Filling in the Clearance of a Forest Road Cross-Section in Beech Forest

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Abstract – Nacrtak

This paper deals with the required width of forest road formation. Forest roads are necessary for emergency forest management. Besides positive effects, forest roads also bring negative effects. One of them is the loss of forest area due to their construction in the forest environment. The estimation of the possible loss of forest area was the main objective of this research. The clearance of a forest road cross-section affects both the forest and the road. The crowns of edging trees that fill in the clearance have a number of positive effects. The intent of this study was to investigate the filling in process of the clearance of a forest road cross-section in beech stands of south-east Slovenia. At the age of 25–35, forest roads undergo the most intensive differentiation in the filling in process of the clearance. The distance between crowns is 6 m in a 15-year old forest road, 0.74 m in a 35-year old road, and 0.24 m in a 50-year old road. Therefore it may be expected that the distance will be reduced to an average roadway width (3.63 m) in 18 years, and in the next 10 years to 50% of the roadway width. The expected number of profiles with the distance between crowns larger or smaller than 2 m and distance between crowns larger than 2 m at the age of 15 is 90 times higher than in case of older roads. On the other hand, the distance between crowns larger than 2 m with roads of the same age is expected to be 1.5 times higher for every additional meter of distance between stems. It can be concluded that the knowledge of the filling in process of the clearance of a forest road cross-section can be of great help in planning forest road maintenance.

***Keywords**: forest road, clearance of a forest road cross-section, filling in, forest road maintenance*

1. Introduction and research problem – *Uvod i problematika istraživanja*

In the seventies and eighties of the 20th century intensive construction of both primary and secondary forest communication system was carried out in Slovenia. Recently, however, there has been a considerable reduction of construction of new forest communications. Current problems of forest construction in Slovenia concern primarily maintenance of the existing network of forest roads. In addition to bedrock, particularly traffic and atmospheric factors affect the condition of forest roads. If we restrict ourselves to atmospheric factors, meteoric water constitutes the main problem. Striking directly against the roadway, rain drops damage the upper road layer of a forest road by washing out minute bonding agents, and thus they make the road susceptible to destructive power of water. Appropriate granulation of material, suitable inclination of the levelling line and suitable cross inclination, along with properly installed drainage facilities allow roadway drainage and thus they help preserve the forest road. Trees and other vegetation, which fill in the clearance of a forest road cross-section play a special role. Branches and leaves intercept rain drops, preventing them from striking directly against the roadway. They also absorb part of meteoric water, mitigate the effects of direct solar radiation and prevent excessive drying up of the roadway. In this way permanent humidity and coherence of the upper layer are ensured, which means less damage to the roadway and lower maintenance costs.

The effectiveness of a green protective shelter above a forest road depends on a number of factors.

Barna (2001) concluded that twigs of beech trees in each third of the crown responded to cutting by means of enhanced length increment always in the 2nd vegetation period after cutting.

The width of a forest road clearance and tree species are probably the most important factors (Potočnik 2003). Rock base and terrain slope were analysed as some of the factors that impact the road formation width. Comparison of the road formation width and basic rocks shows that limestone is the most favourable and tonalite the least favourable. It was concluded that road formation width could increase up to 80% more on steeper terrain (comparing to gentle terrain slope) and 20% on less solid rock base regardless the terrain slope. It varies between 5.4 m (solid rock base, gentle slope) and 11.4 m (soft rock base, steep slope).

Conifers do not fill in the gaps at all or only to a smaller extent, while deciduous trees are more aggressive. Webster and Lorimer (2004) report that minimum opening sizes and time required for successful canopy recruitment of tree saplings are not well known because the gap capture process is slow and difficult to monitor. They investigated canopy recruitment in harvest openings created by group selection in hemlock-hardwood forests to determine if yellow birch (*Betula alleghaniensis* Britt.), a species with intermediate shade tolerance, could successfully reach the canopy via small openings.

On the other hand Brisson (2001) paid attention to tree crown plasticity. A tree neighbouring a new gap must show a certain degree of morphological plasticity in its lateral growth to take advantage of the available space, expanding branches preferentially on the side of the gap. The morphological plasticity of sugar maple (*Acer saccharum* Marsh.) was evaluated by measuring crown asymmetry with respect to four several neighbourhood contexts. Isolated trees had the most symmetrical crown, while all trees at the edge of a field had the largest part of their crown growing away from the forest.

Seiler and McBee (1992) developed a simple, rapid technique for estimating the projected tree crown area on the ground. The technique utilizes photographs of tree crowns taken from two directions with an object of known scale present in each photograph. The photographs are then displayed onto a dot grid and the projected (two dimensional) crown surface area in square feet is estimated.

The intent of the study was to investigate the filling in of the clearance of a forest road cross-section in relation to road age. It was based on the a priori assumption: the older a road the more filled in the clearance of its cross-section. Such information may be of help in planning maintenance measures of forest roads.

