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Determining the maximum allowable cross slope of skid trails for rubber-tired skidder Timberjack 450C

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ABSTRACT

The forest harvesting is a most expensive system in forest management plans. The main objective of the harvesting is to minimize logging time, cost and damage. In order to correct management and minimize cost, all of the components of a system must be recognized. Primary transportation is a component of harvesting system, which is carried out using rubber-tired skidders and skid trails in Iran. Cross slope of skid trails is one of the effective factors on skidding time. In this study, the effects of the cross slope of skid trail on skidding time for loaded and unloaded skidder was investigated. After measuring the effective factors on skidding time, data were analyzed in SPSS software and then models were produced. Results showed that skidding time was a function of cross slope, number and volume of pieces. For unloaded skidder, the relation between cross slope and skidding time was incremental and for loaded skidder the relation between cross slope and skidding time was multiplier parabola. The skidding time increased with increasing the volume of pieces in all cross slope classes.

Keywords: Cross slope, Ground skidding, Mathematical model, Time study, Timberjack 450C

INTRODUCTION

Forest harvesting is the second step of wood production which is called mechanical production. This expensive system is included of feeling, bucking, primary transportation, loading, secondary transportation and road construction. To access more efficiency in system, the system components must be organized in economic, environmental and silvicultural issues [5]. Primary transportation is the important component of harvesting system. In the northern forests of Iran, the rubber-tired skidder is frequency used after skid trails and roads planning. So, because of the sensitivity and high cost of this step, development of skidding machines and conservation of forest environment, the efficiency analysis of harvesting machines is important [11].

One of the limitations during timber extracting operation is the slope of skid trail. The excavation area in these trails is less than that of the forest roads, because approximately 50 % of skid trails in northern forests have slope less than 30% [6]. [11] in a research about performance of rubber-tired skidding machine in Guilan forests concluded that skidding time is a function of the number of load pieces, skidding distance, volume of pieces and longitudinal slope of skid trail. In another studies which was conducted by [4], it was proved that skidding time for rubber-tired skidder machines is a function of skidding distance, volume of pieces per cycle and longitudinal slope of skid trail.

By comparing the efficiency of cable rubber-tired skidder and grapple skidder in a southern pine stand, it was concluded that efficiency and speed of grapple skidder is more than that of cable skidder. Moreover, skidding distances, pieces size, number of load pieces and trees density in stand are the main factors affecting grapple skidder efficiency [12]. Besides, studies about harvesting cost in Canada showed that pieces size, skidding distance, topographical status of forest (gentle, moderate and steep terrain) and operator skill are the main factors affecting harvesting cost [8].

During research carried out in west of the Virginia state of USA, ground skidding in a broad leaved forest stand was investigated. Results indicated that among the factors affecting skidding time, slope and distance increases the skidding cost and the volume of pieces decreases the skidding cost [2]. Investigation of Harwarder efficiency during lightening operations in Sweden forests showed that by selecting a suitable method the machine productivity increases. In addition, skidding distance, length and volume of pieces are the main factors affecting the movement time of Harwarder [7].

[1] studied the performance of mechanized harvesting machines. They showed that the effect of the volume of pieces on loaded skidder speed (Skidding time) in a steep skid trail is more effective than that of slope and number of load pieces. The productivity of a Timberjack 240C in extracting round wood of beech was studied in two regions with different conditions in Croatian forests. Results showed that skidding time is a function of the number of load pieces, skidding distance, volume and size of pieces. The mean speed of skidder in uneven steep slopes was about twice the speed in even gentle terrain [3].

[13] In a study in Croatian forests indicated that the importance of the volume of load pieces in uphill skidding time for ground skidding machines is more than that of downhill skidding. To optimize forest roads in Nowshahr, [10] applied NETWORK 2000 software. Results showed that skidding time is a function of the number of load pieces, skidding distance and volume of pieces. The skidding time increased with increasing these factors.

