A Damage Prediction Model for Quantity Loss of Skidded Spruce Logs during Ground Base Skidding in North Eastern Turkey

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Abstract – Nacrtak

In Turkey ground base skidding method is frequently used to extract log material. Physical damages occurring on the skidded log during ground based skidding cause quality and quantity loss of the log. This damage is formed by the ground structure, mass of transported logs, friction coefficient and skidding distance. In this study to improve a »Damage Prediction Model« means to predict the quantity loss that can occur as a result of ground skidding on steep areas. Spruce forests in Maçka, Trabzon, Eastern Blacksea, was selected as the study area. The slope of study area ranged between 45% and 80%. In this context, a total of 318 logs were researched. These logs were skidded in 6 harvested areas where skidding is done both in summer and winter. It was determined during research that the types of damage causing quantity loss are breakage and wood wearing out. In the meantime, the quantity loss occurring as a result of breakage and wood wearing out was calculated as volume. A prediction model was developed by taking into consideration friction vector affecting skidded log, friction surface area of the log and skidding distance parameters. The model was developed based on data related to logs skidded in summer and winter. Damage prediction model coefficients were obtained for two production seasons by solving models according to the least squares method. Statistical significance of coefficients was done and damage prediction models were obtained with significant coefficients for summer and winter production seasons. This enabled producers to predict the quantity loss before skidding and to take necessary precautions.

Keywords: ground base skidding, log volume loss, damage prediction model

1. Introduction – *Uvod*

The extraction of logs with minimum wearing out of wood and with the least quantity loss is very important since forestry sector is an enterprise based on the cost of the last production and sale. It has been emphasized that annual global harvest will reach 5.1 billion m^3 from the year 2010 (Dykstra and Heinrich 1996). If the existing forest fields continue to be constricted annually by 15 million hectares, the quantity of the logs to be produced in 2010 will be 60% more than today. It will nearly be 1.6 m^3 ha^{-1} (Dykstra and Heinrich 1996). Therefore, the quantity loss formed during production phase of logs becomes increasingly important.

In a study carried out on damages occurring on skidded logs, it was established that more than 16% of the product is damaged during log harvest done by regional techniques (Favreau 1998). Legere (2001) determined that serious damages occur in 5% of logs in the fields where regional techniques are used (Legere 2001). Gürtan (1975) pointed out that a 15–17% volume loss occurred after extraction without disintegration done in study areas as a result of his study (Gürtan 1975). Acar and Dinc (2001) found the quantity loss of 13% and quality loss of 39.7%, respectively, during extraction of logs skidded on areas with lower snow cover.

The most frequently used extracting method in Turkey is ground based manual skidding. On the other hand, the production of industrial logs cannot compensate the market demand since this method causes more damage to logs. Economic loss occurs when 15% of market demand is imported (Kaplan 2007, Acar et al. 2008). Also, mostly 50% of wood in the world can be burnt, while this amount is 64% in Turkey. Obviously skidding logs on the ground also causes quality loss.

The most frequent types of damage occurring during skidding on the ground are breakage on the tips, shriveling and total wood wearing out of logs (FAO 1998). Before stowing the log extracted without wood wearing out, the breakages on tips are cut and the log is shaped in neat cylinders. It was emphasized that the quantity of damage caused by skidding depends on peculiarities of the ground, possible ways of skidding, ruggedness of the area and the quantity of bushes around (Wang et al. 2004).

The aim of this study is to develop an improved damage prediction model that would indicate the effects of ground-based skidding without disintegration of logs and determine the model separately for both summer and winter skidding activities. Damage prediction model was improved by taking into consideration some factors such as log diameter and mass, tree species, ground structure, skidding distance and friction coefficient. This model was separately developed according to data on damages of 186 spruce logs skidded in summer and 132 spruce logs (*Picea orientalis* /L./ Link.) skidded in winter in the study area. Regression models were solved with the Least Squares Method and coefficients were calculated. Significance tests of these coefficients were statistically analyzed. Models for summer and winter production seasons were determined with the coefficients which were found significant. The obtained regression models were compared with respect to production seasons. As a result of this study, producers will be able to predict the quantity loss of logs before skidding by applying models obtained for summer and winter production seasons.