2. Research area and research methods – *Područje i metode istraživanja*

Study sites were selected according to similar ecological conditions (site, forest community, developmental stage, bedrock, terrain inclination, inclination of levelling line). Thus three forest roads of different ages were selected: 15 years, 35 years, and 50 years, respectively. They are located in the forest management unit Soteska (district unit of Novo Mesto Forest Service in the south-east of Slovenia). Bedrock consists of Cretaceous limestone, the forest community is *Enneaphyllo-Fagetum*. The selected roads are situated in forests dominated by beech. The stands are uniform and mature, the growing stock being 305–360 m^3/ha with an annual increment of about 10 m^3/ha. The average terrain inclination is around 35%.

According to Fig. 1 fields the following data were taken: distance between crown of beech trees (*Fagus sylvatica* L.) as a vertical projection of their edges (Cd), roadway width (Cw), road body width (Rw) and distance between the first stems from each side of the road (Sd). Due to field work, accuracy of 10 cm was implemented.

A flat segment was selected from each forest road (age classes) and 30 cross-sections were sampled for

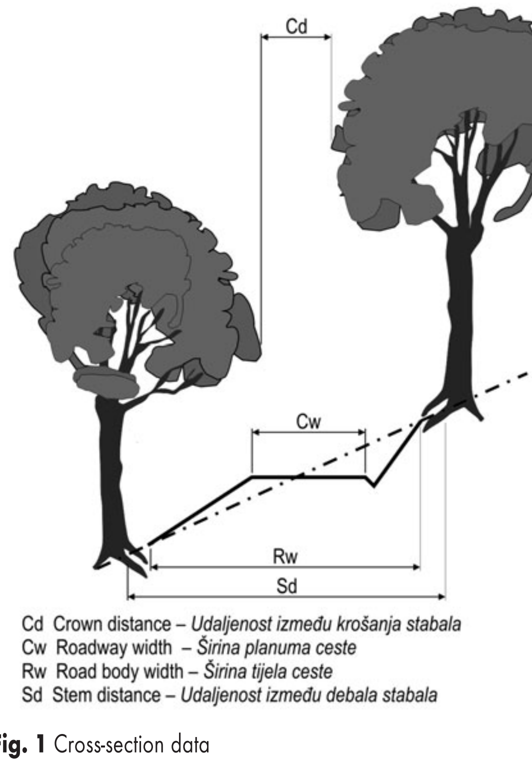

Fig. 1 Cross-section data

Slika 1. *Podatci o poprečnim profilima* measuring roadway width, road body width, distance between stems, and distance between crowns. The other elements of cross-sections were considered less important for the purposes of this pilot study.

3. Results of research – *Rezultati istraživanja*

Average values of individual parameters were determined for each sample group of cross-sections separately (Fig. 2). Roadway width slightly decreases with age, which may be attributed to differences in construction technology, rather than to differences in technical elements. The oldest road was built manually and thus the differences in relation to machine construction are evident. Road body is the widest in the most recently built road and the narrowest in the oldest road. Different construction techniques are again responsible for the differences. Distance between trunks, too, decreases with road age. But the decrease also results from the filling of

