Modelling Stand Damages and Comparison of Two Harvesting Methods

Boštjan Košir

Abstract – Nacrtak

This paper deals with the problem of tree damage in a remaining stand. Two models were used for assessment of stand damage over the entire production period. Damage accumulates on the trees and in the stand, which is why the total share of damage tends towards the limit 100% if the number of thinnings increases. Parameters used in the models were established partly by previous field measurements and partly by simulations measurements. Motor-manual and cut-to-length technologies were analysed and compared according to the total number of damaged trees and the structure of trees according to the number of injuries. It was found that motor-manual technology causes more damage to trees and results in worse tree structure, meaning more than one injury. Many unanswered questions provide plenty of opportunities for further research.

Keywords: *stand damage, harvesting, technology, motor-manual, cut-to-length*

1. Introduction – *Uvod*

Slovenian forestry has a long tradition of sustainable, multifunctional and co-natural forest management. The doctrine of forest management in Slovenia has been abundantly discussed and presented to the international community (Mlinšek 1977, Mlinšek 1994, Diaci and McConnell 1996). Uniform and group shelterwood systems are predominant. It is obvious that such doctrine demands a specific approach and exerts a considerable influence on all aspects of practical forestry (Matthews 1999). Forest harvesting has developed and it is adapted today to the specifics of silvicultural philosophy and to restrictions which originate from different sources. Clear-cuttings have been forbidden for many decades. Frequent thinnings (one to two cuttings in the same stand per decade – state forests), difficult terrain and large tree dimensions are the reason why motor-manual cutting and tractor or cable skidding are still predominant today. Final cuttings are more an exception than a rule.

Social changes in human resources, changes in energy prices, new possibilities in information technology and severe competition on the timber market are putting into question the economics and future of recent technologies, in which motor-manual cutting and skidding with various tractors prevail (M-M technology). The main reasons why cut-to-length (CTL technology) technology (harvester and forwarder) took off after 2000 were: demand for cost reduction and problems with recruitment of new professional workers for traditional forest work (Košir 2004). These reasons have been also crucial in the first debates in which forest enterprises tried to find a common language with the Slovenian Forestry Service. Compatibility of new CTL technology with the existing forest management doctrine raised a hot debate in which damage to existing trees and damage to forest soil were the most controversial issues. In this context damage to the remaining stand has been understood as injured trees with visible scars on stem, butt, roots or branches (scar area >10 cm^2), broken branches in canopy and bent trees.

In case of tree damage (MM technology) we already have reliable data from abroad and from field observations (Krivec 1975, Ivanek 1976, Eriksson 1981, Butora and Schwager 1986, Leinss 1991, Košir 1998a, Sabo 1999 and other sources not mentioned here) as well as results gained from models (Košir and Cedilnik 1996, Košir 1996, Košir 2000). At the time when we published quite unfavourable results concerning tree damage research nobody took too much notice when traditional technologies were in question, while a negative attitude towards the new CTL technology introduction appeared following the first cases of damage.

The performance of the general model of tree damage gave good results in the past, which were later confirmed by field observations. Therefore we decided to use the same model for comparing the damage to trees caused by traditional motor-manual and by the new CTL technology. We hope that in this manner we can present an unbiased assessment of this sensitive aspect of new technology introduction.

2. Research methods – *Metode istraživanja*

Tree damage models

Tree damage after forest operations decreases the value of forest yields in future, stability of stands, and it should be of utmost concern to every good forest owner (Spinelli 1999). Frequent thinnings also mean more chances for increased share of injured trees after finishing the work (Košir 2001). The model used in this comparison was developed for shelterwood forest management where cutting intensity was defined as the proportion between marked trees and all trees in the stand. The stand damage intensity was defined as the proportion between damaged trees after operations and all remaining trees.

We assumed that:

⇒ each tree has the same probability of being chosen for felling at a certain time,

⇒ each tree has the same probability of being damaged at the time of the last logging,

⇒ a tree which is damaged more than once in the same thinning is counted as one injury, and

⇒ a tree is marked as injured regardless of the severity of injury.

The share of damaged trees remaining in each thinning during the production period depends on the probability of the tree being chosen for cutting or probability of the tree having been damaged up to now. Obviously some trees will be damaged once, twice or more times at the end of the rotation period.

The basic model development and evaluation (Košir and Cedilnik 1996) gives more criteria than required for this analysis (such as increment of injuries). For our purposes we used the following formula, the so-called »rule of tree damage accumulation«:

$$\Delta_n = 1-(1-\Delta_0)\prod_{i=1}^{n}(1-\delta_i) \qquad (1)$$

where:

n number of thinnings in rotation period,

Δ_0 share of tree damage before forest operations started (beginning),

Δ_i share of tree damage in the stand after *i* thinning,

δ_i share of tree damage in *i* thinning.

Δ_n obviously tends to the limit = 1 if speaking of known $\delta_i > 0$ values.

The share of damaged trees is not directly dependant upon the intensity of thinning (equation 1), but as it has already been proved (Košir 2000), this dependence enters the model indirectly, because the intensity of cutting (ε_i) and skid trail density (G) impact the share of damaged trees (δ_i) after *i* thinning. Instead of intensity of cutting (ε_i), concentration of wood cut per ha can be used (V_i). We may write:

$$\delta_i = f(V_i, G)$$

where:

V_i intensity of cutting in *i* thinning (m^3/ha),

G density of skid trails (m/ha).

