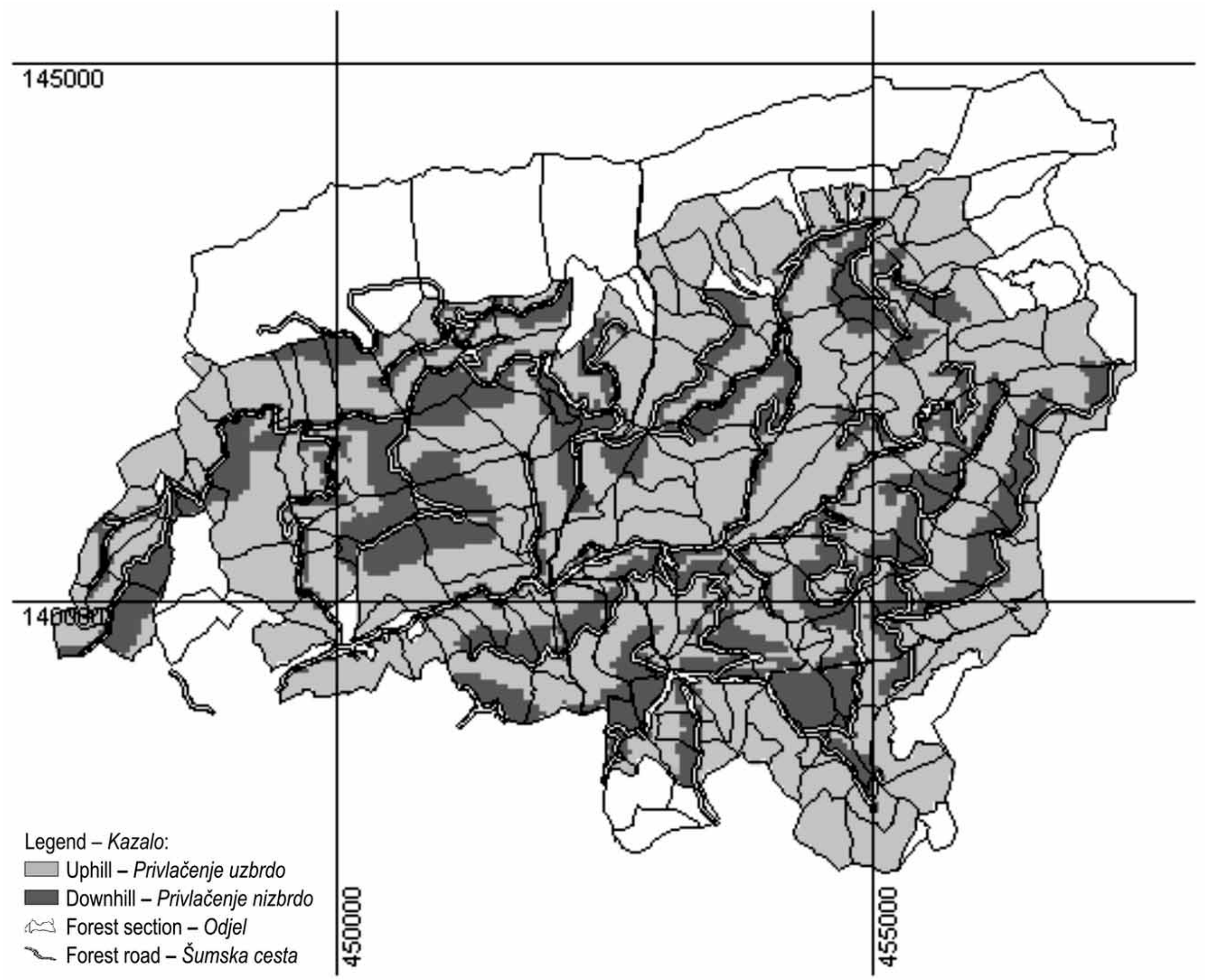

Fig. 4 Map of wood skidding direction acquired from DTM for FMU Jelendol

Slika 4. *Prikaz smjera privlačenja drva preuzet s DMR-a za GJ Jelendol*

senting the prediction of wood skidding direction. Knowing ground cell equivalent of raster cell permits deriving data per hectare. In the case study, the 0.25 ha (50 x 50 m) resolution of raster point (cell) has been used. For the case study area of FMU Jelendol the share of 65% (2,235 ha) is predicted as suitable for downhill skidding, and the remaining 35% (1,220 ha) for uphill skidding.