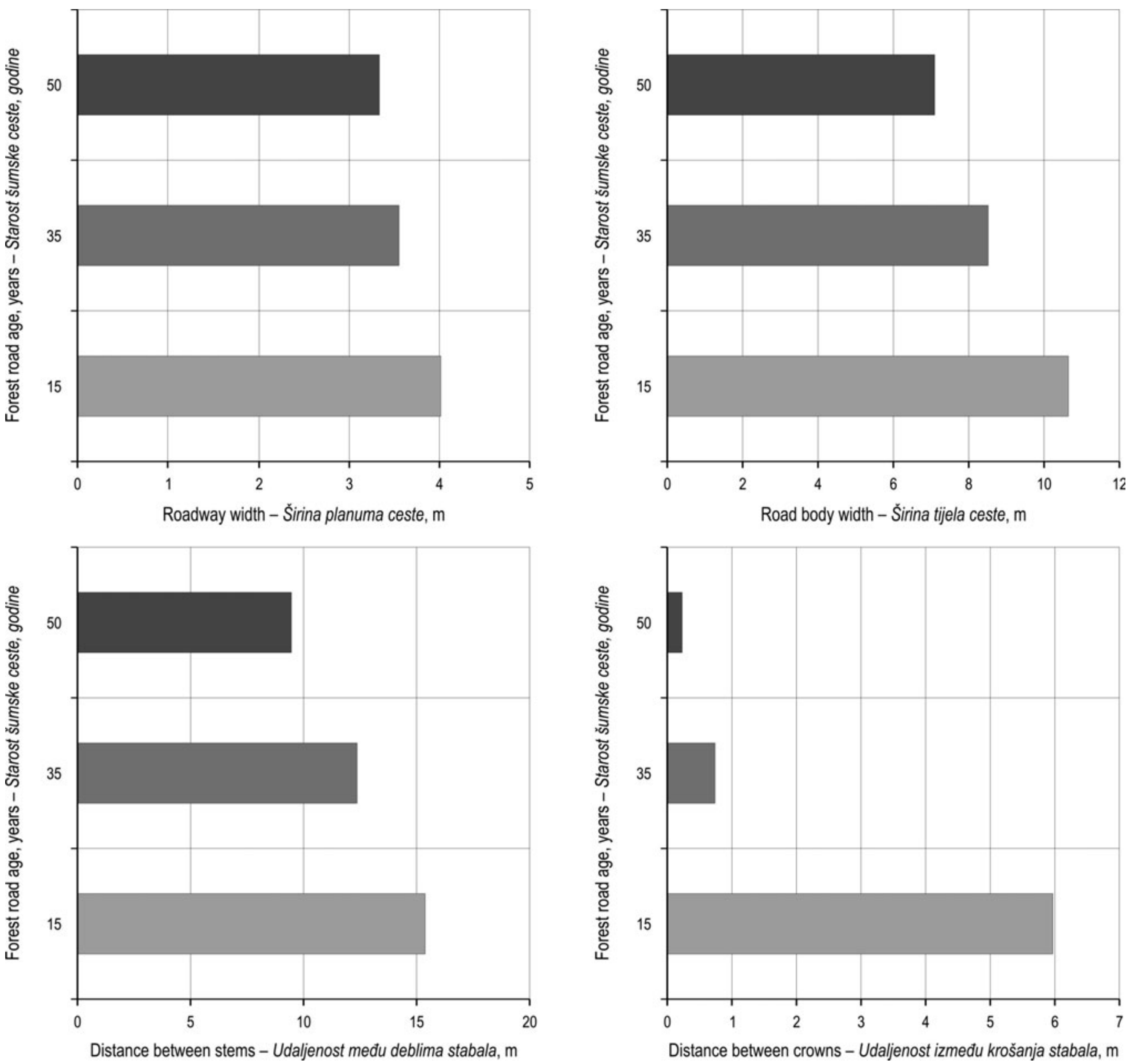

Fig. 2 Differences in parameters of the cross-section in relation to forest road age

Slika 2. *Razlika pojedinih sastavnica poprečnoga profila šumskih cesta različite starosti*

Table 1 Average values and significance of differences between means controlled by age of forest road

Tablica 1. *Statistička analiza utjecaja starosti šumske ceste na pojedini parametar poprečnoga profila*

	Road age *Starost ceste*	*N*	Mean ± St. Dev. *Arit. sred. ± stand. dev.*	Mean difference between years *Srednja razlika između starosti*		Significance of differences between means – *p* *Značajnost razlike između srednjih vrijednosti – p*	
	years – godine		m	m	m/year – *m/god.*		
Roadway width *Širina planuma*	15	30	4.01 ± 0.30	0.46 0.21	0.02 0.01	(15–50) 0.000	(15–35) 0.000 (35–50) 0.003
	35	30	3.55 ± 0.21				
	50	30	3.34 ± 0.31				
	Total – *Ukupno*	90	3.63 ± 0.39				
Road body width *Širina tijela ceste*	15	30	10.65 ± 1.43	2.12 1.43	0.11 0.10	(15–50) 0.000	(15–35) 0.000 (35–50) 0.000
	35	30	8.53 ± 1.29				
	50	30	7.10 ± 0.85				
	Total – *Ukupno*	90	8.76 ± 1.90				
Distance between stems *Udaljenost između debala stabala*	15	30	15.39 ± 2.65	3.00 2.94	0.15 0.20	(15–50) 0.000	(15–35) 0.000 (35–50) 0.000
	35	30	12.39 ± 2,67				
	50	30	9.45 ± 2.42				
	Total – *Ukupno*	90	12.41 ± 3,53				
Distance between crowns *Udaljenost između krošanja stabala*	15	30	5.97 ± 2.63	5.23 0.50	0.26 0.03	(15–50) 0.000	(15–35) 0.000 (35–50) 0.080
	35	30	0.74 ± 1.46				
	50	30	0.24 ± 0.48				
	Total – *Ukupno*	90	2.32 ± 3.13				

the forest road edge with tree species as well as from different construction techniques.

Comparison of the distance between crowns is very interesting. Regardless of the fact that more recent roads are wider (roadway and road body), the differences in the distance between crowns are highly characteristic of each age group. The extreme example is the most recently built road with an average distance between crowns of nearly 6 m. There is not much difference in the distance between crowns between the 35-year-old (0.74 m) and 50-year-old road (0.24 m). In the author's view, there are hardly any gaps between crowns after 25 years. It should be underlined, however, that the clearance of a forest road cross-section was filled in here by the beech, which has a highly adaptable crown. Conifers would have filled in the clearance to a much lesser extent or not at all.

