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Research Paper

Comparison of timber skidding using two ground-based skidding systems: grapple skidding vs. cable skidding

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Abstract: This paper presents research results of comparison of two harvesting systems from which one is recently introduced in forest harvesting in Iran. The study is done in the plantation of aspen *Populus deltoides* and pine *Pinus taeda* in even terrain conditions in Shafaroud forest, North Iran. Patch cutting as a silvicultural method was used in the plantation. In order to compare two machines for finding the most suitable system, an empirical time study was conducted. The elements of skidding work phase were identified and 62 cycles were recorded for the study. The models for effective time consumption, total productivity and work phase models are 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 was 1.76 m^3 and 2.07 m^3; the average one-way skidding distance was 220 m and 285 m, for Timberjack C-450 skidder and HSM-904 skidder, respectively.
The average travel speeds of unloaded skidder were 7.29 km/h and 5.96 km/h, and the average speeds of loaded skidder were 4.13 km/h and 5.17 km/h for Timberjack C-450 and HSM-904 skidders, respectively. The average output was 6.67 m^3/effective hour and 7.2 m^3/effective hour, and skidding cost was 20.7 US$ and 12.9 US$ for Timberjack C-450 skidder and HSM-904 skidder, respectively

KEYWORDS: time consumption, HSM-904 skidder, Timberjack C-450 skidder, Hyrcanian forest, cost

Introduction

The natural forest vegetation in the Hyrcanian forest is predominated by temperate deciduous broadleaved trees. About 32.7 % of volume of the Hyrcanian forest consists of Oriental beech *Fagus orientalis*. Considering the terrain conditions, the Hyrcanian forest can be divided into three altitude sections: plain forest, middle elevation forest (below 700 m above sea level) and upper mountain forest (above 700 m above sea level). In each altitude section the tree species composition differ significantly from each other (Marvi Mohajer 2006). The coastal plains at the Caspian Sea were once covered by chestnut-leaved oak *Quercus castaneifolia*, European box *Buxus sempervirens*, black alder *Alnus glutinosa*, Caucasian alder *Alnus subcordata*, white poplar *Populus alba* and Caucasian wingnut *Pterocarya fraxinifolia*, but these forests have been almost entirely converted into urban and agricultural lands (Mosadegh 2000; Marvi Mohajer 2006) both legally and illegally. However, there are still some patches which are not converted to other land use types or have not been reforested with coniferous species. In the north of Iran, there are several small patches of plantations which are established by the forest wood companies. Due to the new forest policy in Iran concerning decreasing the wood removal from natural forests, such plantations are good resource in order to respond to the high wood demand in the country. The state-owned forest company manages both relatively small plantations and large areas of natural forest.

Ground-based harvesting systems are common types of equipment used in primary transportation by all of these companies. Limited financial capacity and high costs of highly efficient multi-operational machinery limits the use of special machines for harvesting in plantations, therefore, forest companies use the same ground-based machines and equipments for extracting wood. Rubber-tired skidders such as Timberjack C-450 and TAF E655 are the most commonly used logging equipment in the mountainous forests of Iran. All these machines work with cable system, however, grapple skidder such as HSM-904 are introduced recently for wood extraction.

Numerous studies about skidding have been done in different countries and stand conditions. Kluender et al. (1997) studied the productivity of rubber-tired cable and grapple skidders in southern pine stands in the U.S. and found that grapple skidders were considerably faster and more productive than cable skidders. They also indicated that the productivity of grapple skidding was sensitive to skidding distance, stem size, number of stems in a load and harvesting intensity. Mederski et al. (2010) compared the productivity of grapple skidder and rope skidder in the same stand conditions in North Poland. Results of their study showed that the HSM-904 grapple skidder achieved more than twice higher productivity than the RSG rope skidder.