Table 1 Cross tabulation indicating terrain classification into wood skidding direction classes

Tablica 1. *Zajednička distribucija kao pokazatelj razredbe terena u različite kategorije smjera privlačenja drva*

Inventory database *Inventurni podatci*	Model *Model*	Ground cell equivalent (raster cells) *Ekvivalent rasterskih polja terena*	Share, % *Udjel, %*	Comment *Napomena*
Down – *Niz nagib*	Down – *Niz nagib*	**5,882**	43	Compliance – *Sukladno*
Up – *Uz nagib*	Down – *Niz nagib*	**2,033**	15	Difference – *Različito*
Down – *Niz nagib*	Up – *Uz nagib*	**2,775**	20	Difference – *Različito*
Up – *Uz nagib*	Up – *Uz nagib*	**2,914**	21	Compliance – *Sukladno*
Sum – *Ukupno*		13,604	100	

6. Model validation – *Pouzdanost modela*

Validity of the model has been tested by comparison of model results with terrain classification in forest inventory data maintained by Public Forest Service. In forest inventory database the predominant skidding direction is defined as downhill, uphill and even for each basic unit – forest compartment. Classification of skidding directions provided by Slovenian Public Forest Service (field inventoried) for Forest Management Unit Jelendol is shown in Fig. 5.

It has been proven that the accuracy of determination of skidding direction in forest inventory database is quite poor, speaking about predominant (average) skidding direction in the forest compartment. Table 1 shows the results of cross tabulation – error matrix. Error Matrix showed a 35% of different classified area based on which »ground truth« cells have been assigned differently as in the case of terrain inventory.

The analysis of different classified areas showed that the majority of misclassified areas in inventory data base are caused by treating the forest compartment as an undivided unit with one average assigned skidding direction. There are many forest compartments positions which are placed between two forest roads on slopes. The unique classifications of wood skidding direction are a correct decision only in cases where there is no forest road on borders or if one of the »border« forest roads is unproductive for wood skidding.

Determination of prevailing wood skidding direction for forest compartment has also the effect of compensation misclassified areas in both classes (Up, Down). The phenomena can be stated in our