Measuring selected factors by stratums (three different groups by the road age) turned out as a good solution. Average values are significantly different among the age groups and they get reduced by the age, respectively (Table 1).

Differences are not only significant within age groups but also in majority of paired comparisons between age groups. Therefore differences are significant in all factors between the age group of 15 and 35 years and greater when comparing groups of 35 and 50 years. It may be concluded that changes of factors investigated are more intensive in the first two or three decades than later. Two results should be pointed out: relative change of distance between stems is larger in older groups (0.20 m/year) than younger groups (0.15 m/year). Assuming that the forest road was of the same width, and the width of road formation and roadway was enlarged due to machinery construction in time, a larger growing space would be available at the road edge without a crown shelter. On the other hand distances between crowns in older groups were not different ($p = 0.080$)

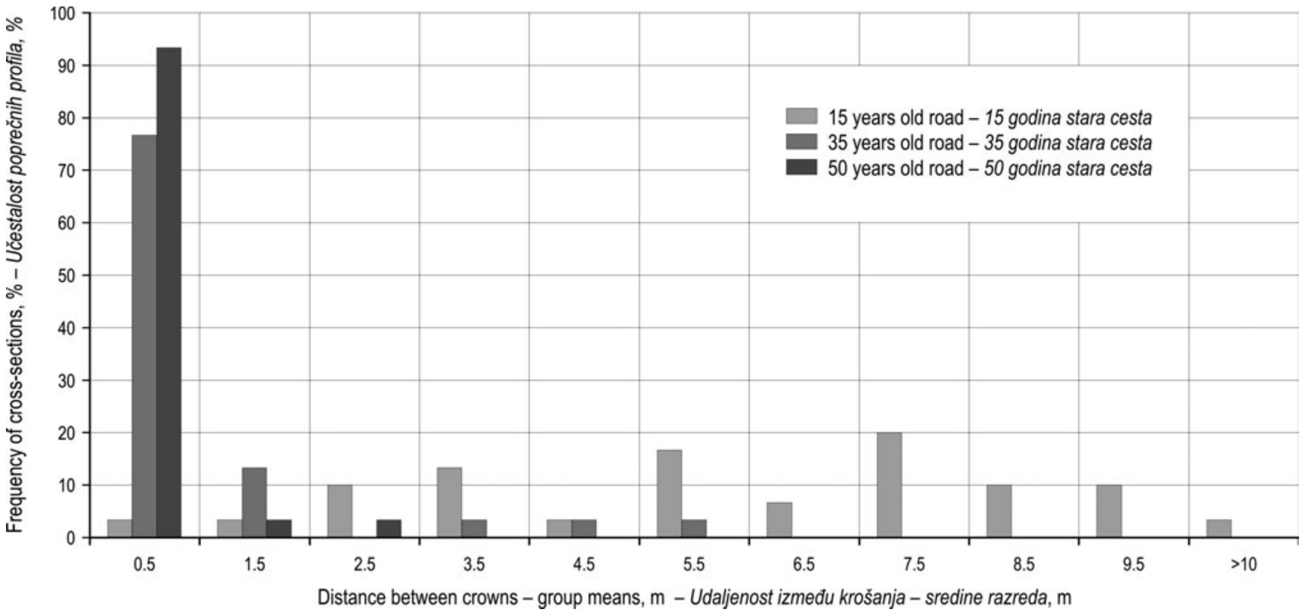

Fig. 3 Frequency distributions of distances between crowns in respect to road age

Slika 3. *Učestalost raspodjele udaljenosti između krošanja stabala u ovisnosti o starosti šumske ceste*