From the second model (where some results of field studies were used) the following formulas were used in this article:

$$\delta_i = \frac{\delta_{vi}\cdot N_v + \delta_{si}\cdot(N_{si}-N_v)}{N_{si}} \qquad (2)$$

where:

δ_{vi} share of tree damage after *i* thinning along skid trails after *i* thinning,

δ_{si} share of tree damage after *i* thinning between skid trails after *i* thinning,

N_v number of trees along skid trails,

N_{si} number of trees in the whole stand after *i* thinning.

and:

$$\delta_{vi} = 1-e^{(V_i/G)} \qquad (3)$$

$$\delta_{si} = a + b_1\cdot V_i - b_2\cdot G \qquad (4)$$

where:

e basis of natural logarithm,

a, b_1, b_2 equation parameters.

For distinction between technologies the values from Table 1 were used.

Tree damage simulation

The above formulas give us a good estimation of total tree damage in the remaining stand after *i* thinnings, but we were also interested in the frequency of injuries to the trees at the end of the rotation period. The question was: how many injuries can we expect to the trees and how many removals?

Table 1 Values of parameters in model computation

Tablica 1. *Vrijednosti parametara u modelu*

Parameter *Parametar*		MM	CTL
Number of trees in the whole stand after *i* thinning* *Broj stabala u sastojini nakon i-te prorede**	N_{si}	Taken from yield tables for spruce in Alpine region, strong thinning (Halaj et al. 1987) *Preuzeto iz prirasno-prihodnih tablica, obična smreka u alpskom području, jake prorede (Halaj i dr. 1987)*	
Intensity of cutting in *i* thinning (m^3/ha)* *Sječna gustoća i-te prorede (m^3/ha)**	V_i		
Density of skid trails (m/ha) *Gustoća traktorskih vlaka (m/ha)*	G	200	500
Number of trees along the skid trails** *Broj stabala uzduž traktorske vlake***	N_v	$= 0.05\ N_s$	$= 0.15\ N_s$
Equation parameters *Parametri jednadžbe*	a	0.19	
	b_1	0.0005	
	b_2	0.00014	

*Rotation period of 160 years has been analysed; 10 years thinning interval has been used

*Analizirana je duljina ophodnje od 160 godina uz 10-godišnji interval prorjeđivanja

**In the original model (Košir 2000) a different formula was used

**U izvornom modelu (Košir 2000) upotrijebljena je drugačija jednadžba

After i thinnings we can expect a certain number of trees to have δ_i injuries, but this number will be small, as we must expect that during the thinning period the majority of injured trees have been already removed. To answer the question above we built a simulation matrix with $N_s = N_0$ rows and $i = n$ columns. Trees were randomly chosen for cut and marked as injured in the range of V_i and δ_i for each technology separately. The final share of tree damage was the same as the share calculated using the basic model.

Apart from numeric values of the simulated events we can also make a graphical picture of the situation after each i thinning. The main advantage of the simulation is that we can analyse the frequency of injury distribution after each thinning. This provides the possibility to calculate the value of money lost due to decay. The graphical part of the simulation is also valuable for student training.

3. Results of research– *Rezultati istraživanja*

Results of the general model

The results are partly shown in Table 2 (formulas 2, 3 and 4). The reason for this calculation was to get the whole picture of expected differences between the two technologies. First we calculated δ_i as an input variable for formula 1 and for the simulation program.

Computed δ_i do not differ significantly from field studies. For MM technology δ_i are comparable with the averages for this combination of skid trail density and thinning density from the field measurement (Košir 2000). Another example (Košir and Robek 2000) shows that in an artificially established Scotch pine stand, about 50 years old, 8% of injuries were found in one cutting-unit and 12% of injuries in the second cutting-unit after the application of CTL technology (harvester Timberjack 1270 and forwarder Timberjack 1410).

Fig. 1 shows the results of calculations of Δ_i for MM and CTL technologies (formula 1). Early thinnings in the model start at the age of 30 years and continue up to 160 years when the rotation period ends and regeneration cuttings begin. The total number of damaged trees in the stand continuously grows and reaches around 90% at the end of the rotation period.

Table 2 Shares of injured trees after thinning with MM and CTL technology*

Tablica 2. *Udio oštećenih stabala nakon prorede pri MM i CTL sustavu pridobivanja drva**

Year – *Godina*	δ_i MM	δ_i CTL
30 (i = 1)	0.1701	0.1277
60 (i = 4)	0.1882	0.1461
90 (i = 7)	0.1896	0.1475
120 (i = 10)	0.1868	0.1447
150 (i = 13)	0.1841	0.1419

*30 – year age class (10 year interval has been used in the model)