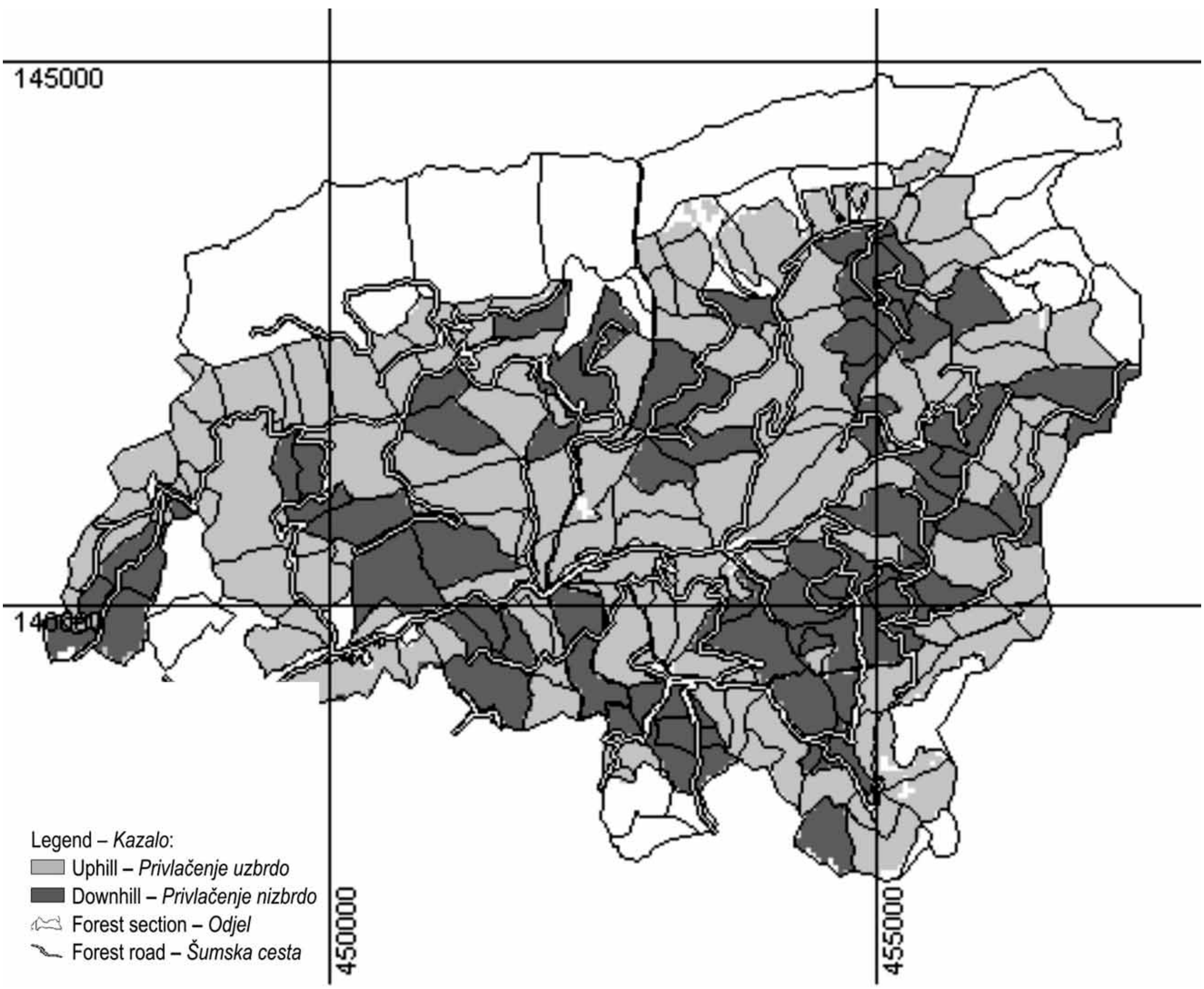

Fig. 5 Classification of skidding direction provided by Slovenian Public Forest Service for Forest Management Unit Jelendol

Slika 5. *Razredbu smjera privlačenja drva za gospodarsku jedinicu Jelendol provela je slovenska Šumarska agencija*

