Effect of log length on productivity and cost of Timberjack 450C skidder in the Hyrcanian forest in Iran

R. Mousavi

Faculty of Natural Resources, Urmia University, Urmia, Iran

ABSTRACT: This paper presents research results on the performance of the Timberjack 450C skidder in timber skidding at two working sites of broadleaved trees in mountainous conditions in the Hyrcanian forest. To evaluate the current skidding system in the Hyrcanian forest in northern Iran and possibility of finding out better techniques and group organization an empirical time study has been conducted. The elements of the skidding work phase were identified and 123 cycles were recorded for short-log and long-log method. The models for effective time consumption, total productivity and unit cost of skidding in short-log and long-log method were calculated. The time consumption and productivity of skidding depend on several variables such as distances and slope, number of logs per cycle and volume. The average load per cycle in short-log and long-log method was 2.77 m^3 and 3.08 m^3, the average one-way skidding distance was 380 and 497 m, the average slope was 18 and 20% in the short-log and long-log method, respectively. The average travel speeds of unloaded skidder were 5.74 $km·h^{-1}$ and the average speeds of loaded skidder were 7.67 and 6.16 $km·h^{-1}$ in short-log and long-log method, respectively. The average speeds of pulling the cable were 1.71 $km·h^{-1}$, and of load winching 0.72 $km·h^{-1}$ and 0.69 $km·h^{-1}$. The average outputs in short-log and long-log method were 10.86, 11.11 m^3·effective h^{-1}. Results indicated that hourly costs of operation were higher for the short-log method than for the long-log method (12.69 vs.12.40 USD·m^{-3}).

Keywords: Hyrcanian forest; skidding; Timberjack 450C; short-log method; long-log method

Although 12 million hectares of the Iranian land is covered with forests, the Hyrcanian forest is the only commercial forest which covers 1.8 million hectares. These forests are often situated in a very steep terrain and managed by the single tree selection method (Hosseini 2000). In recent years in Iran, the timber extraction system based on traditional methods has combined wheeled skidder and crawler (Sobhani 1998) and sometimes farm tractor. Primary transportation is one of the most sensitive and the most expensive operations in forest utilization (Dvořák 2005, Mousavi 2009).

Several studies about the ground-based skidding system have been carried out in order to find the influence of different factors on productivity and cost or to compare different methods. For example in Iran, Naghdi (1996) compared the productivity and cost in uphill and downhill skidding. The production rate of downhill skidding was 16% higher than uphill skidding (10.93 m^3·effective h^{-1} vs. 12.687 m^3·effective h^{-1}). Lotfalian et al. (2011) studied the production rate in 980 m skidding distances. The production rate in his study was 16.58 m^3 and the production cost was 6.2 USD·m^{-3}. Naghdi et al. (2008) compared skidding productivity in planned and unplanned logging conditions in Shafaroud Company. The study showed that the productivity of planned logging was 47.7% higher than in the unplanned conditions. Behjo et al. (2008) studied the skidding productivity of Timberjack 450C skidder in a steep and difficult terrain in the Caspian forest. He showed that the skidding cycle time was mainly affected by skidding distances, winching distances and interaction between

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skidding distance and slope. Globally, many studies carried out on skidding were realized to rationalize the work or to improve the production rate. Egan and Baumgras (2003) conducted a comprehensive study in West Virginia to examine the association among several ground skidding and harvested stand attributes. They found a strong positive association between skidding distance and cycle time, and a significant negative relationship between the percentage of trees removed in the stand and total cycle time. Wang et al. (2004) mentioned that the skidding cycle time was mainly affected by turn payload size and skidding distance. They studied the interaction between different variables in the components of skidding. Stand density, slope, undergrowth, soil, volume per tree and skidding distance were the most important factors influencing the skidding productivity. As it is mentioned, time study was applied as an important tool for studying the effect of management factors on the productivity of logging systems.