*30-godišnji dobni razredi, s 10-godišnjim intervalima korišteni su u modelu

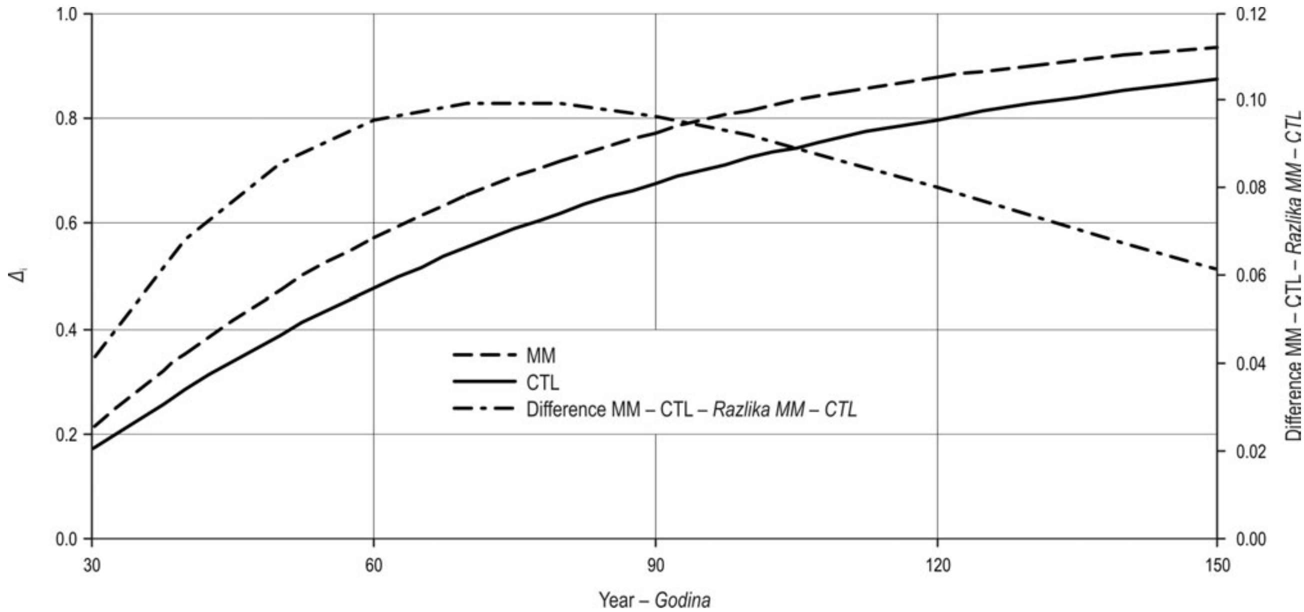

Fig. 1 Δ_i for MM and CTL technologies through the rotation period and difference between technologies

Slika 1. *Δ_i za MM i CTL sustav pridobivanja drva u ophodnji i razlika među sustavima pridobivanja drva*

This is a rather shocking result, and the question is whether it is possible to prove such predictions by a field observation. The answer is positive if we take into account the fact that many smaller injuries disappear during the decades of tree growth. In practice it is thus possible to expect some smaller values of damaged trees (Robek and Medved 1997) than shown in Table 3, where the results of the field measurement are shown (Košir 1998a). In old stands 64–70% of damage have been recorded. The difference between model predictions and the actual situation can be explained with some facts that are not included in the model, but have an impact on field observations, such as the disappearing of visible injuries due to the healing of stem scars and the disapearing of wounded branches over a long period of time, insufficient knowledge of past technologies and the rate of damages they had induced, as well as insufficient accurate evidence about past cuttings.

It can also be concluded from Figure 1 that the difference between MM and CTL technology is not constant during the whole tree age, but that it reaches its maximum value (0.10) at the age of 70–80 years and from then on decreases toward the limit = 0.

Table 3 Structure of tree damage in remaining spruce stands (databank of tree damages – Košir 1998a)

Tablica 3. *Struktura oštećenja stabala u preostaloj sastojini (baza podataka oštećenja stabala – Košir 1998a)*

Spruce stands on Alpine plateau *Smrekove sastojine na alpskoj visoravni*	Undamaged trees *Neozlijeđena stabla*	Old injuries *Stare ozljede*	Old and new injuries *Stare i nove ozljede*	New injuries *Nove ozljede*
Polewood (40–60 years) *Stupovlje (40–60 godina)*	0.58	0.31	0.05	0.06
Old and younger mature stand (80–100 years) *Starije i mlađe zrele sastojine (80–100 godina)*	0.33	0.47	0.16	0.05
Mature stand (100–140 years) *Zrele sastojine (100–140 godina)*	0.32	0.50	0.12	0.06
Stand in regeneration (> 140 years) *Sastojine u pomlađivanju (>140 godina)*	0.21	0.64	0.13	0.03
Old mature stand (> 140 years) *Prezrele sastojine (> 140 godina)*	0.15	0.70	0.15	0.00

Motor-manual felling and extraction with tractors show very bad results in early thinnings in comparison with CTL technology.

Results of simulations

An overall picture of tree damage behaviour during the rotation period should be close to the general model, though we can expect some minor deviations due to the stochastic process. The advantage of this approach is that we can obtain the structure of injuries according to the time of appearance and the number of trees, which have been injured several times (Table 4). We may also analyse the injuries of the removed part of the stand. These results enable

Table 4 Number of trees in stands in 30-year age classes

Tablica 4. *Broj stabala u sastojini za 30-godišnje dobne razrede*

MM								
Year *Godina*	Undamaged trees *Neoštećena stabla*	Number of each injured trees in different thinning period *Broj ozljeđivanja svakoga pojedinoga stabla tijekom različitih proreda*						
		1	2	3	4	5	6	7
30	3680	747	–	–	–	–	–	–
60	693	582	193	30	–	–	–	–
90	211	295	213	97	22	–	–	–
120	96	163	155	120	49	8	1	–
150	39	92	123	109	58	24	8	1
CTL								
Year *Godina*	Undamaged trees *Neoštećena stabla*	Number of each injured trees in different thinning period *Broj ozljeđivanja svakoga pojedinoga stabla tijekom različitih proreda*						
		1	2	3	4	5	6	7
30	3731	570	–	–	–	–	–	–
60	822	507	123	5	1	–	–	–
90	304	354	157	48	3	–	–	–
120	134	213	161	62	24	3	–	–
150	70	130	138	81	40	8	1	–