2. Materials and methods – *Materijal i metode*

Spruce forests within the borders of Maçka Forest Range Management, region of Trabzon, Eastern Blacksea, were selected as the study area. The location of the research is 39° 39′–39° 45′ E, 40° 45′–40° 52′ N, 900–1,600 m above sea level. The Region has a per-humid climate with a mean annual temperature of 14°C with little seasonal variation. The average annual precipitation is about 731.6 mm. The slope of study areas ranges between 45% and 80%. Field data from six mature spruce forests were taken for model initialization. All production fields selected as research area are pure eastern spruce (*Picea orientalis* /L./ Link.) stands. The growing stock of stands is 464 m^3 ha^{-1} (for all trees with DBH >10 cm) (Anonymous 2002). Forest roses (*Rhododendron Pentium* and *Rhododendron lustrum*) are found in understory sections. Fig. 1 illustrates general view of research areas.

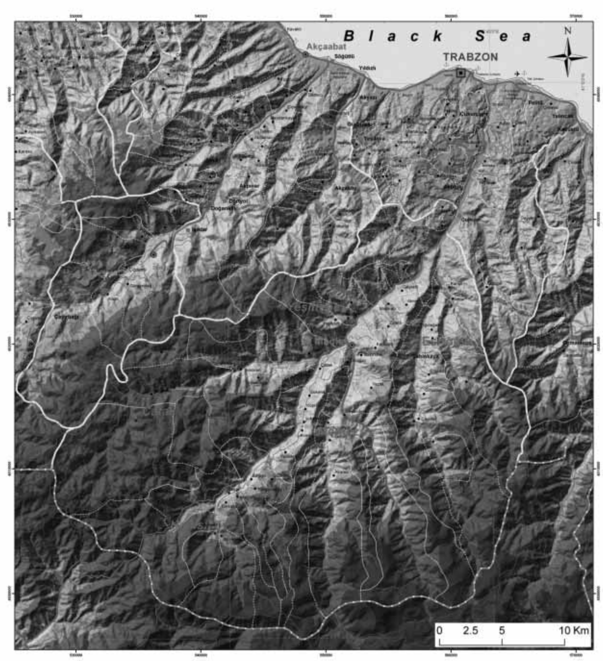

Fig. 1 The location of researched area in Trabzon Region

Slika 1. *Položaj mjesta istraživanja u regiji Trabzon*

Area studies were carried out between May and July in summer and between January and March in harvesting sections shown in Fig. 1. Studies were carried out during skidding or soon after it. After skidding, every log brought to the transporting area was checked and it was determined whether it was damaged or not. The diameters and heights of dam-

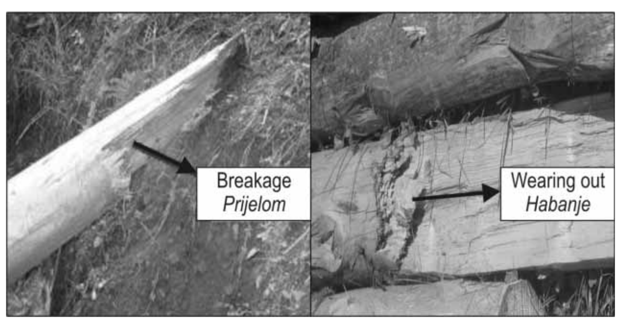

Fig. 2 Types of damage of transported logs

Slika 2. *Vrste oštećenja na privučenim trupcima* aged logs were surveyed and the breakages on the tips and total disintegration were determined (Fig. 2).

The diameters and lengths of broken logs were calculated, as well as the length of breakages that have to be cut out, and diameters and lengths of disintegrated pieces. The size of pieces obtained from logs is very important since this changes the quality class and type of the log. Before stowing the transported products, they were re-bucked by cutting out completely the damaged parts. As the result of this operation, the size, type and class of logs changed.