Time study is one of the most common practices of work measurement and is used to determine the input – element of productivity, to study factors affecting productivity and to develop work methods by eliminating ineffective time. One of the applications of time study is its use in comparative time studies. The objective of comparative study is the assessment of different conditions in relation to productivity when other influencing factors are almost fixed (e.g. worker impact) (Harstela 1991).

Many issues related to skidding were studied but no study was conducted inclusively about the effect of log length on the skidding productivity and cost. Therefore the study was important to find out the issue.

The objective of this study was: (1) to evaluate skidding performance in the short-log and long-log method; (2) to calculate time consumption and productivity of both methods; (3) to build up productivity and time consumption models of skidding in the short-log and long-log method.

MATERIAL AND METHODS

Study area

The study area, a part of the Hyrcanian forests, is located to the west of the Caspian Sea (Action Plan 2000). The study area is located between 37°61' and 37°20'N, and between 48°39' and 48°44'E. The primary requirement for the study was to use similar working sites; therefore a decision was taken on the location of the study plot in compartments 240 and 252 in the Nav Watershed (Fig. 1). Table 1 shows the stand description of the study area.

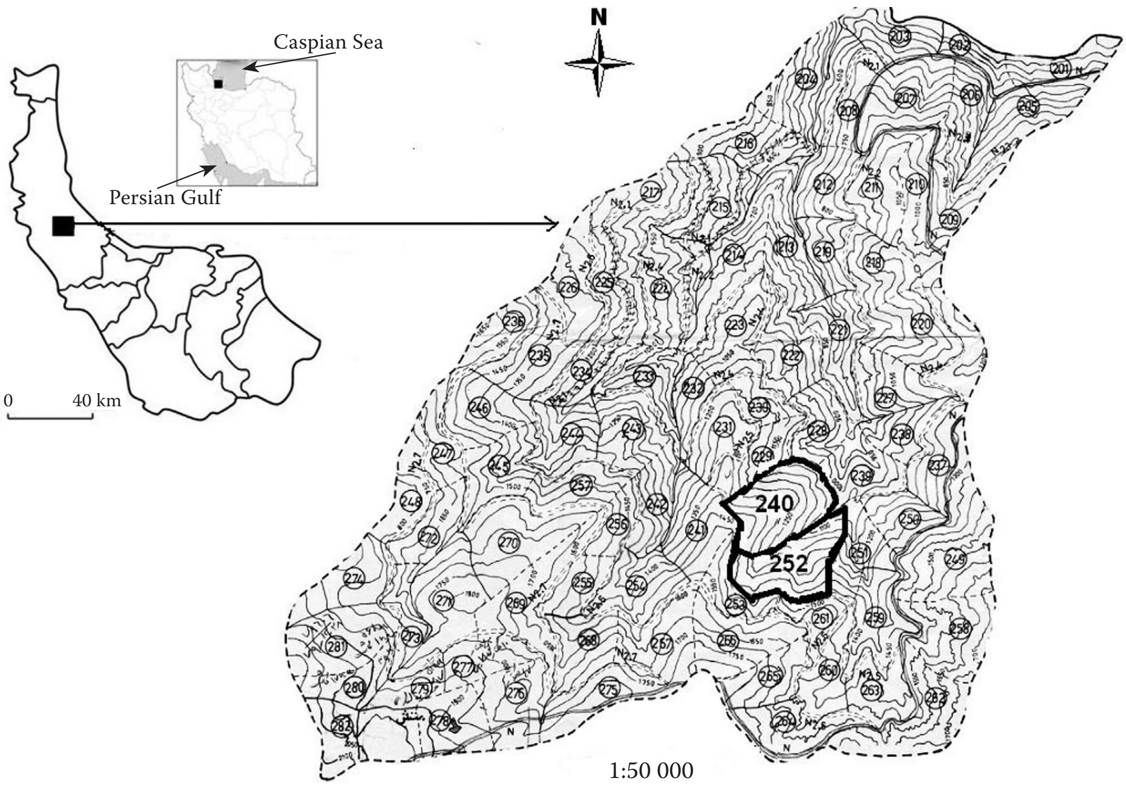

Fig. 1. Location of the case study

Table 1. Stand descriptions for short-log and long-log methods

Study area	Long-log treatment	Short-log treatment
Surface area (ha)	58	41
Silvicultural treatment	single tree selection method	single tree selection method
Elevation range (m)	1,250 (1,050–1,450)	1,250 (1,050–1,450)
Aspect	north-west	north
Treatment size (ha)	58	41
Slope (average) (%)	0–30 (16), 30–60 (64), 60–80 (10), 80–100 (7), > 100 (3)	0–30 (10), 30–60 (44), 60–80 (34), 80–100 (10), > 100 (2)
Regeneration condition	medium to good	medium to good
Grade and capacity of forest	2 and production potential is good	2 and production potential is good
Crown cover (%)	60–65	50–60
Weedy species	ferns (*Polypodium vulgare, Pteris cretica, Phyllitis scolopendrium, Hypericum androsaemum*)	ferns (*Polypodium vulgare, Pteris cretica, Phyllitis scolopendrium, Euphorbia amygdaloides, Hypericum androsaemum*)
Soil pH	5–5.7	5–5.7
Gross volume ($m^3 \cdot ha^{-1}$)	233	227
Species per volume (%)	*Fagus orientalis* (39.3), *Carpinus betulus* (24.6), *Alnus subcordata* (4.5), other species (31.6)	*Fagus orientalis* (41.3), *Carpinus betulus* (9.8), *Alnus subcordata* (4.3), other species (44.6)

Data collection