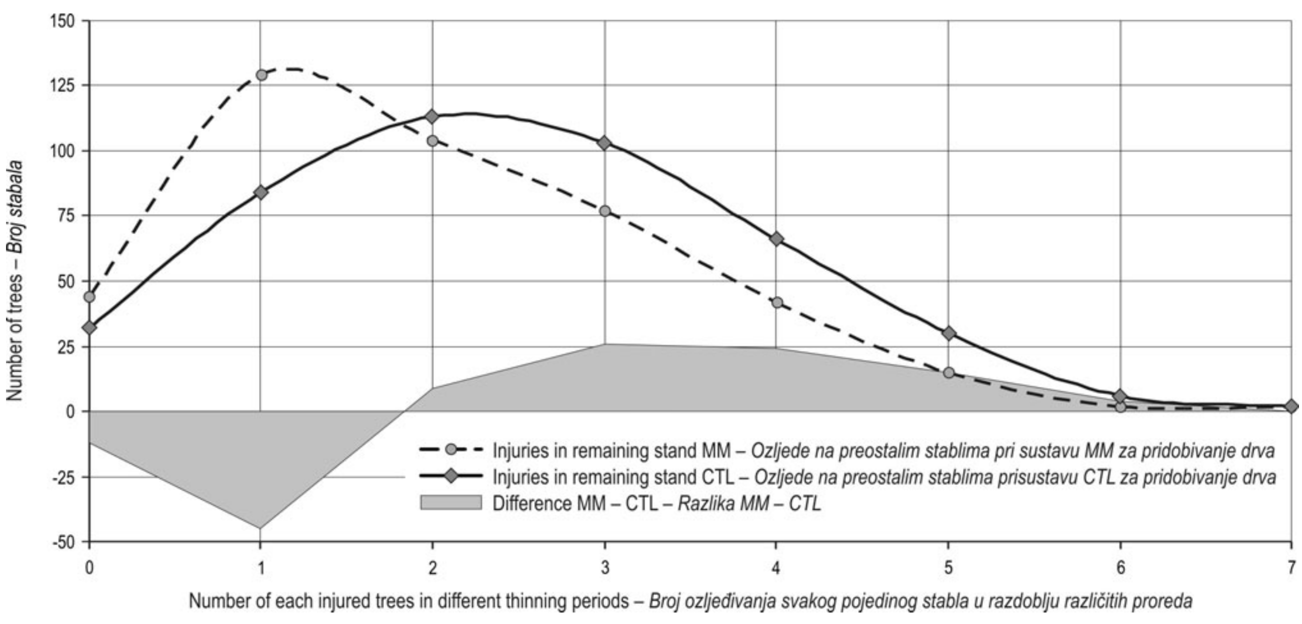

Fig. 2 Differences in number of injured trees between MM and CTL technology

Slika 2. *Razlike u broju oštećenih stabala između sustavâ MM i CTL za pridobivanje drva* us to make a better assessment of the lost value than ever made so far (Košir 1998b). Nevertheless, this is not within the scope of this article.

Differences in the number of injured trees after the whole rotation period are shown in Fig. 2. With CTL technology we can expect a greater number of undamaged trees. Later in the stand development we can also expect a greater number of trees that have been injured once or twice on one hand, and a smaller number of trees that have been damaged more times on the other hand, than is the case when using MM technology.

The whole structure of relative frequencies according to age is given in Fig. 3 and 4. First we notice