The prediction of damage that can occur on the spruce log by ground skidding is important in order to reduce the possible quantity loss of the log. For this reason, a damage prediction model can be developed by taking into consideration the forces affecting the skidded log. This damage prediction model will enable producers to determine in advance the quantity of possible loss in the logs as a result of skidding.

The main types of damage causing quantity loss during skidding are breakages at the tip parts and total wood wearing out of the log. Therefore, the volume loss V_L (m^3) occurring as a result of skidding is equal to the volume of the totally disintegrated logs and cut out of the broken parts. The developed model took into consideration the following parameters: friction force F (N), friction surface area A (m^2) and skidding distance s (m).

$$V_L = \{F, A, s\} \tag{1}$$

The most important forces affecting the log skidded on inclined ground are friction force and the weight of the log (G) as shown in Fig. 3.

As shown in Fig. 3 friction force is obtained with Eq.2 depending on the pitch angle (α), gravity acceleration (g), friction coefficient (k) and the log mass (m) (Serway and Beichner 2002, Bueche and Jerde 1995).

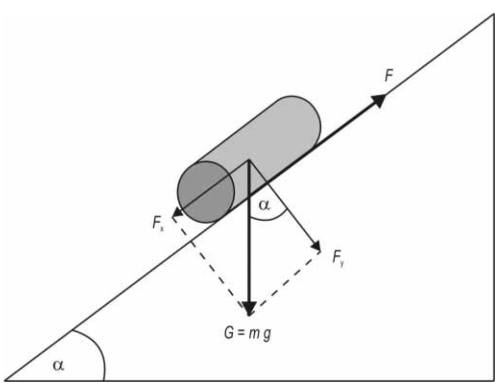

Fig. 3 The forces affecting the log skidded on inclined ground

Slika 3. *Utjecajne sile pri vuči trupca na nagibu*

$$F = k \cdot m \cdot g \cdot \cos\alpha \tag{2}$$

m is calculated by taking into consideration the specific density of the log ρ (kg/m^3).

$$m = V\rho \qquad 3$$

The lateral surface area of the log S_A (m^2) is calculated from Eq. 4.

$$S_A = \pi\, r\, l \tag{4}$$

where, r is diameter of the log and l is the length of the log. Friction surface area A (m^2) is calculated depending on the proportion of the log/ground touch area (t).

$$A = S_A\, t \tag{5}$$

t can be determined based on experience as a result of observation of logs skidded on grounds having different characteristics. Another variable affecting skidded logs is skidding distance. Skidding distance is measured and added to the model as a parameter.

The volume of the lost part after skidding is calculated by measuring the size of breakages and disintegrated parts. Thus, a »Damage Prediction Model« indicating the functional relation between the determined friction force, friction surface area, skidding distance and damage volume is developed as follows:

$$V_L = \mathrm{a}\, F + b\, A + \mathrm{c}\, s \tag{6}$$

where a, b, and c are the regression coefficients. The data group forming the model such as friction force, friction surface area, skidding distance and the volume loss have different units. For this reason the data should be standardized before the solution. The regression coefficients in the model have been calculated by the Least Squares Method (Koch 1999, Wolf and Ghilani 1997, Bill 1994).

The regression model in Eq. 6 can be written for all logs as in Eq. 7 using Gauss Markoff model.

$$V_{L1} + e_1 = \mathrm{a}\, F_1 + \mathrm{b}\, A_1 + \mathrm{c}\, s_1$$

$$V_{L2} + e_2 = \mathrm{a}\, F_2 + \mathrm{b}\, A_2 + \mathrm{c}\, s_2$$

$$V_{Ln} + e_n = \mathrm{a}\, F_n + \mathrm{b}\, A_n + \mathrm{c}\, s_n \tag{7}$$

where $e_1, e_2, \ldots, e_n$ are errors and n is the number of logs. Eq. 7 can be shown in matrix form:

$$y + e = X\beta \tag{8}$$

where X is the coefficients matrix, β is the regression coefficients vector and y is the volume loss vector. The regression coefficients (β) have been calculated according to the Least Squares Method.

$$\beta = (X'\,X)^{-1}\,X'\,y \tag{9}$$

where, X' is the transpose of the coefficients matrix and $()^{-1}$ is the inversion of the matrix.