The time study data on skidding consisted of 51 skidder cycles for short-log method and 72 cycles for long-log method. Short-log and long-log methods were conducted in order to study the effect of log length on skidding productivity and cost. In the short-log method, maximum log length was 5.20 m, while in the long-log method the minimum log length was 7.80 m. Within both methods uniform equipment, tools and operators were used. A Timberjack 450C model skidder was used in skidding. A skidder operator had experience over 10 years. For each cycle, the following data were recorded: time consumption by video camera, log size, number of log(s) per cycle, slope, and skidding and winching distance. The data were used to calculate speeds and productivity, and ultimately costs per cubic meter. Volume per load was calculated by multiplying the average cross-sectional area of the stem by the stem length. The average cross-sectional area is based on diameter measurements including bark made at both ends of the log. Volume of each log is calculated using the following formula [Eq. 1]:

$$x_{vl} = \left(\frac{g_1 + g_2}{2} l\right) \quad (1)$$

where:
x_{vl} – volume of log (m^3),
g_1, g_2 – basal area at butt and top end of log (m^2),
l – log length (m).

The sample size required for a reliable estimate on the average was calculated by formula. For practical and economic reasons, it is not possible to study the whole phenomenon; therefore a preliminary inventory was necessary to find the required number of samples. Regarding the statistical literature of work phases, the decision was taken on the number of samples needed for the preliminary inventory. The variance and mean of the certain parameter of population (s^2) are obtained from the preliminary inventory. Then the sample size required for a reliable estimate on the average can be calculated by formula [Eqs 2 and 3] (Saarilahti, Isoaho 1992; Zobeiry 1994).

$$n = \frac{t^2 \times (S_X\%)^2}{(E\%)^2} \quad (2)$$

$$S_x\% = \frac{S_X \times 100}{X} \quad (3)$$

where:
n – sample size,

Table 2. Summary of detailed machine cost calculation parameters

Cost factor	Cost	Cost factor	Cost
Purchase price (USD)	270,270	Interest (USD·year^{-1})	24,121
Salvage value (USD)	27,027	Deprecation (USD·year^{-1})	24,324
Service life (years)	10	Tax and insurance (USD·year^{-1})	4,844
Tire life (hours)	4,000	Total fixed cost (USD·h^{-1})	59.2
Tire price (USD)	1,950	Maintenance and repair (USD·h^{-1})	24.3
Number of tires	4	Fuel and lubricant cost (USD·h^{-1})	42
Repair factor (f)	0.9	Tire cost (USD·h^{-1})	2.26
SMH annually (hours)	1,200	Total variable cost (USD·h^{-1})	68.5
PMH annually (hours)	900	Total labour cost (USD·h^{-1})	9.6
Utilization (%) Ut = (PMH × 100/SMH)	75	Total cost (system cost) (USD·h^{-1})	137.3

SMH – scheduled machine hour, PMH – productive machine hour

t – value from the normal distribution table (e.g. t = 1.96 for a 95% confidence interval),
S_x – standard deviation from preliminary inventory,
E – tolerance error for the confidence interval (10%),
$\bar{x}$ – average value (time consumption value) from preliminary inventory.