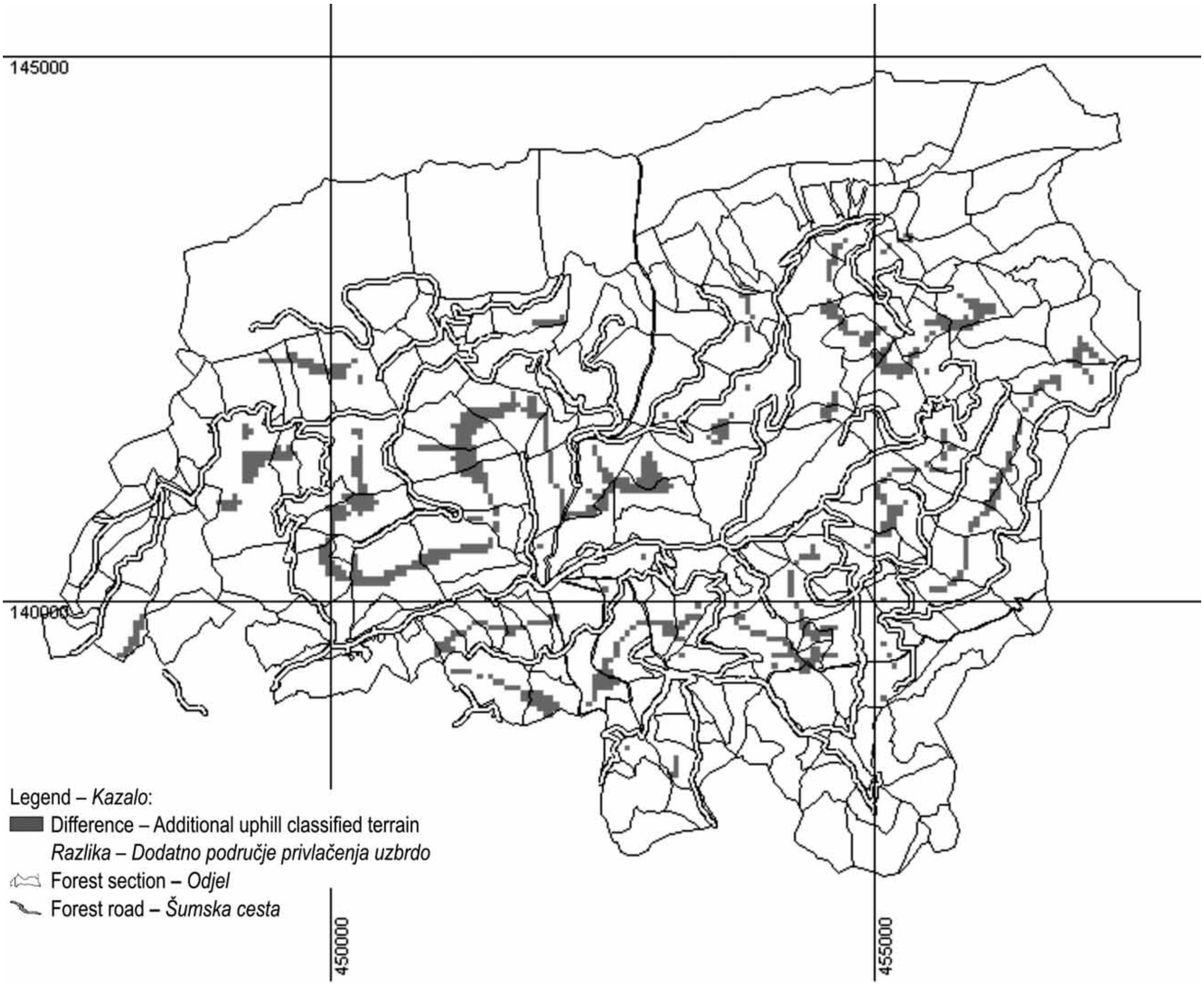

Fig. 6 Location of areas for additional uphill skidding after model modification (advantage is given to uphill skidding on steep terrain)
Slika 6. *Prikaz dodatnih područja za privlačenje drva uzbrdo (nakon prilagodbe modela)*

case study, too. The difference between total Up and Down classified areas is only –9% (Down, GCE: (7915-8657)/8657) and +15% (Up, GCE: (5689-4947)/4947), which is much less than individually misclassified cells (35.34%).

We have also tested a modified model where the uphill skidding on the steepest terrain was given advantage. The reason was that in this way we estimated possible changes in the classification with a broader use of full tree method and cable cranes with a processor head. The width of buffer zones of cut bank was cut by 2/3, which has resulted in a relative approach of the steep terrain to fill banks in order to promote uphill skidding direction.

The result of such terrain allocation is an increase in the share of uphill wood skidding class by 18%. At the same time there is a 10% drop in areas classified as suitable for downhill wood skidding direction. The differences between the basic and changed model are shown in Fig. 6. All additional areas can be further analysed for wood stock, allowable cut, tree species, etc.

7. Discussion and conclusions – *Rasprava i zaključci*

The presented solution for the prediction of wood skidding direction is simple and not demanding in terms of specific software solution and required data availability. The solution can be derived by using only the procedure of combining standard modules in GIS software packages (Eastman 1997). In this respect we can expect that the procedure will be used for analytical and operational purposes in developing optimal forest roads and second forest opening with skid roads and cable corridors in state forest and in case of large scale private property.

The procedure will be further developed and adapted to new possibilities in forest operation technology. The changing of influential factors is evident through the introduction of:

⇒ a) mechanized cutting in combination with cable skidding (Visser and Stampfer 1998) and

⇒ b) combination of full tree method, cable skidding and processing on the forest road (Stampfer 2001).

On mountainous terrains the share of uphill skidding will probably increase. The reason is very efficient cable skidding in combination with mechanized processing. This method is less expensive than downhill skidding – especially for slopes with gradients between 40 and 65% (Streif 2001) – as it needs fewer roads and skid trails construction.

The development of different cable systems is permanent. Cable systems are suitable, more than before, for downhill skidding, and the setting up and down times are shorter. The new cable systems are environmentally friendly in comparison to other skidding means – especially ground-based skidding (Owende et al. 2003). Cable crane layout (parallel, fan-shaped) and skidding distances (= cable corridor lengths) influence the cost of forest operation. On the basis of costs, optimal cable length can be calculated (Košir 2003). The cost calculation is not included in the present model development, while the indirect influence of costs using friction system allows various modifications. The described model is also not intended to optimise the situation in the described case study, but merely to make such an optimisation possible with further analysis. The problem of model accuracy is connected with the possibility of alternative skidding means on the same area, but the share of the so called »Gray« area in Alpine conditions has not been sufficiently analysed. There is, therefore, the problem of »what is true« or better »what is optimal«. The proposed problem solution may be a step away from the relative accuracy of field determination of skidding direction, but it also means a step toward a simpler and faster problem solution.