Very few studies have addressed the use of HSM-904 skidder as skidding vehicles in Iran. Najafi et al. (2007) carried out a time study on HSM-904 skidder to obtain a mathematical model and to calculate the production cost in north of Iran. Study showed that the skidding time depends on skidding distance and number of logs skidded in each travel. The production rate was 6.53 m^3/effective hour, and the production cost was US$ 52.7/m^3. Naghdi et al. (2010) evaluated hourly production and wood extraction costs of HSM-904 and Timberjack 405C wheeled skidders utilized by the Wood and Paper Industries in Mazandaran. The results of this study showed that the delay free productivity was 11.3 m^3 and 8.7 m^3 per hour, and skidding costs were US$ 8.45/m^3 (10359 IRR) and US$ 12.32/m^3(15104IRR) respectively. Although these studies clarify ground based skidding system from many aspects, none of them show the differences between two skidding systems in a plantation, therefore, this study was done.

Time study is an important tool used in studying the effects of management factors on productivity of logging systems. It had been used for many years for calculating the costs for logging practices (Gardner 1963), and is fundamental in the analysis of forest operations (McDonald 1999). Time study is a basis for the establishment of a rating system. The results of time studies have been used to set the piece rate and rationalizing the production (Björheden 1991, Sarikhani 2001, Nurminen et al. 2006). Time study methods are used by public forest agencies in timber sale appraisal and by companies that employ operation research staff or consultants (Stenzel et al. 1985, Sarikhani 2001), as well as in determining the input – element of productivity, in studying the factors affecting productivity and in developing work methods by eliminating ineffective time (Harstela 1991). A time study can also be used for assessing the different harvesting methods for finding the most profitable one.

Methodologically, there are two different types of time studies: correlation studies and comparative studies. Correlation studies are done to establish relationships between the time consumption for the work task and the factors influencing the work. Samset (1990) found that correlation studies emphasize how time consumption varies with the difference of influencing factors. Comparative studies compare the time consumption or productivity for different equipment or work methods used to perform the same work task. They are usually done to evaluate the performance of new equipment or work methods compared to the prevalent way of doing work. The basic statement in comparative time studies is that the relative time consumption by using different working methods and conditions is constant and independent of the workers. In comparative time studies, the same workers are employed in both work methods being compared in varying work conditions if the aim is to study the influence of condition factors on time consumption (Harstela 1993).

In order to compare and apply the results of different studies, a time concept should be identified (Harstela 1993). According to the Nordic Forest Work Study Council recommendations, time concept includes total working time (moving time, change-over time, work place time, interruption time, and meal time) and unutilized time. The main portion of the total working time is work place time that is divided into effective time and delay times (Harstela 1993). Delay time is divided to operational delays, technical delays and personal delays. Recently a new time concept is introduced by the International Union of Forest Research Organization (IUFRO 1995, Mousavi 2009) but the NSR time concept is still used in Iran. The main application of a time study is in the calculation of the productivity.

Comparison of productivity and cost is key factor for manager to find the most suitable methods, however, many variables may also influence on decision making. This study is important because it clarifies many aspects of using these systems. We hypothesize that productivity of grapple skidding is higher than in the cable skidding. The aims of this study were: (1) to compare two harvesting systems, cable skidding and grapple skidding, in Iran; (2) to find out the most influencing factors of each system; (3) to calculate productivity and cost for each system in Iran.

Materials and methods

Study area

The study was carried out in the Haft-Daghanan plain in the Shafaroud forest, Guilan province, Iran (Figure 1). The study site was located in plain, and runs at gentle slope. The study area covered 1881 ha of the area. In 2011, the plantation had reached the target diameter and was ready for harvesting. The study was carried out in September 2011. During the study the skid trail was dry and covered with leaves and branches of felled trees.

All trees were felled with a chainsaw and delivered to the landing with HSM-904 grapple skidder and Timberjack C-450 skidder.

Diameters of all cut trees in skidding time were measured, and the average volumes were calculated using local tree volume table which was available at the company. The skidder operators had several years of experience, and the drivers performed all services and most of the repair works.