According to above descriptions in previous studies, the cross slope of skid trail wasn't considered in models. So, the main objective of this study was to assess the effects of cross slope of skid trail on skidding time (unloaded and loaded skidder).

MATERIALS AND METHODS

Description of the study area

This study was conducted in compartment 2, district 3 of forest management plan in company of Mazandaran wood and paper industries. This region is located between 36˚ 22′ to 36˚ 26′ N, 53˚ 02′ to 53˚ 07′ E, in watershed number 71 of Tejen and on the lowlands. The maximum altitude in district is 715 meter. Minimum altitude in compartment 2 is about 360 meter and the maximum 530 meter. The majority of slope inclination is less than 30%. According to nearest climatology station and Embergeh classification, the climate of study area is moist. The region receives 808 mm of precipitation annually. The general aspect of the hillside is northern. The bed rock is marl, calcareous sandstone and sandy limestone with weak infiltration. The soil is washed brown with pseodoglay. Soil texture is heavy to very heavy and relatively deep. Forest type is *Fageto-carpinetum* and the forestry method is mixed uneven aged. The amount of harvesting was 817 m^3. The depot was constructed at the edge of the haul road in the down of the felling compartment. Therefore, the direction of the skid trails was downward.

Data collection

In this study, the effect of the cross slope of skid trail and the other effective factors on skidding time were investigated using time study method. The cross slope along a skid trail was classified into 0-2%, 2-4%, 4-6%, 6-8%, 8-10% and control (without cross slope). Then, loaded skidding time and unloaded skidding time as well as other effective factors in each working cycle of skidder were recorded. The longitudinal slope, number of load pieces, length of load pieces, type of pieces, and diameter of pieces and maximum deviation of logs from skid trail were measured for each travel on cross slope. The length of all the cross slope classes and control point on skid trail was considered fixed. The volume of load pieces was estimated using Huber equation in each working cycle. Data were entered into SPSS software 16 and then the stepwise regression model was used for calculating the time model of skidder travel in points which have cross slope. Moreover, the numerical estimation model of cross slope was computed. Table 1 illustrates the primary statistical calculations of measured variables in study area. Besides, the characteristics of the selected slope classes are shown in Table 2.

Table 1- Statistical parameters for the measured variables during skidding in study area

Variable	Mean	Standard deviation	Minimum	Maximum
Number of load pieces per cycle	1.9	0.71	1	3
volume of pieces per cycle (m^3)	6.14	1.22	4.36	8.7
Length of pieces (m)	8.12	1.07	6	11

Table 2- Properties of the selected slope classes in nature

Row	Longitudinal slope (%)	Skid trail length (m)	Cross slope (%)	Soil moisture (%)
Ctrl	16	20	0	7
1	18	20	0-2	7
2	16	20	2-4	6
3	17	20	4-6	4
4	17	20	6-8	4
5	15	20	8-10	3

RESULTS

The SPSS program and stepwise test was used for obtaining the mathematical model of skidding time prediction. Then, travel time model for loaded and/or unloaded skidder Timberjack 450C (in Sec) during pass on cross sloped trails was obtained as following:

$$Y = 46.72 + 1.392CS + 0.372v - 0.610n \qquad \text{(Sec)}$$

Where *Y* is the travel time of skidder Timberjack 450C (loaded and unloaded skidder), *CS* is the cross slope (%), *v* is the volume of pieces (m^3) and *n* is the number of load pieces.

The results of the analysis of variance showed that there was a significant correlation between the cross slope and volume of pieces as well as cross slope and number of load pieces at probability level of 0.01%. In fact, the variables of cross slope, volume and number of pieces were the main effective factors which could predict skidding time (loaded and unloaded skidder). The variables which entered in the multiple regression models, could describe 0.85% of variations (Table 3).