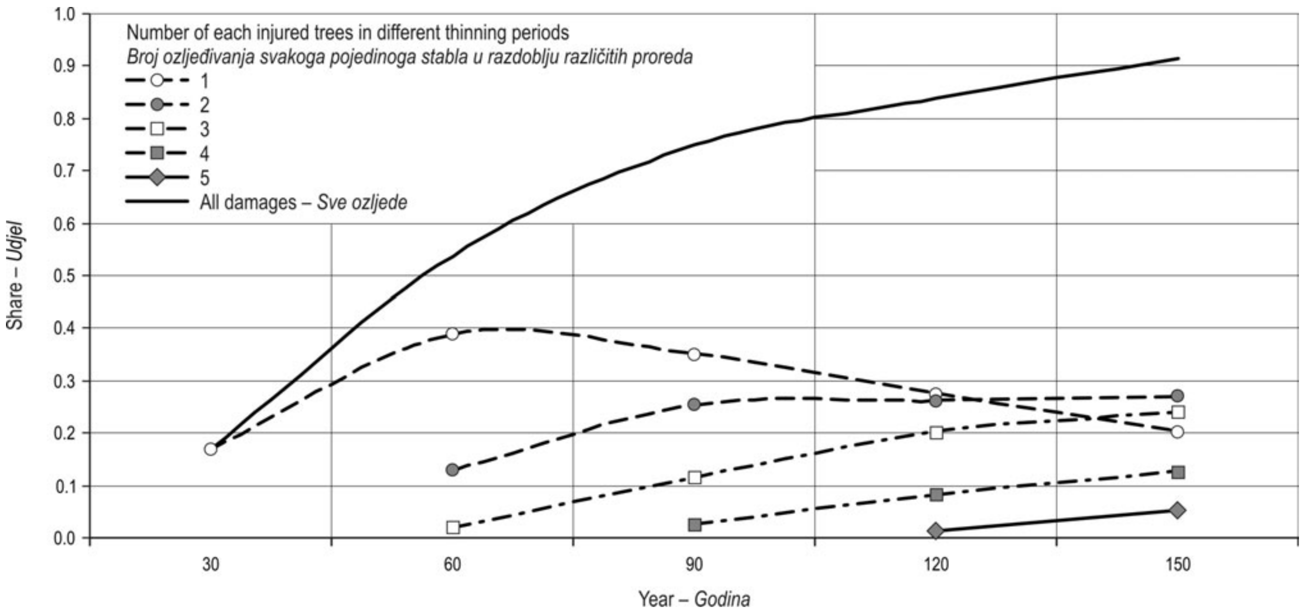

Fig. 3 Changes in the structure of injured trees for MM technology

Slika 3. *Promjene u strukturi oštećenih stabala pri MM sustavu pridobivanja drva*

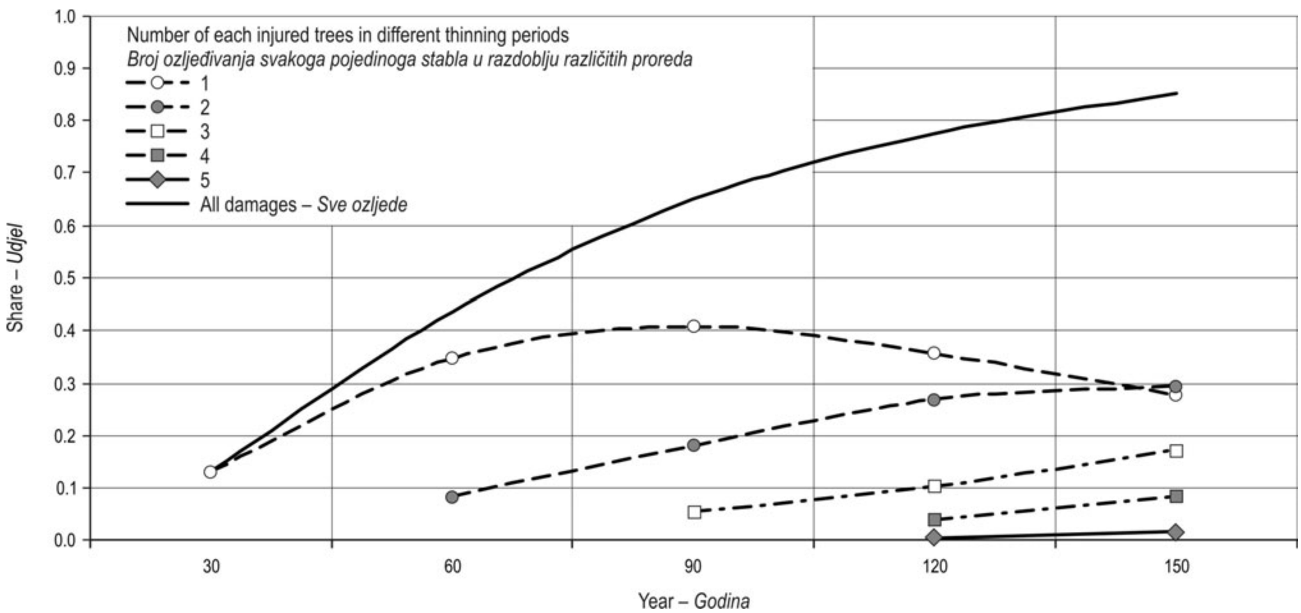

Fig. 4 Changes in the structure of injured trees for CTL technology

Slika 4. *Promjene u strukturi oštećenih stabala pri sustavu CTL za pridobivanje drva* similar flows of undamaged stand curves, which are slowly closing towards the limit of 100% damaged trees. The share of tree injured once appears after the first thinning and at 70 (MM) and 90 (CTL) years it reaches its maximum, and thereafter slowly decreases as more and more trees with one injury receive more injuries or are removed from the stand. Trees with two injuries appear one thinning later and show a similar trend. The maximum is at 100 (MM) or 150 (CTL) years, and later the share of such trees slowly decreases. Other curves in both figures show similar logic flow. Comparison of both figures shows that the CTL curves have maximums at later stages of the stand, because there is less damage at each thinning.

This can be better understood if we consider Figure 2 once more, where the situation after the end of the observed period is shown. The MM system shows a strong tendency of injury distribution towards more injuries per tree. This also means that the maximum of distribution is at three instead of two injuries per tree, as shown in the distribution of CTL technology. A compared distribution of injuries in earlier development stages shows the same relations between MM and CTL technologies, but with a higher number of undamaged trees (0 injuries) and a smaller number of trees injured more than once.

4. Discussion and conclusions – *Rasprava i zaključci*

Models of tree damage in the remaining stand are a valuable tool for analysing the consequences of forest operations in the time to come. It is of minor importance that the technologies are changing in the direction of less brute force, and what is even more important, machine operators, supervisors and forest owners are more aware than before of the damaging potential of modern technology. Education and training of machine operators and all others who deal with forest management is therefore a permanent issue. With respect to the described facts, the change of technology means that the same relations will appear on a different level, hopefully better for the forest. In this paper we compared two technologies which seem to compete at present in different conditions, where stand composition and terrain characteristics play a major role. An older technology, where motor-manual work prevails, has been studied much closer and for a longer period of time. Cut-to-length technology is well known, with a long tradition in the Nordic and many other countries, but the results of damage studies (Frödig 1992, Frohm 1993) or models (Siren 1999, Dvořak 2005) cannot be used directly in Slovenian conditions, as stand composition, stand density, terrain characteristics and other circumstances of forest operations are different. This does not mean that the validation of the model is questionable, but there is a doubt whether the input variables are reliable and representative for a certain technology. There is also a challenging question of whether historical data can support our findings.