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Sažetak

Određivanje smjera privlačenja drva prema postojećoj mreži šumskih cesta na strmim terenima

U radu je predstavljen model određivanja smjera privlačenja drva na strmim terenima. Model se koristi za razredbu većih šumskih površina, a prikazana je njegova primjenjivost u gospodarskoj jedinici Jelendol u Sloveniji. Pri gospodarenju šumskim resursima ekološka i tehnološka sastavnica snažno su povezane. Razredbom su terena obuhvaćene određene šumske površine koje su razvrstane u homogene jedinice temeljem prethodno vrlo precizno definiranih kriterija. Pri tome se primjenjuju različite metode te razlikuju mnogi utjecajni čimbenici. Šumarstvo je, prema Löffleru (1984), prihvatilo razredbu terena kao važan logički alat za gospodarenje šumskim resursima, planiranje radova u šumarstvu te provedbu radova u uzgajanju šuma i u pridobivanju drva.

Alpsko je područje sa stajališta operativne razredbe terena vrlo zanimljivo. Naime, pri redovitom pridobivanju drva prevladavaju zglobni traktori (vuča drva), međutim vrlo su česte šumske žičare kojima se iznosi drvo i različiti oblici strojeva za izvoženje drva – forvarderi. Operativno planiranje nudi smjernice za radove u pridobivanju drva u specifičnim uvjetima uz preporuku najpovoljnijega načina rada. Važna je sastavnica operativnoga planiranja, kako zbog samoga obavljanja šumskih radova tako i zbog ekonomski isplativijega gospodarenja, tematska karta koja prikazuje obilježja terena (Krč 1999). Definiranje se najpogodnijega načina najčešće temelji na tehničko-tehnološkim, okolišno-ekološkim i sociološkim kriterijima uz ograničenja koja nameću smjernice za potrajnim i održivim gospodarenjem šumskim ekosustavima.

Pri izradi se modela primjenjivih postupaka za pridobivanje drva, uz odabir najpovoljnijega s obzirom na razredbu terena, koriste: topografski podaci, podaci o tipu tla, nosivost tla i sadržaj vode u tlu, mreža vodotokâ, mreža primarnih šumskih prometnica i mreža sekundarnih šumskih prometnica.

Na sječu i izradu te na privlačenje drva, posebno na nagnutom terenu, utječe odabir smjera privlačenja drva do pomoćnoga stovarišta (do mreže šumskih cesta). Smjer se privlačenja drva dijeli u tri kategorije: privlačenje uzbrdo, privlačenje nizbrdo i privlačenje po ravnom terenu. Na strmom terenu prostorni položaj mreže šumskih cesta ima snažan utjecaj na smjer privlačenja drva i na provedbu sječe stabala (usmjereno rušenje). Mogući su oblici privlačenja drva na nagnutim terenima: vuča drva po tlu zglobnim traktorima, iznošenje drva šumskim žičarama i izvoženje drva forvarderima, uz njih povezani sustavi sekundarnih šumskih prometnica (traktorski putovi i žične linije) koji su povezani s opasnošću od erozije. Sve to čini dizajniranje modela zahtjevnim.

U dosadašnjim se sličnim istraživanjima, pri optimizaciji mreže šumskih cesta na strmim terenima, najčešće koristio digitalni model terena (DMR). Mnoge su se studije bavile najboljim mogućim rješenjem pri izboru položaja novih šumskih cesta (Chung 2001, Aruga i dr. 2004), ali i mogućnošću izvedivosti pojedinih inačica te njihovim utjecajem na gustoću šumskih cesta (Košir i Krč 2000). Dosta se istraživao odnos prostornoga položaja šumskih cesta, njihove gustoće i okoliša (Newnham 1995, Tucek 1995, Yoshimura 1997) te izbor najpogodnijega sredstva za privlačenje drva uspoređujući najčešće zglobni traktor i šumsku žičaru (Tucek 1999, Stuckelberg 2006).