Table 3- ANOVA skidding model for variables

Source	Sum of square	Degree of freedom	Mean square	F	R^2	Sig
Regression	4830.35	3	1610.11	477.74	0.85	0.00
Residual	832.44	247	3.37			
Total	5662.79	250				

Validity of the model

Confidence limits of skidding time estimated by the model are calculated and compared with real skidding time. To calculate confidence limits estimated by model (estimated time) following formula is used:

$$\gamma \pm = \%5\sqrt{(Mse)(1 + \frac{1}{n} + \xi^{1} sp^{-1} \xi)}$$

Where *Y* is estimated time by model for each turn of skidding without considering delay time, *Mse* is mean square error, *n* is number of skidding turns used in the model, ξ is numeric value obtained from time study of effective variables in the model to calculate time for each turn of skidding, *and sp* is inversion of sp^{-1} Matrix.

Table 4- Validity of model in control samples

Confidence limit	Measured time	Estimated time
44.3< 47 <51.76	47	48.03
55.21 < 52 <60.55	52	56.38

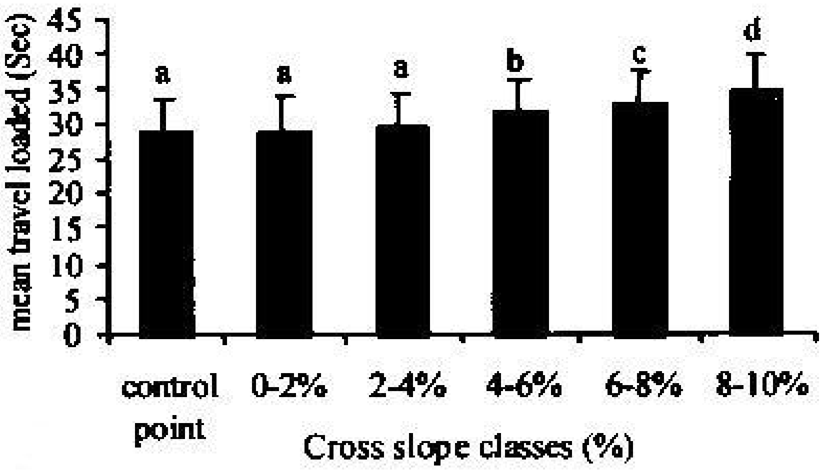


Fig 1- The effect of cross slope on travel time of loaded skidder

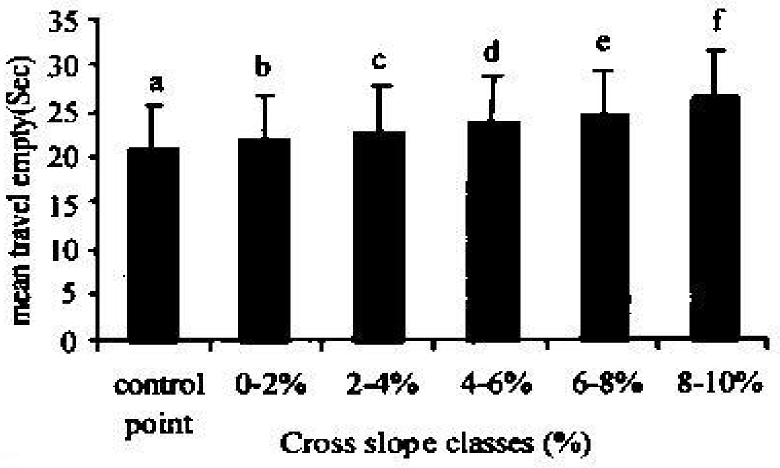
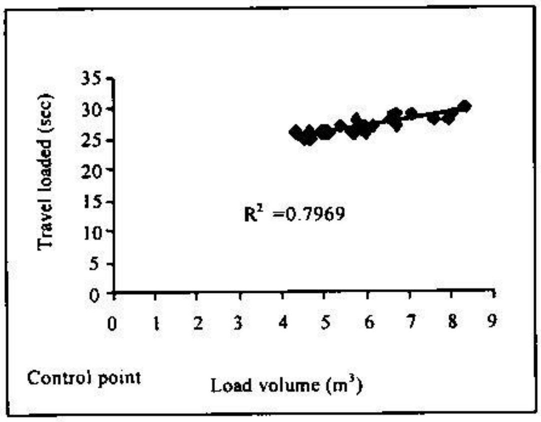