Significance of the regression coefficients are tested using multi-variance analysis. The test values are computed from mean errors of the regression coefficients. These values are compared with *t*-table value and decision is made whether the regression coefficients are significant or not (Grafarend 2006, Koch 1999, Tatsuoka 1971, Cooley and Lohnes 1971).

3. Research results and discussion – *Rezultati istraživanja s raspravom*

The damage prediction model was developed based on data of 186 logs damaged in summer production areas and 132 logs damaged in winter production areas. Model coefficients were calculated according to the process order as shown below:

⇒ Friction force *F* (N) – The friction force of each log is calculated by Eq. (2) by taking into consideration mass (m), slope angle of the area, gravity acceleration and friction coefficient. Friction coefficient of 0.4 was assumed for soil ground in summer season and 0.1 for snowy ground in winter season.

⇒ Friction surface area *A* (m^2) – The surface area of each damaged log was calculated by Eq. (4). When the proportion of log touch to the ground of 1/3 was assumed for soil ground in summer season based on observations carried out in research areas and of 1/4 for snowy ground in winter season, the friction surface area was calculated by Eq. (5).

⇒ Skidding distance *s* (m) – Skidding distance was measured for each section where both summer and winter production seasons were established and averages were calculated according to production seasons.

Table 1 Average values of parameters

***Tablica 1**. Srednje vrijednosti parametara*

Harvesting seasons *Razdoblje izvođenja radova*	Friction force *Sila trenja*	Friction surface area *Dodirna površina*	Skidding distance *Udaljenost privlačenja*	Amount of damage *Količina oštećenja*
	F	A	s	V_L
	N	m^2	m	m^3
Winter *Zima*	–213,847	0,081	450	0,045
Summer *Ljeto*	–235,187	0,157	600	0,057

⇒ Amount of damage V_L (m^3) – The amount of damage, the volume of broken parts and disintegrated logs, was calculated by Eq. (3).

The data were standardized. This process was carried out by assigning each data element (*F, A, s* and V_L) into mean value of their group (Table 1).

The models were developed by V_L, *F, A* and *s* determined for winter and summer seasons separately. These models were solved with the Least Squares Method for both production seasons and the regression coefficients were calculated by Eq. (9). Table 2 presents the following parameters: coefficient of friction force (a), coefficient of friction surface area (b) and coefficient of skidding distance (c).

Table 2 Damage prediction model coefficients for summer and winter

***Tablica 2.** Koeficijenti modela predviđanja oštećenja za ljetno i zimsko razdoblje*

Harvesting seasons *Razdoblje izvođenja radova*	Coefficients – *Koeficijenti*		
	a	b	c
Winter – *Zima*	3.094377	–0.027386	2.203501
Summer – *Ljeto*	1.885007	0.058544	2.773475

As shown in Table 2, the coefficients of a and c have the same sign (plus) for both summer and winter production seasons, whereas the coefficient of b has the inverted sign (plus/minus).

The coefficients of a, b and c were tested using multi-variance analysis. To determine whether the calculated coefficients are statistically significant, the mean errors of the regression coefficients (m_β) and the test values (T_β) for each coefficient were calculated. The test values were compared with the t-table value at the 95% significance level and it was decided whether the regression coefficients were significant or not (Table 3).

Table 3 shows that the test values of model coefficients in both summer and winter are bigger than table-*t* values. It was thus determined that the coefficients given in Table 2 are statistically significant.