For modelling, two different techniques were used: modelling the overall time consumption and total time consumption. In order to examine the goodness-of-fit of regression models and to test the co-significance of coefficient, *F*-test was conducted. Each coefficient of the work phase models was also tested separately by *t*-test. The null hypotheses were rejected if the test results indicated *P*-values higher than 0.05 that the null hypotheses were not true and the differences in the time consumption resulted only from random variation.

Work phase classification

In this study the winching and skidding operations were processed as follows:
– travel unloaded: begins when the skidder leaves the landing area and ends when the skidder stops in the stump area.
– release: begins when the skidder driver releases the cable and ends when the choker setter is next to the log.
– hooking (setting choker): begins when the chokerman wraps the cable around the logs and ends when the skidder operator starts for winching.
– winching: begins when the driver starts to winch and ends when the logs arrive on skid trail.
– travel loaded: begins when the skidder starts to move and ends when the skidder arrives on landing.
– unhooking: begins when the chaser opens the load and ends when all cables are wrapped on the winch drum.
– piling: starts with stacking and ends when the load is piled up.
– delay time: operational delay, technical delays, and personal delay are recorded.

Cost calculation

Costs are classified by fixed costs and variable costs. Fixed costs are constant over a definite period and thus independent of the level of production. They will continue whether or not any timber is harvested. They include most of overhead costs and capital investments. Variable costs de-

Table 3. Average work phase times of skidding as a proportion of total effective time (%). Range in time proportions between the methods is in the brackets

Work phase	Short-log	Long-log
Travel unloaded to the load	27.3 (9–49)	29 (10–68)
Release (extension of cable/chain)	8.3 (3–27)	6 (1–28)
Hooking	10.9 (2–29)	7 (1–19)
Winching	12.3 (2–39)	9 (1–36)
Travel loaded to the landing	22 (9–37)	32 (7–54)
Unhooking	6 (1–23)	5 (2–17)
Piling (decking)	13 (0–37)	11 (0–23)

pend on the amount of production. The costs of fuel, lubricants, service, maintenance, repair and wages increase in relation to the machine cost (Kantola, Harstela 1988). Costs may be divided into labor and machine costs. The cost of labor is comprised of direct wages and fringe benefits including annual leave etc. (Kantola, Harstela 1988). Machine costs are more complicated than labor costs. The higher the machine purchase price, the higher the hourly cost of the machine. The annual work capacity determines the size of the machine need to be purchased. Table 2 shows the cost calculation of skidding in the study site. Salvage values for skidder are considered 10%.

RESULTS

Time consumption and productivity

Distribution of time consumption

Table 3 shows the time consumption distribution of the work phases. In the short-log method, time consumption for personnel, technical and operational delay was 8, 32, and 40 seconds per cycle, while in the long-log method, it was 14, 56, and 32 seconds per cycle, respectively.

The average time consumption per cycle of skidding in the short-log method was 8% less than in the

Table 4. Time consumption and productivity of skidding in the short-log and long-log method