This paper showed that under the given presumptions CTL technology causes less damage to the forest. In the long run that means a slower increase of damaged trees in the stand and better distribution of accumulated damages in the stand. This would improve the stability of stands (less damage by bark beetles, for example) and increase the yield value. Other advantages and disadvantages of CTL technology have not been discussed in the paper.

There are still numerous questions connected to CTL technology and stand damages. Stand density influences considerably the share of injuries in the stand. If the reports of tree damage from northern countries (<0.05) are compared with those from Central Europe, a large discrepancy is obvious. Stand density is already included into the model, but not directly. In this respect the model should be upgraded by additional choices, based on actual field measurements.

During recent observations and measurements (not yet published), according to the slightly modified Frödig method (1992), we noticed that tree damages are greater when the machine operator is working in a dark environment (with lights engaged). There is also no reliable research of extended work time (Nicholls et al. 2004) and work quality where work quality also includes tree damage. Answers to these and other questions will also improve the results of comparisons described above.

5. References – *Literatura*

Butora, A., Schwager, G., 1986: Holzernteschaden in Durforstungbestanden. Berichte, 288, Birmensdorf, Eidgenossische Anstalt fur das forstliche Verzuchswezen, 51 p.

Diaci, J., McConnell, S. 1996: Close-to-nature forestry and ecosystem management. Zb. gozd. lesar. 49: 105–127.

Dvořak, J. 2005: Variability of Tree Damage with Respect to Felling – Technological Factors that can be Changed in Short Term. Proceedings: FORMEC 2005, Ljubljana, 139–146.

Eriksson, L. 1981: Strip roads and Damages Caused by Machines when Thinning Stands. The Swedish University of Agricultural Sciences, Dep. of Operational Efficiency, Garpenberg 1992, Rep. No. 193: 1–44.

Frödig, A., 1992:. Thinning damage – A study of 403 stands in Sweden in 1988. The Swedish University of Agricultural Sciences, Dep. of Operational Efficiency, Garpenberg 1992, Rep. No. 193: 1–45.

Frohm, S., 1993: Efficient and Safe Thinning. In: Efficient, Sustainable and Ecologically Sound Forestry, Skogforsk Report 5: 43–49.

Halaj, J., Grék, J., Pánek, F., Petráš, R., Øehák, J., 1987: Rastové tabul'ky hlavnýh drevín ÈSSR. Príroda, Bratislava, p. 362.

Harstela, P., 1995: Environmental impacts of wood harvesting in Nordic countries. Environmental impacts of Forestry and Forest Industry. EFI Proc. 3: 37–44.

Ivanek, F., 1976: Vrednotenje poškodb pri spravilu lesa v gozdovih na Pohorju. IGLG, Strokovna in znanstvena dela 51, Ljubljana, 142–147.

Košir, B., Cedilnik, A., 1996: The model of number increasing of tree damages at thinnings. Zb. gozd. lesar. 48: 135–151.

Košir, B., 1996: How to manage thinning with low damages of standing trees – experience from the model. Proceedings »Planning and implementing forest operations to achive sustainable forests« 19th Annual Meeting of COFE & IUFRO SG S3.04–00, July 29–August 1, 1996, Marquette, Michigan USA, 82–91.

Košir, B., 1998a: Damage to mountain spruce stands due to harvesting. Conference proceedings »Gorski gozd«, Ljubljana: Biotechnical Faculty, Department of Forestry and Renewable Forest Resources, p. 95–107.

Košir, B., 1998b: Critical evaluation of frequent thinnings from the aspect of energy consumption and damage in the stands. Zb. gozd. lesar. 56: 55–71.

Košir, B, Robek, R., 2000: Characteristics of the stand and soil damage in cut-to-lenght thinning on the Žekanc working site (SW Slovenia). Zb. gozd. lesar. 62: 87–115.

Košir, B., 2000: Primerjava rezultatov modela poškodb drevja v sestoju zaradi pridobivanja lesa in terenskih opazovanj. – Research Reports, University of Ljubljana, Biotechnical Fac., Dep. of Forestry and Forest Resources, 62, p. 135–151.

Košir, B., 2001: Frequent thinning – impact on stand quality. In: Thinnings: a valuable forest management tool., Montreal, Quebec, Canada, September 2001, Canadian forest service, 2003.

Košir, B., 2004: Factors affecting technological changes. Gozd. vestn. 62(1): 3–11.

Krivec, A., 1975: Racionalizacija delovnih procesov v sečnji in izdelavi ter spravilu lesa glede na delovne razmere in poškodbe. Research Reports, University of Ljubljana, Biotechnical Fac., Dep. of Forestry, 13, 2, Ljubljana, p. 145–193.

Leinss, C., 1991: Unterzuchungen zur Frage der nutzungstechnischen Folgen nach Fall-und Ruckeshaden bei Fichte (*Picea abies* /L./ Karst.). Mitteilungen der Forstlichen Versuchs- und Forschungsanstalt Baden-Wurttemberg, Freiburg im Breisgau, Heft 157, 172 S.