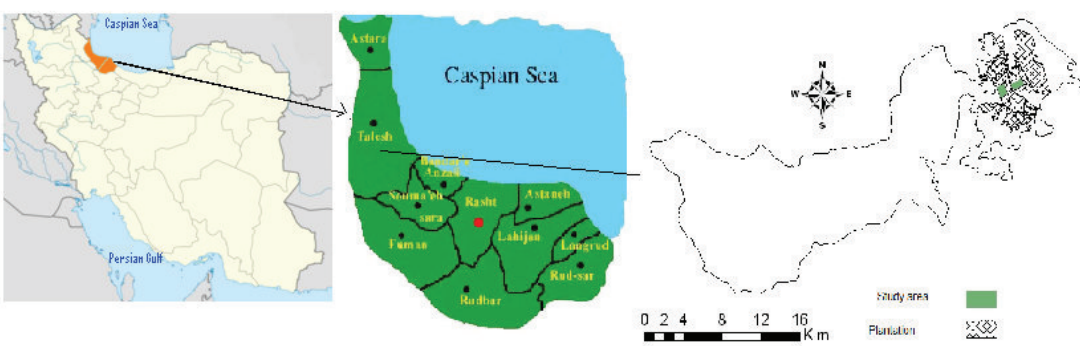

Figure 1. Location of the study area in Guilan province.

The work consists of several phases for both systems. Travel unloaded begins when the skidder leaves the landing and ends when the skidder arrives at the working site. Maneuvering time starts when skidder arrives at cutting area and ends when it ready for next phase. Collecting time begins when the skidder starts to collect logs and ends when one set of load is collected. Grabbing (grappling) begins when the grapple of skidder opens and takes the cut tree in the grapple and ends when the grapple is closed (in grapple skidder). Travel loaded starts when the skidder leaves the cutting area and ends when it arrives at landing. Unhooking time starts when the operators open the cable and ends when the cable is gathered (in cable skidder). Piling starts when the operators pile the logs and ends when it is ready to start next cycle.

Data collection and statistical analysis

A deci-minute stop watch is used for recording the time of skidding elements. All work phases were recorded just as if the operators were in a normal working condition without any special arrangements. A number of variables including skidding distances, number of trees per turn and load volume were measured.

In order to develop productivity model for the skidding machine, multiple regression analysis using the least square method was applied to test the correlation among the skidding cycle times and the variable under study. Prior to our study, the same model was used by Bavaghar et al. (2010). The number of sample plots was calculated by applying preliminary inventory. The number of required samples for the study was 21 and 18; however, data on 48 and 35 work cycles were collected for HSM-904 and Timberjack C-450 skidders, respectively. SPSS 17 package was used for the statistical analysis. 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 hypothesis was rejected if the test results indicated p-values higher than 0.05 – then the null hypotheses were assumed as not true, and the differences in the time consumption resulted only from random variation. In order to compare the average productivity of two machines, t-test was applied. The p-value shows the significance of differences between two means.

Cost calculation

The operation cost of the skidder was based on fixed cost and variable cost. Total cost was calculated by totaling machine cost and labor cost (Table 1). For calculation of the cost, instruction prepared for harvesting planning by the Iranian forest organization was used (Instruction for preparing harvesting plan1999). Fixed costs included cost for interest, depreciation and tax and insurance. The interest rate was 16.5 %. The depreciation was calculated assuming an economic life of 10 years. The fuel consumption rate was 21 liters/h. The lubricants costs were assumed to be the 30 % of the fuel cost. All costs were estimated in U.S. dollars (US$).

Table 1. Detailed costs of skidding by grapple skidder HSM-904 and cable skidder Timberjack C-450.