	Short-log (log length < 5.20 m)		Long-log (log length > 7.80 m)	
	effective time	gross effective time	effective time	gross effective time
Avg. skidding time (min·cycle^{-1})	15.3	16.65	16.65	18.35
Min. skidding time (min·cycle^{-1})	6.14	7.39	7.55	7.64
Max. skidding time (min·cycle^{-1})	23.32	35.59	37.9	40.31
Avg. volume skidded (m^3)	2.77	2.77	3.028	3.08
Min. volume skidded (m^3)	0.75	0.75	1.20	1.2
Max. volume skidded (m^3)	6.17	6.17	6.14	6.14
Avg. productivity (m^3·h^{-1})	10.87	9.98	11.11	10.06
Min. productivity (m^3·h^{-1})	3.94	2.9	3.69	3.51
Max. productivity (m^3·h^{-1})	43.3	40.65		23.19
Number of observations	51	51	72	72

Table 5. Effect of log length on time consumption and productivity in classes (m)

	Class 1 (2.6–5.2)		Class 2 (7.8–10.4)		Class 3 (10.4–13)		Class 4 (13–15.6)		Class 6 (18.2–20.8)	
	ET	GT	ET	GT	ET	GT	ET	GT	ET	GT
Avg. skidding time (min·cycle^{-1})	15.3	16.6	15.8	17.7	16.5	17.3	19.7	21.3	23.5	25.8
Min. skidding time (min·cycle^{-1})	6.1	7.43	8.8	8.8	9.2	9.2	11.4	14.0	18.1	19.2
Max. skidding time (min·cycle^{-1})	23.3	3.6	37.9	40.3	33.6	39.1	26.5	27.3	29.3	29.8
Avg. volume skidded (m^3)	2.8	2.8	2.7	2.7	3.1	3.1	2.4	2.4	4.5	4.5
Min. volume skidded (m^3)	0.7	0.8	1.2	1.2	1.2	1.2	1.2	1.2	2.9	2.9
Max. volume skidded (m^3)	6.2	6.2	5.5	5.5	4.4	4.4	4.2	4.2	6.1	6.1
Avg. productivity (m^3·h^{-1})	10.9	10.0	10.7	9.6	14	13.3	10.1	9.3	11.5	10.5
Min. productivity (m^3·h^{-1})	3.9	2.94	3.7	3.5	3.4	3.4	5.5	4.5	7.6	6.1
Max. productivity (m^3·h^{-1})	43.3	0.6	37.8	23.2	23.1	23.1	20.8	18.1	13.1	12.3
Avg. skidding distances (m)	400	400	486	486	470	470	528	528	637	637
Number of observations	51	51	53	53	9	9	6	6	4	4

ET – effective hour, GT – gross effective hour

Table 6. Statistical characteristics of regression analysis based models

Model	Dependent variable	R^2	*F*-test		*N*	Term	Constant/ coefficient	Estimated std. error	*t*-test	
			F-value	*P*					*t*-value	*P*
Travel unloaded (BM)	t_{s1}	0.88	552.0	< 0.001	191	constant	–2.635	0.353	–7.465	< 0.001
						x_{sd}	0.013	0.000	32.351	< 0.001
						x_{ls}	0.086	0.015	5.555	< 0.001
Releasing (BM)	t_{s2}	0.77	264.3	< 0.001	83	constant	–0.850	0.139	–6.102	< 0.001
						x_{wd}	0.082	0.005	16.258	< 0.001
Hooking (BM)	t_{s3}	0.35	98.6	< 0.001	183	constant	0.163	0.112	1.460	0.146
						x_n	0.772	0.078	9.929	< 0.001
Winching (SLM)	t_{s4}	0.52	26.3	< 0.001	51	constant	–1.084	0.483	–2.245	0.029
						x_n	0.704	0.159	4.430	< 0.001
						x_{wd}	0.07	0.019	3.705	0.001
Winching (LLM)	t_{s4}	0.68	75.5	< 0.001	71	constant	–1.791	0.397	–4.516	< 0.001
						x_{wd}	0.114	0.010	11.955	< 0.001
						x_l	0.120	0.032	3.704	< 0.001
Travel loaded (SLM)	t_{s5}	0.83	119.1	< 0.001	51	constant	–0.358	0.259	–1.384	0.173
						x_{sd}	0.007	0.001	14.045	< 0.001
						x_n	0.408	0.068	6.005	< 0.001
Travel loaded (LLM)	t_{s5}	0.77	109.0	< 0.001	68	constant	–2.905	0.670	–4.337	< 0.001
						x_{sd}	0.011	0.001	12.555	< 0.001
						x_l	0.279	0.056	4.942	< 0.001
Overall (SLM)	t_{oss}	0.76	48.703	< 0.001	50	constant	1.985	1.276	1.556	0.126
						x_n	2.509	0.316	7.932	< 0.001
						x_s	0.015	0.002	6.855	< 0.001
						x_{wd}	0.081	0.039	2.090	0.042
Overall (LLM)	t_{osl}	0.84	122.16	< 0.001	71	constant	–5.120	1.359	–3.766	< 0.001
						x_{sd}	0.027	0.002	15.766	< 0.001
						x_{wd}	0.198	0.032	6.266	< 0.001
						x_l	0.454	0.108	4.189	< 0.001
Productivity (SLM)	p_{ess}	0.81	48.39	< 0.001	50	constant	12.453	1.633	7.627	< 0.001
						x_{sv}	5.148	0.402	12.814	< 0.001
						x_n	–2.904	0.439	–6.608	< 0.001
						x_{sd}	–0.014	0.003	–5.216	< 0.001
						x_{wd}	–0.144	0.048	–3.036	0.004
Productivity (LLM)	p_{esl}	0.85	92.373	< 0.001	70	constant	13.681	1.029	13.299	< 0.001
						x_{sv}	3.775	0.234	16.152	< 0.001
						x_{sd}	–0.017	0.001	–13.14	< 0.001
						x_l	–0.305	0.083	–3.688	< 0.001
						x_{wd}	–0.082	0.023	–3.480	0.001