Matthews, J. D., 1999: Sylvicultural systems. Oxford Univ. Press, Oxford, p. 98–137.

Mlinšek, D., 1977: Übertragbarkeit und die Bedeutung des Prinzipes der Nachhaltigkeit und der Theorie der Waldpflege für die Naturgerechte Bewirtschaftung von erneuer--baren Naturgutern. Die Waldpflege in der Mehrweckforstwirtschaft. Österreichischer Agrarverlag, Wien, p. 45–57.

Mlinšek, D., 1994: Was ist naturnahe Waldwirtschaft?. In: HATZFELDT, Hermann Graf (Ed.). Ökologische waldwirtschaft : Grundlagen – Aspekte – Beispiele, (Alternative Konzepte, 88). Heidelberg: C. F. Müller, p. 67–76.

Nicholls, A., Bren, L., Humphreys, N., 2004: Harvester Productivity and Operator Fatique: Working Extended Hours. Int. J. of For. Eng. 15(2): 57–65.

Robek, R., Medved, M., 1997: Poškodbe drevja zaradi izvajanja gozdarskih del po podatkih popisov propadanja gozdov Sloveniji. Research Reports, University of Ljubljana, Biotechnical Fac., Dep. of Forestry and Forest Resources, 52, p. 119-136.

Sabo, A., 2000: Damaging Trees at Timber Skidding by the Skidder LKT 81 in Selection Forests of Different Openness in the Region of Gorski Kotar. Mehanizacija šumarstva 25(1–2): 9–27.

Siren, M., 1999: One-Grip Harvesting Operations, Silvicultural Results and Possibilities to predict Tree Damage. In: Proc. IUFRO 3.09.00 Harvesting and Economic of Thinnings, Ennis, Ireland, p. 152–167.

Spinelli, R., 1999: The Environmental Impact of Thinning: More Good than Bad? In: Proc. IUFRO 3.09.00 Harvesting and Economic of Thinnings, Ennis, Ireland, p. 136–143.

Sažetak

Modeliranje oštećenja sastojine i usporedba dvaju sustava za pridobivanje drva

Gospodarenje se šumama u Sloveniji zasniva na prirodnoj održivosti i multifunkcionalnosti. Prevladava grupimično gospodarenje raznodobnim sastojinama, a čiste su sječe već desetljećima zabranjene. Zbog čestih

prorjeđivanja (u državnim šumama – 1 do 2 sijeka u istoj sastojini tijekom 10 godina), teških terenskih prilika i velikih dimenzija stabala najčešće je korišten ručno-strojni sustav za pridobivanje drva – MM (radnik s motornom pilom te zglobni traktor za privlačenje drva). Oplodne su sječe više iznimka nego pravilo.

Zbog brojnih društvenih promjena, promjena u cijenama energenata te razvoja informacijskih tehnologija, ali i zbog sve veće konkurencije na tržištu drva dovedene su u pitanje ekonomičnost i budućnost primjene takva načina pridobivanja drva. Glavni razlog postupnoga uvođenja potpuno mehaniziranoga sustava za pridobivanje kratkoga drva – CTL (sječa i izradba harvesterom te izvoženje forvarderom) nakon 2000. godine bila je želja za smanjenjem troškova, ali i nedostatak kvalificirane radne snage za ručno-strojni rad motornom pilom.

Uvođenje je sustava harvester – forvarder (CTL) dovelo do brojnih rasprava zbog straha od mogućih oštećenja preostalih stabala nakon sječe (moguće ozljede na deblu, panju, korijenskom sustavu i granama, savijena stabla) i šumskoga tla te je od početka bio prisutan negativan stav i suzdržanost prema tomu »novomu« načinu pridobivanja drva. Unatoč nepovoljnim rezultatima prethodnih istraživanja o oštećenju preostalih stabala nakon sječe motornom pilom uobičajeni način pridobivanja drva (MM) nije bio predmetom rasprava zbog svoje tradicionalnosti.

U radu je istraživan problem oštećenja preostalih stabala u sastojini nakon sječe pri primjeni dvaju sustava za pridobivanje drva, različitih s obzirom na razinu mehaniziranosti sječe i izradbe drva. Korišteni su osnovni model procjene i simulacijski model za procjenu oštećenja tijekom cijele ophodnje. Uspoređena su oba sustava s obzirom na ukupan broj oštećenih stabala, ali i struktura oštećenih stabala ovisno o ponavljanju oštećenja svakoga stabla pri izvođenju šumskih radova u različitim razdobljima (prorede).

Upotrebom osnovnoga modela za procjenu oštećenja stabala dobiveni su dobri rezultati u prošlosti (što je i potvrđeno terenskim mjerenjima), pa je tako i ovdje korišten isti model za usporedbu oštećenja ovisno o primijenjenim sustavima za pridobivanje drva. Korišteni osnovni model razvijen je za metodu oplodnih sječa, gdje je sječna gustoća određena odnosom doznačenih stabala i svih stabala u sastojini. Intenzitet oštećenih stabala jest odnos između oštećenih stabala po završetku sječe i svih preostalih stabala u sastojini.