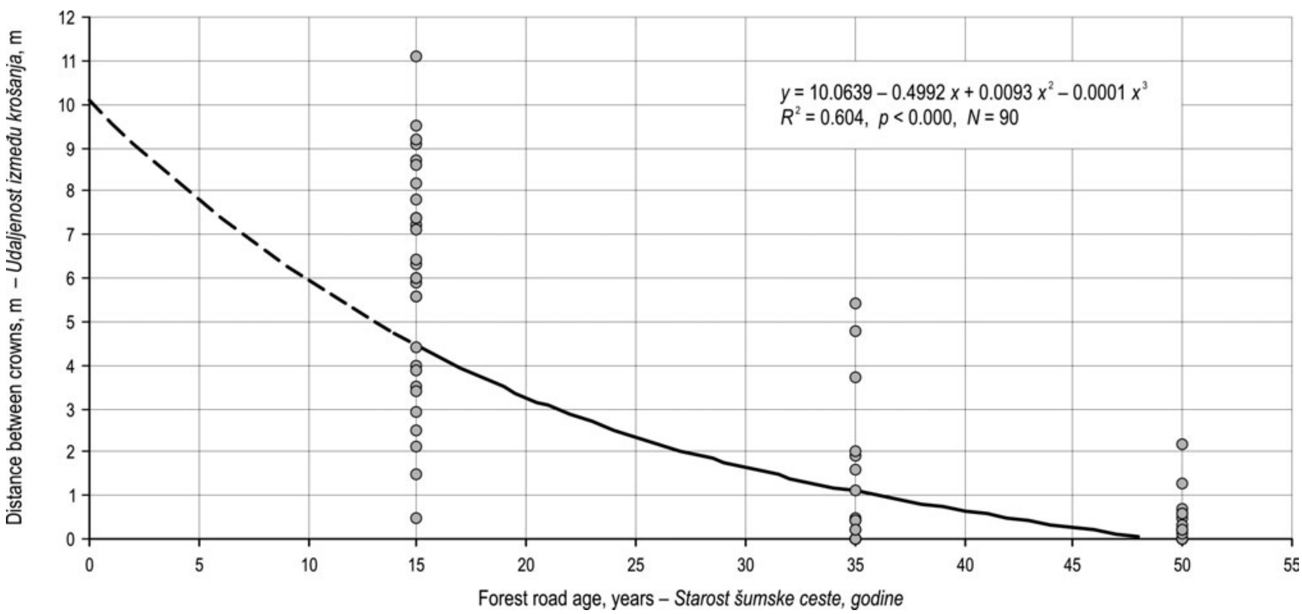

Fig. 4 Dependence of distance between tree crowns and road age

Slika 4. *Ovisnost razmaka između krošanja stabala o starosti šumske ceste*

which means that older groups could be merged and analyzed as a single group.

When comparing frequency distribution of distance between crowns, differences are small as well (Fig. 3).

Fig. 3 shows that frequency distribution of distance between crowns is changing by age from left asymmetrical distribution through normal distribution to right asymmetrical distribution (J distribution) 50 years after the road construction. The share of cross

Table 2 Results of logistics regression
Tablica 2. *Rezultati logističke regresije*

	Estimated parameter *Procijenjeni parametar* *B*	Standard Error *Standardna pogreška*	Wald test	Degree of freedom *Stupnjevi slobode* df	*p*	Odds ratio *Omjer šanse* e^B	95.0% confidence interval for e^B *95 % interval pouzdanosti* e^B	
							Lower limit *Donja granica*	Upper limit *Gornja granica*
Road age under 15 years *Starost cesta do 15 godina*	4.498	0.932	23.285	1	0.000	89.835	14.455	558.316
Distance between stems *Udaljenost između debala*	0.393	0.177	4.925	1	0.026	1.481	1.047	2.096
Constant Stalnica	–7.474	2.451	9.297	1	0.002	0.001		

Table 3 Pearson correlations coefficients between parameters
Tablica 3. *Pearsonov koeficijent korelacije između istraživanih parametara*

	Roadway width *Širina planuma ceste*	Road body width *Širina tijela ceste*	Distance between stems *Udaljenost između debala stabala*
Roadway width *Širina planuma ceste*	1	0.764(**)	0.562(**)
Road body width *Širina tijela ceste*	0.764(**)	1	0.602(**)
Distance between stems *Udaljenost između debala stabala*	0.562(**)	0.602(**)	1

** Correlation is significant at the 0.01 level (2-tailed) – Korelacija je statistički značajna uz razinu značajnosti 0,01 (dvosmjeran test)

sections with connected crowns from both side of the forest road is also growing by age: 0% after 15 years to 60% after 35 and 50 years after the construction. It can be concluded that tree crowns begin to fill up the clearance of the cross section utmost 15 to 20 years after construction, when reducing the distance between tree crowns is the most intensive (Fig. 4).

With no regard to limited validation besides high regression coefficient (R^2 = 0.604; p = 0.000) due to lack of data, the result is still reliable enough to estimate reducing of tree crowns distance by age. Therefore it may be expected that the distance will be reduced to an average width of roadway (3.63 m) in 18 years, and in the next 10 years to 50% of the roadway width. It has to be pointed out that two facts were taken into consideration when the function was established. The inverse function fits the data the best (R^2 = 0.686; p = 0.000), but it is only good for the age over 25 years. Using inverse function and reducing the age the clearance in the cross-section (distance between crowns) theoretically means unlimited enlargement of clearance which is unrealistic. Therefore we used 10 m distance between crowns as a first distance, which is 2 m more than the width of a road formation at 40% terrain slope (Potočnik 2003).