SLM – short-log method, LLM – long-log method, BM – both methods, x_{sd} – skidding distance, x_{ls}– longitude slope, x_{wd} – winching distance, x_n – number of logs, x_l – log length, x_{sv} – volume skidded

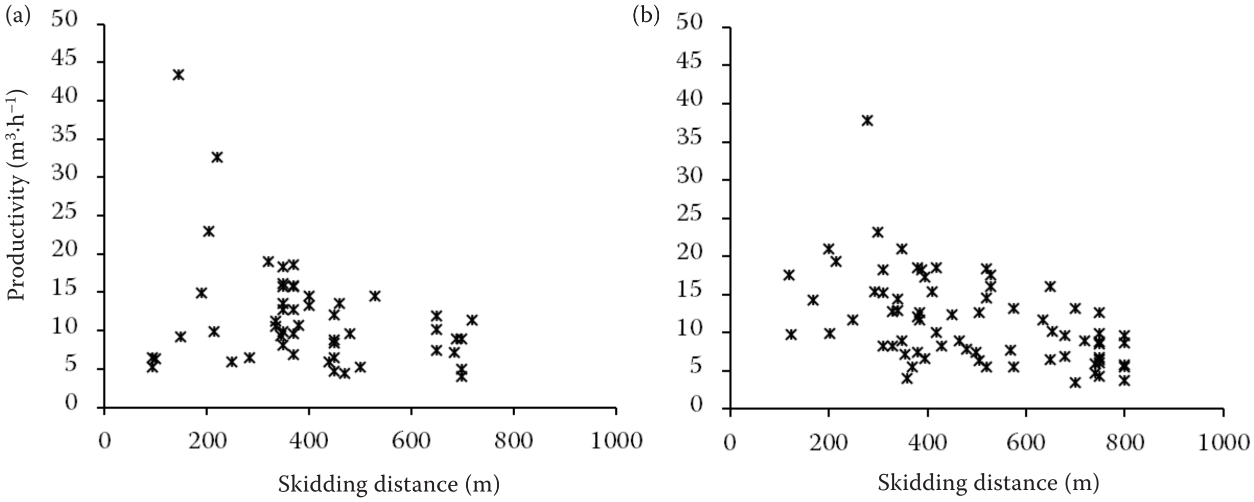

Fig. 2. Scatter plots of skidding productivity at different skidding distances in the short-log (a) and long-log method (b)

long-log method, while the average skidding productivity of the long-log method was 2.2% higher than in the short-log method. The average volume skidded per cycle in the long-log method was 11.2% higher than in the short-log method (Table 4).