Cost factors for HSM-904	Cost, US$	Cost factors for skidder Timberjack C-450	Cost, US$
Purchase price	225000	Purchase price	270270
Salvage value	22500	Salvage value	27027
Economic life, years	10	Economic life, years	10
Tire life, hours	4000	Tire life, hours	4000
Tire price	1950	Tire price	1950
Repair factor, f	0.9	Repair factor, f	0.9
Interest (annually)	22089	Interest (annually)	24121
Deprecation (annually)	20250	Deprecation (annually)	24324
Tax and insurance (annually)	4234	Tax and insurance (annually)	4844
Total fixed cost	51.75	Total fixed cost, US$/PMH	59.2
Maintenance and repair	20.25	Maintenance and repair, US$/PMH	24.3
Fuel and lubricate cost, US$/hour	9.1	Fuel and lubricate cost, US$/hour	42
Tire cost, US$/hour	2.26	Tire cost, US$/hour	2.26
Total variable cost	31.61	Total variable cost, US$ /hour	68.5
Total labor cost, US$/hour	9.6	Total labor cost, US$/hour	9.6
Total cost (system cost), US$/hour	92.96	Total cost (system cost), US$/hour	137.3
SMH (annually), hours	1200	SMH (annually), hours	1200
PMH (annually), hours	900	PMH (annually), hours	900
Utilization, % Ut = (PMH×100 / SMH)	75 %	Utilization, % Ut = (PMH×100 / SMH)	75 %

Results

Time consumption and productivity

Distribution of time consumption

Time distribution of different elements of skidding is presented in Figure 2a and 2b. Collecting time is the most time-consuming element for HSM-904 skidder followed by delay and travel loaded. Similarly to HSM-904, collecting time was the most time consuming element of skidding followed by delay and travel loaded.

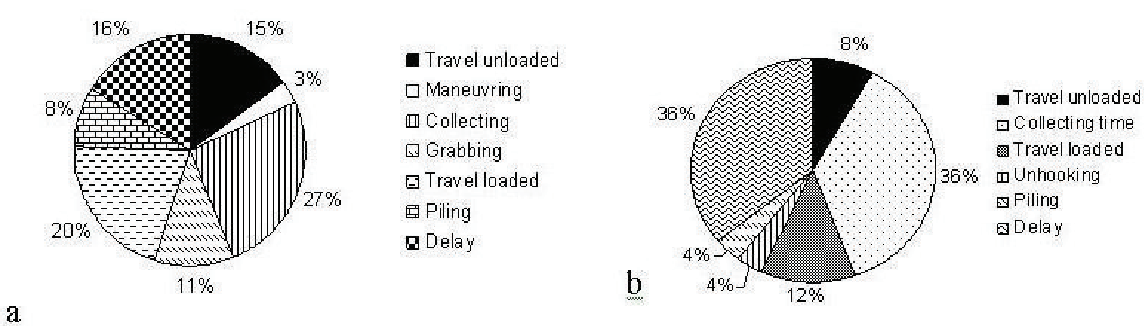

Figure 2. Time consumption distribution of grapple skidder HSM-940 (a) and time distribution of cable skidder Timberjack C-450(b).

Summary of skidding operation with HSM-904 and Timberjack C-450 skidders during the time study is presented in Table 3. The average time consumption of skidding for HSM skidder was 11 % higher than for Timberjack C-450. The average skidding productivity of the HSM-904 skidder was 8 % higher than for Timberjack C-450. The average volume skidded per cycle in HSM-904 skidder was 18 % higher than for Timberjack C-450 (Table 3).

Table 2. Characteristics of timber skidded by skidder HSM-904 and Timberjack C-450.