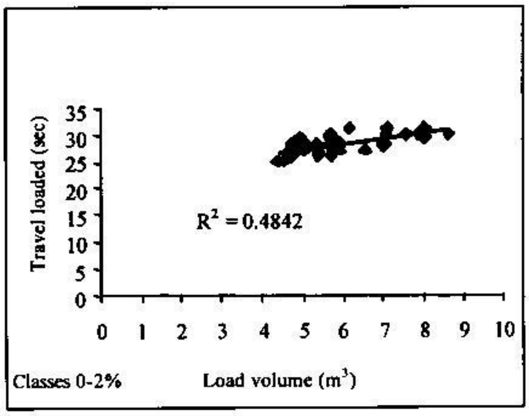
Fig 2- The effect of cross slope on travel time of unloaded skidder

According to Figure 1, the mean skidding time of unloaded skidder increases with the increase of the cross slope. The mean of time in different cross slope classes had significant difference. Moreover, the mean skidding time of loaded skidder increases with the increase of the cross slope. The mean of time hadn't significant difference among the cross slope classes of control, 0-2% and 2-4%, while in other classes (4-6%, 6-8% and 8-10%) the mean of time increased with increasing cross slope (Fig. 2).

The mean skidding time of loaded skidder increases linearly with the increase of the volume of load pieces in all of the cross slope classes (Fig. 3).



(a)



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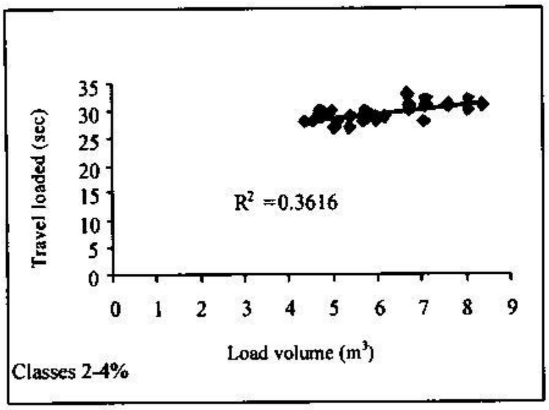
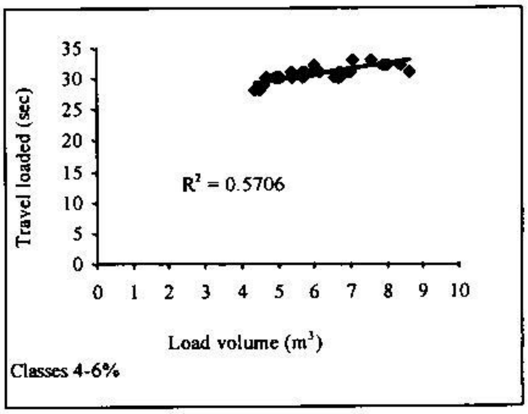
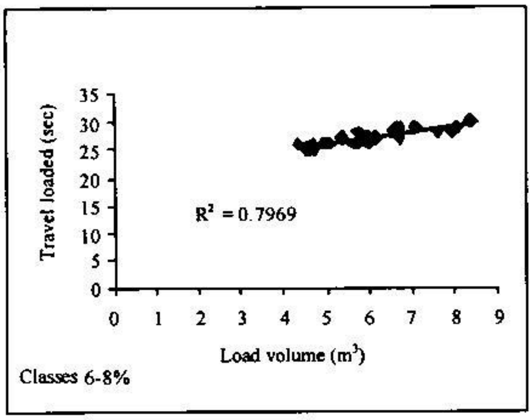