Postavljene pretpostavke su:

⇒ *jednaka je vjerojatnost da svako stablo bude posječeno u određenom vremenu*

⇒ *jednaka je vjerojatnost da svako stablo bude oštećeno za vrijeme posljednje sječe*

⇒ *svako stablo koje je oštećeno više od jedanput u istom sijeku broji se kao jedno oštećenje*

⇒ *stablo je označeno kao oštećeno bez obzira na težinu ozljede.*

Osnovni model razvoja i procjene primjenjuje više kriterija nego što je bilo potrebno za ovu analizu, stoga je primijenjeno tzv. »pravilo akumulacije oštećenih stabala«. Udio oštećenih stabala nije neposredno ovisan o intenzitetu prorjeđivanja, međutim ta se ovisnost posredno javlja kroz intenzitet sječe (ε_i), gustoću vlaka (G) i udio oštećenih stabala (δ_i) nakon i-te prorede. Primijenjene su jednadžbe omogućile dobru procjenu ukupne oštećenosti stabala u sastojini nakon i-toga prorjeđivanja te je zbog želje da se sazna učestalost ozljeda na stablima na kraju ophodnje postavljeno pitanje: koliko se ozljeda može očekivati na stablima i deblima? Za odgovor na to pitanje napravljena je simulacijska matrica sa $N_s = N_0$ redova i i = n stupaca. Ukupni udio oštećenih stabala bio je jednak kao i kod upotrebe osnovnoga modela.

Slika 1 prikazuje usporedbu udjela oštećenih stabala nakon i-te prorede za dva načina pridobivanja drva tijekom cijele ophodnje. Ukupni broj oštećenih stabala stalno raste do vrijednosti od 90 % na kraju ophodnje. Iako su to zapanjujući rezultati, postavlja se pitanje da li se navedeno može dokazati i na terenu. Naravno, treba uzeti u obzir da brojna oštećenja s vremenom zarastaju – time i nestaju, zatim nepoznavanje prije korištenih sustava za pridobivanje drva, a s tim i količine nastalih oštećenja, ali i nedovoljno točni podatci o prijašnjim sječama. Vidljivo je i da razlika između korištenih sustava za pridobivanje drva nije stalna za vrijeme cijeloga životnoga vijeka stabla, ali da doseže najveću vrijednost (0,10) u 70-oj, odnosno 80-oj godini starosti te nakon toga opada (0).

U tablici 4 prikazani su rezultati simulacije. Prednost je ove metode procjene u tome što se mogu dobiti podatci o oštećenjima ovisno o vremenu nastajanja te broj stabala koja su bila oštećena više od jedanput. Moguća je analiza oštećenja na deblu (nakon sječe), pa je tako moguće odrediti i gubitak na vrijednosti zbog nastalih oštećenja, ali to ipak nije bio cilj ovoga istraživanja.

Na slici 2 prikazane su razlike u broju oštećenih stabala nakon cijele ophodnje. Upotrebom se sustava CTL za pridobivanje drva očekuje manje oštećenih stabala.

Slike 3 i 4 prikazuju strukturu relativne učestalosti javljanja oštećenja ovisno o godinama. Udio jednom oštećenih stabala najveći je u 70-oj godini starosti za ručno-strojni način pridobivanja drva (MM), te u 90-oj godini za sustav CTL za pridobivanje drva, nakon čega udio opada dijelom zbog povećanja broja ozljeda na stablu, a dijelom zbog same sječe tih stabala. Udio dva puta oštećenih stabala najveći je za ručno-strojni sustav za

pridobivanje drva u 100-oj godini, a za sustav CTL u 150-oj godini starosti. Ostale krivulje pokazuju sličan tijek. Usporedbom tih krivulja jasno je da sustav CTL za pridobivanje drva doseže vrhunac u kasnijim godinama ophodnje jer je manje oštećenja za vrijeme svakoga prorjeđivanja.

Istraživanje je pokazalo da sustav CTL za pridobivanje drva uzrokuje manje oštećenja u šumi, sporije povećanje broja oštećenih stabala tijekom vremena, ali i bolju distribuciju nakupljenih oštećenja u sastojini, što povećava stabilnost sastojine, ali i povećava vrijednost drva.

Broj stabala po jedinici površine utječe na udio ozljeda pri primjeni sustava CTL te ako se usporede podatci o oštećenjima stabala iz skandinavskih zemalja (<0,05) s podatcima iz srednje Europe, dolazi do određenih odstupanja pa je stoga potrebno unaprjeđenje postojećega modela pomoću stvarnih terenskih mjerenja.

Tijekom nedavnih istraživanja i mjerenja (koja još nisu objavljena) primjenom modificirane Frödigove metode (1992) primijećeno je da su oštećenja na stablima veća ako operater radi u tamnom okruženju (s upaljenim svjetlima). Također ne postoje pouzdana istraživanja o produljenom radnom vremenu i samoj kakvoći rada koja uključuje i količinu nastalih oštećenja na stablima. Odgovori na ta i druga pitanja pojasnit će ovdje dobivene rezultate.

Ključne riječi: *oštećenja sastojine, sječa, tehnologije, ručno-strojna sječa, strojna sječa*

Author's address – *Autorova adresa:*

Prof. Boštjan Košir, Ph.D.
e-mail: bostjan.kosir@bf.uni-lj.si
University of Ljubljana, Biotechnical Faculty
Department of Forestry and Forest Resources
Večna pot 83
1000 Ljubljana
SLOVENIA

Received (*Primljeno*): April 7, 2008
Accepted (*Prihvaćeno*): June 10, 2008