Harvesting item	HSM-904*	Timberjack C-450**
Study duration day (total observation time), hours	6	5
Total volume skidded, m^3	94.88	52.85
Total number of cut trees (average number of logs per turn)	226	202
Average number of logs per turn	4.9	6.7
Min. number of logs per turn	3	3
Max. number of logs per turn	8	9
Average volume of each stem, m^3	2.06	1.76
Min. volume of each stem, m^3	1.16	0.79
Max. volume of each stem, m^3	3.39	2.63
Average DBH of each stem, cm	27.05	20.9
Min. DBH of each stem, cm	17	10
Max. DBH of each stem, cm	47	33

* HSM-904: weight = 9000 kg, HP = 170, width = 2.4 m, length = 6.4 m

** Timberjack C-450: weight = 10275 kg, HP = 177, width = 3.015 m, length = 6.5 m.

Table 3. Time consumption and productivity of skidding for HSM-904 and Timberjack C-450.

	Cable skidder (Timberjack C-450)		Grapple skidder (HSM-904)	
	Effective time	Gross–effective time	Effective time	Gross–effective time
Avg. skidding time,	16.97	19.4	17.2	20.4
min/cycle	10.95	10.95	13	13.1
Min. skidding time,	32.15	34.5	23.7	30.7
min/cycle	1.77	1.77	2.1	2.1
Max. skidding time,	0.8	0.8	1.1	1.1
min/cycle	3.1	3.1	3.4	3.4
Avg. volume skidded, m^3	6.67	5.99	7.2	6.2
Min. volume skidded, m^3	1.63	1.63	4.2	3.2
Max. volume skidded, m^3	16.67	16.67	10.76	10.76
Avg. productivity, m^3/hour				
Min. productivity, m^3/hour				
Max. productivity, m^3/hour				
Number of observations	36	36	48	48

Figure 3 shows the scatter plots of skidding distance and productivity. Cycle time increases with increasing skidding distance which could lead to decrease of productivity. Scatter plots of skidding distances and productivity shows that there is not strong relevance between productivity and skidding distance. In certain skidding distance for example 200 m, the productivity varies from 2 to 10 m^3/effective hour.

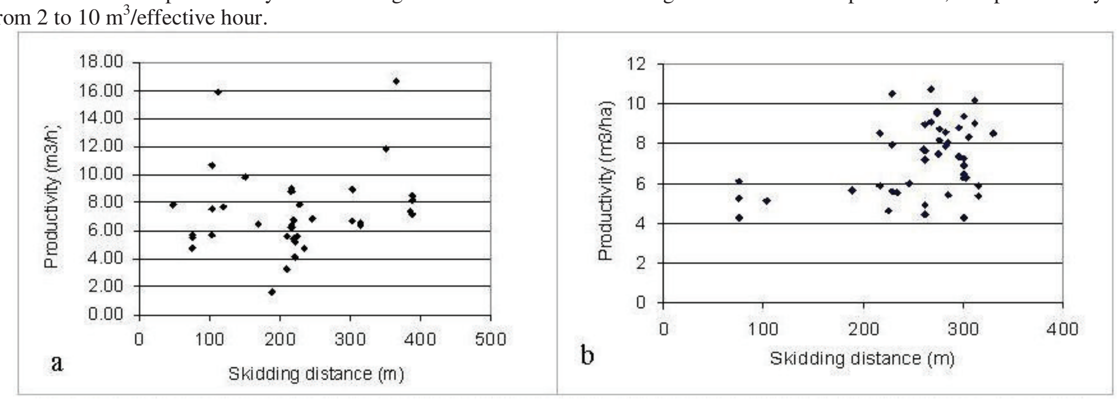

Figure 3. Scatter plots of skidding productivity in different skidding distances for HSM-904 (a) and Timberjack C-450 (b) skidders.

Total time consumption and productivity model

The effect of two most important variables in skidding (skidded volume and number of logs) on its productivity is presented in Figure 4. In both systems, productivity has an inverse relationship with number of logs and direct relation with volume skidded; therefore the highest productivity was found when the number of log is low and volume skidded is high. Results presented in Figure 4 are based on the productivity model.