Razvidno je da danas šumarska operativa ne pridaje dovoljno važnosti rezultatima dobivenim različitim računalnim simulacijama temeljenim na provjerenim računalnim modelima već, radije i češće, koristi rezultate funkcionalnih razredbi temeljenih na dosadašnjim iskustvima.

Osnovni je cilj ovoga istraživanja kreiranje modela za razredbu terena na osnovi smjera privlačenja drva. Pri tome su korištena dva glavna sloja podataka: digitalni model terena i digitalni podaci o mreži šumskih cesta te uz njih GIS-ov programski modul (Eastman 1993). Smjer privlačenja drva utječe na učinkovitost i trošak pridobivanja drva. Model će omogućiti realniji izračun troškova privlačenja drva ako se zna udio i prostorni položaj pojedine kategorije smjera privlačenja. Poznavanje toka drva do pojedine šumske ceste pruža mogućnost boljega planiranja troškova njezina održavanja (Krč 2006). Nadalje, model pruža dodatne koristi za lakšu i uspješniju provedbu postupka daljnjega primarnoga i sekundarnoga otvaranja šumskoga područja, ali i postupka izbora najboljega načina pridobivanja drva.

Postavlja se pitanje gdje se nalazi granica privlačenja drva do pomoćnih stovarišta uz rub dviju šumskih cesta izgrađenih na padini kontinuiranoga nagiba i ravnomjerno raspoređena drva. Do sada se pretpostavljalo kako drvo sa šumske površine između dviju šumskih cesta treba s 2/3 širine površine privlačiti na donju cestu (privlačenje nizbrdo), a s 1/3 širine površine privlačiti na gornju cestu (privlačenje uzbrdo). Navedena tvrdnja može vrijediti za vuču drva zglobnim traktorom, ali se pri iznošenju drva žičarama može očekivati obrnuta situacija. Pronaći jednostavno rješenje i odgovor na pitanje što i kako raditi na kojem području osnovna je ideja ovoga rada.

Za područje istraživanja odabrana je gospodarska jedinica Jelendol površine 3653 ha. Smještena je na nagnutom terenu u Sloveniji, u alpskom području, blizu granice s Austrijom. Nadmorska joj je visina između 750 i 2065 m. Gustoća šumskih cesta iznosi 23 m/ha, prosječna drvna zaliha je 311 m^3/ha uz omjer smjese četinjača i listača 80 : 20 (Skuber 1990). Sjeverni je dio gospodarske jedinice Jelendol izlučen kao zaštićeno područje bez propisanoga etata. Mreža je šumskih prometnica na mrežu javnih prometnica povezana samo na jednom mjestu (jugozapadni dio gospodarske jedinice), a to je ujedno i točka najniže nadmorske visine u GJ Jelendol.

Radi određivanja smjera privlačenja drva spoj sekundarnih šumskih prometnica (traktorskih putova i žičnih linija) s rubom šumskih cesta (pomoćnim stovarištem) razdijeljen je u dvije kategorije:

⇒ *sekundarna se šumska prometnica sa šumskom cestom spaja na strani iskopa zasjeka – privlačenje se drva obavlja nizbrdo*

⇒ *sekundarna se šumska prometnica sa šumskom cestom spaja na strani nasipa zasjeka – privlačenje se drva obavlja uzbrdo.*

Privlačenje po ravnom nije uključeno u model jer je malo vjerojatno da na nagnutom terenu postoji ova kategorija privlačenja drva. Na slici 1 prikazan je postupak razredbe omeđenih površina oko šumskih cesta na iskopanu i nasipanu stranu zasjeka kroz šest koraka.

3 D prikaz GJ Jelendol korišten je u postupku provjere kategorije smjera privlačenja drva. Procijenjen je položaj svake dionice (segmenta) šumske ceste u odnosu na padinu te su formirane tri kategorije:

⇒ *dolinske dionice (dionica šumske ceste ima samo iskope; riječ je o usjeku)*

⇒ *padinske dionice (dionica šumske ceste ima i iskopanu i nasipanu stranu zasjeka; riječ je o zasjeku)*

⇒ *grebenske dionice (dionica šumske ceste ima samo nasipe; riječ je o nasipu).*

Rezultati su navedene kategorizacije prikazani na slici 3.