Significant coefficients were determined for damage prediction models for summer and winter seasons.

$$V_{L\,(winter)} = 3.094377\,F - 0.027386\,A + 2.203501\,s \quad (10)$$

$$V_{L\,(summer)} = 1.885007\,F + 0.058544\,A + 2.773475\,s \quad (11)$$

The volume and mass of logs to be skidded were calculated by producers before skidding activities. The friction force was calculated for each log by taking into account the slope of the skidding area, log

Table 3 Statistical analysis of model coefficients for winter and summer production seasons
Tablica 3. *Statistička analiza modela predviđanja oštećenja za ljetno i zimsko razdoblje radova*

Harvesting seasons *Razdoblje izvođenja radova*	Winter – *Zima*			Summer – *Ljeto*		
Coefficients – *Koeficijenti*	a	b	c	a	b	c
Mean Error (m_β) *Srednja pogreška* (m_β)	0.5208	0.0014	0.36405	0.2149	0.0017	0.33857
Test Values (T_β) *Vrijednosti testa* (T_β)	5.94	19.56	6.05279	8.77	34.44	8.19
t-table (one- tailed test) *Tablična vrijednost (jednostrani t-test)*	1.98	1.98	1.98	1.97	1.97	1.97
Decision (T_β > t-table) *Odluka* (T_β > *t-tablični*)	significant *značajno*	significant *značajno*	significant *značajno*	significant *značajno*	significant *značajno*	significant *značajno*

mass and friction coefficient depending on harvesting season by Eq.2. After that friction surface area of logs (A) was calculated by using surface area of logs (Eq.4) and proportion of log touch to the ground according to harvesting season by Eq.5. The skidding distance of logs (s) was measured in the study area. Each data group was standardized by determining their average value as shown in Table 1 for each harvesting season, winter and summer. Volume loss was calculated by using these values with the above equations in standardized form. Then, volume loss after skidding was calculated in m^3 by multiplying standardized volume loss and the average value of volume loss V_L.

4. Conclusions – *Zaključci*

In this study, a »Damage Prediction Model« was developed to predict the quantity loss that can occur for spruce wood as a result of ground skidding. Quantity loss, caused by broken and disintegrated parts, occurs on transported logs, as a result of extracting logs with Ground Based Skidding Method. It is important to predict the damage that can occur on logs before skidding in order to reduce the quantity loss. The prediction of the possible damage depending on land peculiarities will prevent economic loss and provide an opportunity to take precautions before skidding. For this reason, a damage prediction model was developed to predict the quantity loss occurring on the log as a result of skidding. The model is based on parameters such as the structure of the ground affecting the skidded log, mass of the transported log, friction force and skidding distance. Coefficients for both summer and winter were calculated by solving the model based on data obtained from logs damaged during skidding.

It was established that the coefficient of friction force for summer and winter and the coefficient of skidding distance have the same sign, while the coefficient of friction surface area has the inverted sign. This might be caused by the structure of the ground since the friction surface of the log is smaller on a smoother snowy ground. Also, it was established that friction coefficients of the surface area are nearly the same for both seasons, while the friction force coefficient is different. The coefficient value of friction force parameter for winter is higher than that for summer. The reason for that might be the fact that friction between the log and snowy ground is smaller than friction between the log and soil.

Prediction of volume loss before skidding is important for decreasing the possible volume loss. Therefore, the producers were provided with the opportunity of predicting the quantity loss and taking necessary precautions before skidding activities, e.g. skidding road maintenance and use of wood cover.

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Sažetak

Model predviđanja gubitka drvnoga obujma smrekovih trupaca pri vuči po tlu u sjevero-istočnoj Turskoj

Vuča je drva po tlu česta metoda privlačenja u turskom šumarstvu. Fizička oštećenja trupaca pri vuči po tlu uzrokuju gubitak kakvoće i količine drvnoga obujma. Veličina nastalih oštećenja ovisi o vrsti podloge, stanju tla, masi vučenoga trupca, faktoru trenja i udaljenosti vuče.

Cilj je ovoga rada određivanje modela predviđanja oštećenja, tj. predviđanja gubitaka količine drvnoga obujma pri vuči trupca po tlu na strmim terenima. Model uključuje čimbenike kao što su: promjer i masa trupca, vrsta drva, stanje tla, udaljenost vuče, faktor trenja te razdoblje izvođenja radova (zima, ljeto).