Fig. 2 shows the scatter plots of skidding distance and productivity. Cycle time increases with increasing skidding distance which could lead to a decrease in productivity.

A summary of the skidding operation on the basis of log lengths is given in Table 5. The time consumption of skidding increased 53% when the length class changed from class 1 to class 6, while the productivity increased around 6% when the length class changed from class 1 to class 6.

Total time consumption and productivity model

Table 6 shows the time consumption model of skidding in all work phases, overall time consumption, and productivity model. Total time consumption model of skidding is calculated by summing up different elements of skidding. The statistical characteristics of regression models for skidding are also presented in Table 6. *F*-value and *P*-value show that the presented models are statistically significant.

Table 7 provides a comparison of the means of travel loaded and productivity at two different methods using Student's *t*-test. According to the *t*-test results, productivity of skidding did not show any significant difference between the means of two methods. Mean time consumption of travel loaded showed a significant difference between two methods only in 300 m and 700 m.

Production cost

Production cost of skidding

The average production cost of skidding work phases in the short-log and long-log method was 13.65 and 12.36 USD·m^{-3}. The production cost of

Table 7. *T*-test for the equality of means for travel loaded and productivity of skidding at two different short-log and long-log methods

Skidding distance (m)	Travel loaded			Productivity		
	t-value	df	Sig. (2-tailed)	*t*-value	df	Sig. (2-tailed)
100	–1.352	7	0.218	0.044	7	0.966
200	–3.054	9	0.14	–5.546	9	0.598
300	–3.056	37	0.004	0.158	37	0.752
400	0.316	16	0.756	–1.287	16	0.217
500	–1.614	11	0.135	–0.373	11	0.716
600	–1.569	9	0.151	–0.558	9	0.590
700	–4.237	18.7	0.00	–0.808	19	0.429

df – degree of freedom; Sig — significant skidding in the short-log method was 10.4% lower than in the long-log method. The production cost of skidding in each cycle varied from 3.63 to 37.21 USD·m^{-3} in the short-log method and from 3.17 to 34.8 USD·m^{-3} in the long-log method.

DISCUSSION

The purpose of this study was to compare and find out the influence of log length on the productivity and cost of skidding in the Hyrcanian forest, while the other variables were kept constant. Since the study was done in summer time and good weather conditions, the author cannot guarantee comparable results during other periods.

This study provides time consumption and productivity of skidding using the short-log and long-log methods. Different elements of skidding were timed out by video camera.

Methodologically, the emphasis of this study was on the comparative area with less attention paid to the correlation aspects. The main problem of the correlation study is the multiplicity of influencing factors which was controlled by a detailed division of harvesting work phase into elements (Bergstrand 1991, Nurminen et al. 2006).

Time consumption for travel unloaded was 1% lower than for travel loaded. Travel unloaded was done in positive slope conditions (uphill), therefore it was slower than in the negative slope. Releasing time was directly related to winching distance. Time consumption of releasing depends on the location of logs. Releasing is modelled only based on winching distance, however, the condition of the cable, winch drum, understory trees and worker condition may influence the time consumption of releasing. An old, depreciated and overused cable and winch drum increase the time consumption of releasing. The place where underbrush can have an effect is in pulling the cable and cable setting. More time is required to prepare a load for skidding under heavy brush conditions. Worker condition may also have an influence on the releasing time. Pulling the cable is hard and tedious work and the worker should be in good condition to pull the cable. Time consumption of hooking was directly related to the number of logs. When the number of logs in each cycle increases, the time consumption of hooking also increases. Hooking took 2.4% more time in the short-log method than in the long-log method. The number of logs in each cycle in short-log method was higher than in long-log method, which increased hooking time in the short-log method. Wang et al. (2004) found that travel loaded depends on merchantable length, number of felled stems per cycle and skidding distance. Travel loaded is the most time-consuming element of skidding in both methods. Similar to travel unloaded, travel loaded is strongly related to skidding distances.