Prepoznavanje specifičnih topografskih elemenata uz primjenu DMR-a također je obrađeno putem različitih studija i algoritama (Jenson i dr. 1988, Krč 2006). Moguće je modificirati udio pojedine kategorije privlačenja drva na strmom terenu, a na površini između dviju šumskih cesta. Modifikacija se obavlja promjenom širine omeđene površine na strani nasipa ili iskopa.

Rezultat razredbe GJ Jelendol u definirane kategorije smjera privlačenja drva prikazan je na slici 4. Udio područja pogodnih za privlačenje nizbrdo iznosi 65 % (2235 ha), a za privlačenje uzbrdo 35 % (1220 ha).

Primjenjivost modela potvrđena je usporedbom rezultata dobivenih modelom i razredbom terena koju je obavila Slovenska savjetodavna služba tijekom inventure šuma ove gospodarske jedinice. Za svaki je odsjek smjer privlačenja drva definiran kao: privlačenje uzbrdo, privlačenje nizbrdo i privlačenje po ravnom terenu. Rezultati ove, prilično jednostavne, ali i neprecizne razredbe terena (jer su uopćeni podaci za cijeli odsjek), prikazani su na slici 5.

Iz tablice 1 vidi se da je na 35 % površine utvrđena drugačija kategorija smjera privlačenja drva primjenom modela i procjenom na terenu. U većini je slučajeva do pogrešne kategorizacije došlo zbog procjene prosječne kategorije smjera privlačenja na razini odsjeka (ima puno odsjeka koji se nalaze smješteni na padinama između dviju šumskih cesta).Također je pri procjeni smjera privlačenja po odsjecima prisutan učinak kompenzacije pogrešno razvrstanih površina u oba razreda smjera nagiba (razlika između ukupnih razreda smjera nagiba nizbrdo i uzbrdo mnogo je manja od razlike individualno krivo procijenjenih razreda nagiba po poljima dimenzija 50 x 50 m).

Obavljena je i modifikacija modela radi povećanja udjela područja pogodnih za privlačenje drva uzbrdo na najstrmijim terenima. Pri tome bi se koristila stablovna metoda i šumska žičara opremljena procesorskom glavom. Širina omeđenih površina oko šumske ceste na strani iskopa zasjeka smanjena je za 2/3, što je utjecalo na povećanje udjela privlačenja drva uzbrdo za 18 % uz istodobno smanjen udio privlačenja drva nizbrdo za 10 % (sva područja koja su dodatno uvrštena u razred privlačenja drva uzbrdo zahtjevaju dodatne analize drvne zalihe, etata, vrste drveća itd.). Razlike između baznoga i modificiranoga modela prikazane su na slici 6.

Model se može iskoristiti za analizu postojeće te planiranje i razvoj buduće mreže primarnih i sekundarnih (traktorski putovi i žične linije) šumskih prometnica u državnim šumama i većim kompleksima privatnih šuma. Postupak izrade modela trebat će unaprijediti, dalje razvijati i prilagoditi novim postupcima u pridobivanju drva: mehanizirana sječa u kombinaciji sa šumskom žičarom (Visser i Stampfer 1998), stablovna metoda uz primjenu šumske žičare opremljene procesorskom glavom i izradu na šumskoj cesti (Stampfer 2001).

U planinskim će područjima udio privlačenja drva uzbrdo rasti. Razlog je vrlo učinkovito iznošenje drva šumskom žičarom u kombinaciji s izradom na šumskoj cesti (procesorska glava). Ta je metoda jeftinija od privlačenja drva zglobnim traktorima nizbrdo, posebno za nagibe terena između 40 i 65 %, a manja je i potreba izgradnje šumskih cesta i traktorskih putova (Streif 2001).

Stalno se razvijaju različite šumske žičare. One postaju sve pogodnije za iznošenje drva nizbrdo i okolišno su najprihvatljivije za pridobivanje drva, posebno u usporedbi sa strojevima kretnim po zemlji (Owende i dr. 2003).

Primijenjeni model ne uključuje izračun troškova niti ima namjeru optimizirati postupke pridobivanja drva, iako je određena optimizacija, uz daljnje analize, moguća. Postoji problem primjene alternativnih sredstava za privlačenje drva u alpskim uvjetima jer još uvijek nemamo odgovor na pitanje što je optimalno.

Ključne riječi: pridobivanje drva, smjer privlačenja drva, model, mreža šumskih cesta, strmi teren

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