Istraživanje je provedeno u Šumskom gospodarstvu Maçka u regiji Trabzon (slika 1). Mjereno je u šest čistih sastojina kavkaske smreke (Picea orientalis /L./ Link.). Prosječna drvna zaliha sastojina iznosi 464 m^3/ha. Nagib se terena na mjestu istraživanja kretao u rasponu od 45 % do 80 %. Zimi je istraživanje provedeno od siječnja do ožujka, a ljeti od svibnja do srpnja.

Ukupno je privučeno 186 smrekovih trupaca ljeti te 132 trupca zimi. Pri tome su mjerene udaljenosti vuče i nagibi terena.

Neposredno nakon vuče smrekovih trupaca po tlu na stovarištu su izmjereni promjer i duljina svakoga oštećenoga trupca te određen ukupni drvni obujam trupaca. Također su izmjereni promjer i duljina oštećenja (slika 2) te određen gubitak drvnoga obujma (V_L) koji se naknadnim prikrajanjem izuzima iz prvobitnih dimenzija trupca. Time se uz smanjenje drvnoga obujma mijenja razred kakvoće trupca.

U istraživanju je gubitak drvnoga obujma (V_L) promatran u odnosu na silu otpora trenja (F), dodirnu površinu trupca i tla (A) te udaljenosti vuče po tlu (s) (izraz 1).

Utjecajne su sile pri vuči trupca po tlu težina trupca i sila otpora trenja (slika 3). Sila otpora trenja (F) ovisi o masi trupca (m), nagibu terena (á), gravitacijskom ubrzanju (g) i faktoru trenja (izraz 2). Masa je svakoga trupca određena na temelju drvnoga obujma trupca i gustoće drva (izraz 3). Faktor je trenja iznosio 0,4 kod tla u ljetnom razdoblju, odnosno 0,1 kod tla prekrivenoga snijegom zimi.

Površina je plašta trupca (S_A) određena na osnovi dimenzija trupca, a njezinim množenjem s faktorom dodira trupca s tlom (t) određena je dodirna površina trupca i tla (A) – izrazi 4 i 5. Faktor dodira trupca s tlom iznosio je 1/3 kod tla ljeti, odnosno 1/4 kod tla prekrivenoga snijegom u zimskom razdoblju.

Srednje su vrijednosti izmjerenih i izračunatih parametara prikazane u tablici 1.

Zasebno za oba razdoblja izvođenja radova obavljena je regresijska analiza podataka primjenom metode najmanjih kvadrata te su utvrđeni koeficijenti regresije (tablica 2). Rezultati statističkoga testiranja (t – test) pokazuju značajnost svih koeficijenata (tablica 3).

Izrazi 10 i 11 prikazuju modele predviđanja gubitka drvnoga obujma pri vuči drva po tlu u zimskom i ljetnom razdoblju izvođenja radova u ovisnosti o sili otpora trenja, dodirnoj površini trupca i tla te udaljenosti vuče. Uočava se da je koeficijent dodirne površine negativnoga predznaka u zimskom razdoblju, a pozitivnoga u ljetnom razdoblju izvođenja radova. Pretpostavlja se da je tijekom vuče trupca po tlu prekrivenom snijegom dodirna površina manja nego pri vuči trupca po tlu ljeti. Koeficijent sile otpora trenja veći je pri vuči trupca po tlu zimi jer je manje trenje između trupca i tla pokrivenoga snijegom.

Izrađeni modeli predstavljaju značajan doprinos šumarskoj praksi i ukazuju na potrebu poduzimanja pripremnih radnji (održavanje vlaka, korištenje zastora od drvnih ostataka na vlakama) prije radova privlačenja drva radi smanjenja gubitaka drvnoga obujma pri vuči drva po tlu.

Ključne riječi: vuča po tlu, gubitak drvnoga obujma trupca, model predviđanja oštećenja

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