Further in the study we tested if any other factor, besides the age, impacts the distance between tree crowns. Binary multivariate logistic regression was used for calculating the model. Distances between crowns were split into 2 groups (below 2 m – 58 profiles and above 2 m – 32 profiles) to enable all necessary data in both groups. Forest road age was divided into 2 groups (up to 15 years and more than 15 years) due to insignificant differences. Only one additional factor was added because the number of profiles with distance between crowns over 2 m was relatively small. Theoretically, at least 10 records per factor were to be included. The model shows that besides the age only distance between stems impacts the clearance of the cross-section.

Table 2 shows that odds ratio (number of profiles with distance between crowns less or more than 2 m) for distance between crowns larger than 2 m by the age of 15 years is 90 times higher than in the case of older roads. On the other hand, odds ratio for distance between crowns larger than 2 m at the same age are 1.5 times higher for every additional meter of distance between stems.

We could not include other two technical elements of the cross section (roadway width and road body width) because their impact was already comprised with parameters included in the model. All parameters are significantly correlated (Table 3) which brings the conclusion that one parameter also takes the explanatory role for other parameters. Thus, when excluding the age of the road its contribution is taken over by the width of the roadway. Naturally, the variance explained by the model, is therefore lower.

4. Discussion – *Rasprava*

This pilot study confirmed the assumption that distance between stems and tree crowns as well as road body width and roadway width are decreasing by age, which means the older the road the more it is incorporated in the natural environment. The result is expected and logical in discussing distance between stems and crowns, which is not the case with studied technical parameters of the forest road. Theoretically, road body width and roadway width should remain unchanged in time if regular maintenance were provided. Using different road construction technologies (manual and machine work) is a possible answer to explain the reduction of road body width and roadway width in time. The fact is that machine construction was introduced in late 50's and early 60's of the 20th century which is around the older age classes of forest roads in the present study. Manually constructed roads (older age class) are narrower in terms of roadway compared to those constructed by machines due to hard working conditions. Hence, it may be concluded that the efficiency of overgrowing the clearance of the cross-section depends on time (road age), width of the forest belt removed due to construction and road body width.

Some differences and trends of overgrowing the clearance of the cross-section may also be explained by tree species and their age. The study dealt with beech but we may expect different results with conifers and other broadleaves, too. Younger trees, regardless of tree species, are able to develop tree crowns faster and consequently overgrow the clearance faster. Kmet' and Ditmarová (2001) warn that pollution could cause negative processes (especially chlorophyll fluorescence parameters) and state that a deteriorated physiological state of young beech trees could be observed at more polluted sites even at the stage of a latent (hidden) damage.

Under specific ecological conditions after construction, the clearance of a forest road cross-section is quite rapidly filled in with crowns of edging trees, particularly in beech stands. The filling in of the clearance has the following positive aesthetic, ecological, technical and commercial effects:

⇒ the forest road becomes part of the forest,
⇒ damage caused by construction work is rectified,
⇒ the stand affected by construction work is more stable,
⇒ green shelter protects the forest road against direct solar radiation and against harmful effects of precipitation.

From the point of view of the most efficient maintenance of forest road it can be concluded that:

⇒ at the age of forest road over 30 years we may expect up to 50% lower maintenance costs which is directly caused by the impact of precipitation on the road surface,
⇒ the belt of the forest, which has to be removed due to construction, should be as wide as minimally necessary to enable other trees to overgrow the clearance above the cross-section,
⇒ tree removal, especially on the fill slope, should be minimal because of increased stability of forest road and shorter time necessary to connect tree crowns above the forest road (Potočnik et al. 2005),
⇒ at the edge of the road formation broadleaves should be promoted trying not to develop asymmetrical crowns (lower mechanical stability) performing adequate nursery measures,
⇒ all measures should be thoroughly implemented in the areas of protected nature (Potočnik 2006).

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Sažetak

Popunjavanje svijetloga otvora poprečnoga profila šumske ceste u bukovim sastojinama

Sedamdesetih i osamdesetih godina 20. stoljeća u Sloveniji se intenzivno gradila mreža primarnih i sekundarnih šumskih prometnica. Posljednjih je godina značajno smanjen obujam radova na izgradnji šumskih prometnica, a težište je stavljeno na održavanje postojećih sastavnica primarnoga šumskoga transportnoga sustava. Najveća oštećenja na šumskim cestama uzrokuju oborine. Štete i troškovi održavanja značajno se mogu smanjiti ugradnjom kvalitetnoga kamenoga materijala propisane granulacije u gornji stroj šumske ceste, pogodnim uzdužnim nagibom nivelete, odgovarajućim poprečnim nagibom te izvedbom objekata površinske i podzemne odvodnje gdje god je, na trasi šumske ceste, to potrebno.