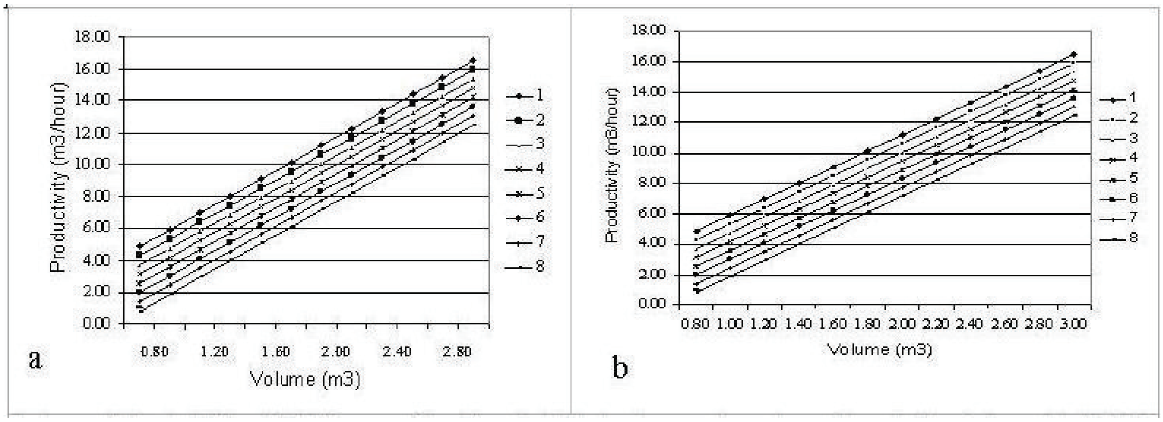

Figure 4. Productivity of skidding as a function of skidded volume and number of logs in the distances for HSM-904 (a) and Timberjack C-450 (b) skidders.

Table 4 shows descriptive statistics for the elements of skidding (e.g. maneuvering) that were not modeled. The mean value was used for constructing the total time consumption model. Maximum and minimum values show possible variation of the time consumption in each element.

Table 4. Descriptive statistics of mean value based work phase model.

Element	Method	Parameter, minute	Mean sec/cycle	Min., sec/cycle	Max., sec/cycle	Std. dev.	N
Maneuvering	HSM-904	t_{h2}	0.6	0.2	1.1	0.26	47
Collecting		t_{h3}	5.3	2.9	1.08	1.87	47
Piling		t_{h6}	1.7	0.2	5.1	0.85	47
Delay (gross productivity)		t_{h7}	3.3	0	10.1	2.93	47
Collecting	Timberjack C-450	t_{t2}	9.5	4.06	24.68	3.87	36
Unhooking		t_{t4}	0.99	0.06	9.7	1.77	36
Piling		t_{t5}	1.01	0.8	2.32	0.5	36
Delay		t_{t6}	1.7	0	10.5	2.7	36

Table 5 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 the regression models for skidding are also presented in the Table 5. F-value and P-value show that the presented models are statistically significant.

Table 6 provides comparison of means of travel loaded and productivity applying two different systems using t-test. According to the t-test results, productivity of skidding showed significant difference between means of two methods only in skidding distances between 200-300 m. Mean time consumption of travel loaded did now show significant difference between two systems in any skidding distances.

Production cost of skidding

The average production costs of skidding work phases using Timberjack C-450 and HSM-904 were 20.7 and 12.9 US\$/m^3, respectively. The production cost of skidding using HSM-904 was 37.4 % lower than for Timberjack C-450. The production cost of skidding in each cycle varied from 8.6 to 22.1 US\$/m^3 using HSM-904 and 8.23 to 84 US\$/m^3 using Timberjack C-450.

Discussion

The purpose of this study was to compare the productivity and cost of skidding using two skidders, grapple skidder HSM-904 and cable skidder Timberjack C-450, while the other variables were kept constant. Data were collected in spring and good weather conditions, the results can be used in similar conditions.

So far Timberjack C-450 cable skidder is used mainly in mountainous conditions and in harvesting in natural forests in Iran. Since there no information about using this machine for wood extraction in plain condition and whole tree harvesting system, this study is important. It is not logical to compare skidding with Timberjack C-450 in mountainous conditions and cut-to-length method with whole tree harvesting method in plain forests.