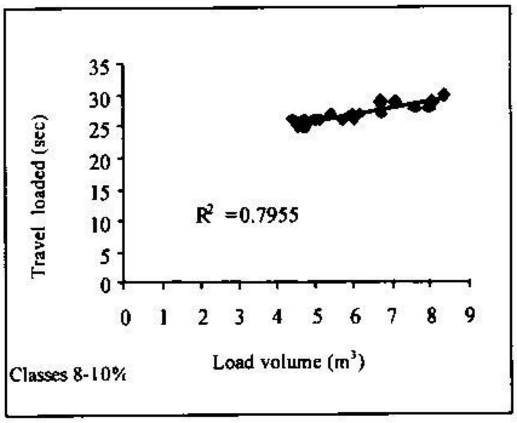
(c)



(d)



(e)



(f)

Fig 3- The effect of the volume of load pieces per working cycle on travel time in cross slope classes of control (a), 0-2% (b), 2-4% (c), 4-6% (d), 6-8% (e) and 8-10% (f)

DISCUSSION

The results of this study showed that the model development and prediction of working time can be useful for estimating the skidding time and its cost. Moreover, these results can help logging planners to improve working condition and to increase working efficiency via selection of suitable method. In the final model of this research the cross slope, volume and number of load pieces had significant effect on skidding time. Among different factors which were entered in the skidder travel time model, the volume of load pieces was the main effective factor on travel time of loaded skidder.

The skidding time increases linearly with the increase of the volume of load pieces in each cross slope class. Moreover, the mean skidding time of unloaded skidder increases linearly with the increase of the cross slope. But, the mean skidding time of loaded skidder increased (parabola multiplier) with the increasing of cross slope. There wasn't significant difference among means of loaded skidder travel time from control (0%) to cross slope class of 2-4%. By increasing the cross slope from class of 2-4% the mean skidding time increased linearly. These results confirm the [7] findings who reported that the volume of load pieces is the main effective factor on travel time of loaded skidder.

[1] Proved that the volume of load pieces is more effective than that of slope. Also, the results of our study indicated that the mean skidding time decreases with the increase of the number of load pieces per cycle. As it was confirmed in previous studies, the number of load pieces is effective factor on skidding time, but in current research the fewer number of load pieces had more volume and in this case the heaviness of load and imbalances of skidder on cross slope increases the skidding time. In data analysis the longitudinal slope was removed because of little variations in different cross slope classes. Besides, the skid trail length was also removed from time model, because it was considered constant.

[9] Reported that there was no effect from volume of load pieces on skidding time of loaded skidder, but the travel time of loaded skidder increased with the increase of the longitudinal slope. In this research, the skid trail was flat and there wasn't cross slope on it. This can be a main reason of differences between our results and findings. [10] Indicated that the number of load pieces, skidding distance and volume of pieces are effective on skidding time. In our study, the skid trail length was removed because of constancy and then the volume and number of load pieces were entered into model.

[3] Investigated the productivity of Timberjack 240C in two regions with different conditions. They found that the skidding time was a function of the number of load pieces, skidding distance, volume and size of pieces. The mean speed of skidder in uneven steep slopes was about twice the speed in even gentle terrain. Indeed, increase of the cross slope of skid trails increases not only skidding time and consequently skidding cost but also skidder imbalance. So, the logs are deviated from skid trail and severe damage is occurred for residual stand and regeneration. The deviation of logs from skid trail increases with the increase of the cross slope and this causes damage to residual stand and regeneration at the edge of skid trail. In above condition, the planning of proper skid trail and applying maximum power of machine to pass the maximum longitudinal slope of skid trail causes trails with minimum cross slope and consequently the skidding time and cost is reduced. In addition, the damage to residual stand due to deviation of logs from skid trail is decreased.

The results of above research can be a powerful tool for managing harvesting units via prediction of machinery efficiency in different skidding conditions. Besides, estimating the machinery efficiency and investigating the effective factors on reduction of skidding time can be pathfinder keys to decrease logging cost in forests of country.

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