Stabla i ostala vegetacija koja popunjava svijetli otvor iznad šumske ceste ima velik utjecaj na zadržavanje šumske ceste u dobrom stanju. Grane i lišće sprječavaju izravan dolazak oborinske vode na šumsku cestu (smanjuju njezinu udarnu snagu), a dio vode i apsorbiraju (manja je količina vode koja dođe do šumske ceste). Zatvoreni sklop stabala zasjenjuje šumsku cestu i na taj način štiti gornji stroj od nagloga isušivanja. Time je osigurana stalna vlažnost, čvrstoća i povezanost kolničke konstrukcije, što također ide u prilog nižim troškovima održavanja šumske ceste.

Cilj je ovoga rada istražiti popunjavanje svijetloga otvora iznad šumske ceste u bukovim sastojinama u ovisnosti o starosti šumske ceste. Pretpostavljeno je da je na starijim šumskim cestama popunjeniji (uži) svijetli otvor. Potvrda navedene hipoteze istraživanja može pomoći pri planiranju vrste, intenziteta i učestalosti radova na održavanju šumskih cesta.

Istraživanje je provedeno u GJ Soteska, UŠP Novo mesto. Riječ je o bukovoj šumi (Enneaphyllo-Fagetum) na vapnenačkoj geološkoj podlozi. Drvna zaliha iznosi od 305 do 360 m^3/ha s godišnjim prirastom od 10 m^3/ha. Prosječni je nagib terena oko 35 %. Kao objekti istraživanja odabrane su tri šumske ceste različite starosti (15 godina, 35 godina i 50 godina) smještene u vrlo sličnim sastojinskim, stanišnim, terenskim i tehničkim uvjetima (geološka podloga, pedološka podloga, šumska zajednica, razvojni stadij šume, prosječni nagib terena, poprečni nagib terena i uzdužni nagib nivelete šumske ceste).

Prikupljanje je podataka na terenu, u 30 odabranih poprečnih profila svake šumske ceste, obuhvaćalo izmjeru: udaljenosti između krošanja stabala (Cd), širine planuma šumske ceste (Cw), širine tijela šumske ceste (Rw) i udaljenosti između debala stabala (Sd) sukladno prikazu na slici 1. Izmjera se obavljala s točnošću od 10 cm.

Za svaki je od mjerenih parametara izračunata prosječna vrijednost po svakom objektu istraživanja (slika 2). Širina planuma i širina tijela šumske ceste lagano pada sa starošću šumske ceste, što možemo objasniti prije različitim metodama gradnje (najstarija je šumska cesta građena ručno) nego različitim tehničkim značajkama. Razmak se između debala stabala smanjuje sa starošću šumske ceste, za što je također zaslužan način gradnje šumskih cesta u različitim razdobljima. Usporedba udaljenosti između krošanja stabala daje najzanimljivije

rezultate. Na šumskoj je cesti starosti 15 godina razmak između krošanja stabala 5,97 m, dok razlika između udaljenosti krošanja stabala na šumskoj cesti starosti 35 godina (0,74) i na onoj starosti 50 godina (0,24) nije velika. Iako je bukva vrsta čija se krošnja brzo i lako prilagodi novonastaloj situaciji u šumi (svijetli otvor šumske ceste), 25 godina nakon izgradnje šumske ceste smanjenje udaljenosti krošanja stabala gotovo se i ne primjećuje.

U tablici 1 prikazana je statistička analiza pojedinoga istraživanoga parametra poprečnoga presjeka šumske ceste za svaku od triju šumskih cesta različite starosti unutar grupe i između grupa.

Slika 3 prikazuje promjenu frekvencije udaljenosti između krošanja stabala kroz godine starosti šumske ceste od lijeve asimetrične distribucije preko normalne distribucije do desne asimetrične distribucije (J distribucija) 50 godina nakon izgradnje šumske ceste.

Udio izmjerenih poprečnih profila sa sastavljenim krošnjama bukovih stabala u odnosu na ukupno izmjereni broj poprečnih profila (30) u svakoj starosnoj grupi iznosio je 0 % za šumsku cestu starosti 15 godina te 60 % za šumske ceste starosti 35 i 50 godina. Zatvaranje sklopa iznad izgrađene šumske ceste u bukovim sastojinama najintenzivnije je 15 do 20 godina nakon izgradnje šumske ceste (slika 4).

Razmak između krošanja stabala trebao bi se smanjiti na prosječnu širinu planuma šumske ceste (3,63 m) nakon 18 godina, a u idućih 10 godina udaljenost će između krošanja stabala iznositi 50 % prosječne širine planuma šumske ceste (tablica 4).

U nastavku istraživanja ispitali smo da li bilo koji drugi čimbenik, osim starosti šumske ceste, utječe na razmak između krošanja stabala. Pri modeliranju smo se koristili binarnom multivarijantnom logističkom regresijom. Izmjerenu smo udaljenost između krošanja za 90 poprečnih profila šumske ceste podijelili u dvije grupe: udaljenost do 2 m (u ovu grupu je ušlo 58 poprečnih profila) i udaljenost preko 2 m (32 profila). Starost šumskih cesta podijeljena je također u dvije grupe: do 15 godina starosti i preko 15 godina starosti (u drugoj su grupi objedinjene dvije šumske ceste, ona starosti 35 i ona starosti 50 godina, što je bilo moguće učiniti zbog statistički neznačajnih razlika). Modeliranje je rezultiralo tvrdnjom kako uz starost šumske ceste na širinu svijetloga otvora iznad šumske ceste utječe samo razmak između debala rubnih stabala.