The study showed that the log lengths were an important variable to construct the time consumption model of travel loaded in the long-log method. When the skidding route is straight, the log lengths may not influence time consumption, but as the vertical or horizontal angle between skid trail and skidder increases, the efficiency, especially in very long-logs, drops. Maximum efficiency is achieved in straight line pull. Travel loaded in the short-log method took 10% more time than in the long-log method. Time consumption of unhooking did not show any relevance with any variable. Nevertheless, Wang et al. (2004) found that unhooking time depends on butt diameter, average merchantable length, and number of felled stems per cycle. Piling is the last element of skidding which took approximately 10% of the total time consumption of the work phase in both methods. Piling in the short-log method took 1.7% less time than in the long-log method.

Similarly to other harvesting work phases, the time consumption of skidding involves delay times. Different types of delays were considered in skidding. Operational delay and technical delay accounted for almost 85% of the delay time. Percentage of personal delay was low; therefore it was not a significant part of the total delay time. In general, delay time took only 3% of the skidding time, which was low in comparison with other elements.

In the overall time consumption model of skidding, a regression equation was developed for each method to predict skidding time as a function of significantly independent variables: number of logs per turn, skidding distance, winching distance, log lengths, and volume per turn. Time free delay was the dependent variable. According to the high level of the determination coefficient, and the results of the F-test, both models proved to fit with the observation.

Skidding productivity and cost of short-log method and long-log method are affected by many variables, however, only a few of these variables have been documented and shown. The percentage by which short-log skidding cost exceeded long-log skidding cost is 10.4%. Skidding costs were mainly affected by skidding distances, volume of load, and log length and number of logs per cycle.

Skidding distance is the single most important variable affecting skidding cost and productivity. If other variables remain constant, the farther the machine has to travel from the logs to the landing, the lower will be the productivity. In a rugged terrain with steep slopes, an operator will have to travel farther to skid a given horizontal distance. Optimum skidding distance varies with terrain and other physical conditions as well as with the type of machine being considered (Conway 1979).

The productivity of skidding in this study was similar to other studies conducted in the Hyrcanian forest. Feghhi (1989), Eghtesadi (1991), and Naghdi (2005) calculated 8.6, 10.4 and 11.7 m^3·effective h^{-1}, respectively. Naghdi et al. (2008) found out that the production rate was 11.7 and 18.8 m^3·effective h^{-1} in planned and unplanned logging system, respectively. Jourgholami (2008) calculated the productivity rate up to 8.22 m^3·effective h^{-1}, which is lower than in this study. In a similar study Behjo et al. (2008) showed that the production rate was 22.93 m^3·effective h^{-1}. Productivity of skidding in this study was 31% lower than in a study done by Pilevar (1995) and 54% less than in Naghdi's (2005) study. Production rate of Timberjack 450C skidder varied from 8.22 to 22.93 m^3·effective h^{-1}. The main reason for such a difference could be related to different skidding conditions including skidding distances, terrain, slope, weather, the quality of worker, and machine condition.

Unit cost of skidding was mostly affected by machine cost. Machine cost accounted for 93% of the hourly cost of skidding while only 7% was related to labour cost. The hourly cost (system cost) of skidding took approximately 41% of the hourly cost of the whole harvesting work phase, which was the highest.

Skidding cost can be minimized in harvesting by adequate planning of the harvesting operation to reduce operational delays such as planning and marking skid trails, increasing the quality of skidding trail, applying directional felling, routine control of logging, reducing waiting time at the stump area, and sorting. In addition, technical delays can be reduced through the regular service of equipment and replacement of machines when frequent technical delays are observed and changing service schedule time to non-working time. Similarly, preparing the landing area before harvesting operations reduces delay time on the landing.

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Corresponding author:
Rostam Mousavi, Urmia University, Faculty of Natural Resources, P. O. Box 165, Urmia, Iran
e-mail: r.mousavi@urmia.ac.ir