U tablici 2 prikazan je očekivani razmak veći od 2 m između krošanja stabala na šumskoj cesti starosti do 15 godina. Očekivani razmak veći od 2 m između krošanja stabala na poprečnim profilima šumske ceste starosti do 15 godina 90 je puta veći nego na poprečnim profilima starije šumske ceste. S druge je strane očekivani razmak između krošanja stabala veći od 2 m kod šumskih cesta iste starosti 1,5 puta veći za svaki dodatni metar udaljenosti između debala rubnih stabala.

Pilot-projekt potvrdio je pretpostavku da udaljenost između debala, udaljenost između krošanja te širina tijela i širina planuma šumske ceste padaju s godinama starosti šumske ceste. To znači da su starije šumske ceste bolje uklopljene u svoje okruženje. Rezultat je očekivan u pogledu udaljenosti između debala i krošanja rubnih stabala, dok bi, teoretski, širina tijela i širina planuma šumske ceste trebali ostati nepromijenjeni tijekom vremena uz dobro održavanje.

Strojna izgradnja šumskih cesta u Sloveniji uvedena je kasnih pedesetih i ranih šezdesetih godina prošloga stoljeća, dakle nakon izgradnje najstarije šumske ceste istraživane u ovom radu. Zbog teških radnih uvjeta pri ručnoj se gradnji šumskih cesta izvodio uži planum šumske ceste (a time i uže tijelo šumske ceste) u usporedbi sa strojnim načinom izvedbe. Može se zaključiti da intenzitet zatvaranja sklopa iznad šumske ceste ovisi o vremenu izgradnje (starosti šumske ceste), širini pojasa šume koji je posječen zbog izgradnje šumske ceste i širini tijela šumske ceste.

Neke razlike u popunjavanju svijetloga otvora mogu se objasniti i vrstom drveća te godinama starosti sastojine. Ovdje je istraživana bukva, ali se bitno različiti rezultati mogu očekivati u istraživanju četinjača te drugih vrsta listača. Mlađa su stabla, bez obzira na vrstu, sposobnija razviti svoju krošnju brže te posljedično brže popuniti svijetli otvor od starijih stabala.

U istraživanim sastojinskim i stanišnim uvjetima svijetli se otvor iznad šumske ceste uistinu brzo zatvarao krošnjama rubnih bukovih stabala. Zatvaranje sklopa krošanja iznad šumske ceste ima ove pozitivne estetske, ekološke, tehničke i komercijalne učinke:

- ⇒ *šumska cesta postaje neraskidiva, estetski oblikovana, cjelina sa šumom*
- ⇒ *posljedice i štete za šumski ekosustav nastale izgradnjom šumske ceste umanjene su i ispravljene*
- ⇒ *sastojina i stanište poremećeno izgradnjom šumske ceste postaju puno stabilniji*
- ⇒ *zeleni zastor krošanja bukovih stabala štiti šumsku cestu od izravnoga sunčanoga zračenja i od štetnih posljedica oborina.*

S gledišta provođenja što učinkovitijega održavanja šumskih cesta mogu se donijeti ovi zaključci:

- ⇒ *sa starošću šumske ceste preko 30 godina može se očekivati smanjenje troškova održavanja za 50 %, što je uzrokovano sprječavanjem izravnoga pridolaska oborina na površinu šumske ceste*
- ⇒ *šumski pojas koji je potrebno posjeći pri izgradnji šumske ceste treba biti što je moguće uži kako bi rubna stabla što prije zatvorila sklop iznad šumske ceste*
- ⇒ *sječa stabala pri izgradnji šumske ceste (pripremni radovi), posebno na nasipnoj strani mješovitoga profila (zasjeka), trebala bi biti što manja radi povećanja stabilnosti šumske ceste i skraćivanja vremena potrebnoga za sklapanje krošanja stabala iznad šumske ceste (Potočnik i dr. 2005)*
- ⇒ *rubna bjelogorična stabla uz šumske ceste trebala bi imati simetričnu krošnju (jer asimetrična krošnja smanjuje mehaničku stabilnost stabla), što se postiže odgovarajućom njegom stabala*
- ⇒ *sve bi navedene mjere u potpunosti trebalo primijeniti u zaštićenim područjima prirode (Potočnik 2006).*

Ključne riječi: *šumska cesta, svijetli otvor šumske ceste, popunjavanje svijetloga otvora, održavanje šumskih cesta*

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