Production cost

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). In the comparative time study, two methods and machines are compared in the similar working condition.

Table 5. Statistical characteristics of regression analysis based models (Tj = Timberjack C-450, x_{sd}=skidding distance, x_n= number of logs, x_{sv}= volume skidded).

Model	Dependen t variable	R^2	F-test F- value	 P	N	Term	Constan t/coeffic ient	Estimate d std.error	t-test t-value	 p
Travel unloaded (Tj)	t_{t1}	0.13	5.2	0.029	36	Constant x_{sd}	1.354 0.004	0.392 0.002	3.45 2.28	0.001 0.029
Travel unloaded (HSM-904)	t_{h1}	0.146	7.52	0.009	48	Constant x_{sd}	1.229 0.007	0.699 0.003	1.75 2.74	0.086 0.009
Grabbing (HSM-904)	t_{h4}	0.113	9.5	0.004	48	Constant X_n	0.113 0.447	0.723 0.145	0.15 6 3.08 5	0.877 0.004
Travel loaded (Tj)	t_{t3}	0.25	11.6	0.02	36	Constant X_{sd}	2.070 0.006	0.420 0.002	4.92 7 3.40 9	0.000 0.002
Travel loaded (HSM-904)	t_{h5}	0.13	5.2	0.029	48	Constant x_{sd}	1.354 0.004	0.392 0.002	3.45 2.28	0.001 0.029
Overal time (Tj)*										
Overal time (HSM-904)	t_{oh}	0.45	17.6	<0.0 01	48	Constant x_{sv} x_n	5.403 2.408 1.383	2.069 0.547 0.348	2.61 2 4.40 1 3.97	0.012 <0.00 1 <0.00 1
Productivity (Tj)	p_{et}	0.75	51.43	<0.001	35	Constant x_{sv} x_n	1.175 5.302 -0.577	1.243 0.517 0.157	0.94 6 10.2 5 - 3.67	0.351 <0.00 1 0.001
Productivity (HSM-904)	p_{eh}	0.73	57.98	<0.001	35	Constant x_{sv} x_n	5.011 2.501 -0.596	0.937 0.248 0.158	5.35 10.0 9 - 3.78	<0.00 1 <0.00 1 0.001

*Overall time consumption of skidding did not make any equation with variables.

Table 6. T-test for equality of means for travel loaded and productivity of skidding using two skidding systems

Skidding distance, m	Travel loaded t-value	 df	 Sig. (2- tailed)	Productivity t-value	 Df	 Sig. (2-tailed)
0-100	-0.664	5	0.536	-0.787	5	0.467
100-200	0.833	8	0.429	-0.906	8	0.391
200-300	-1.637	40	0.109	2.60	40	0.013
300-400	-1.883	21	0.083	-1.538	21	0.139

Time consumption of skidding is individually analyzed for different elements of skidding in the both systems. Time consumption of travel unloaded took 15 % and 8 % in HSM-904 and Timberjack C-450, respectively. The average speeds of Timberjack C-450 in travel unloaded was 35 % higher than that of HSM-904 skidder. The faster speed of Timberjack C-450 might be a reason for less time spent in travel unloaded using Timberjack C-450. Time consumption of travel unloaded depends on skidding distance. Since the operations were performed in plain, there is no influence of slope on skidding time, while normally slopes in natural forests have significant influence on skidding time (Mousavi 2009).

Time consumption of maneuvering was calculated as an average value. For HSM-904 skidder, time consumption of grabbing showed direct relation with number of logs, while time consumption of collecting trees for one payload did not show any relevance with any variable. In the both skidding systems, the number of logs might have influence on the time consumption for collecting of logs, but it is not proved in the study. Time consumption of colleting logs was the most time consuming element in both systems.

Travel loaded was the most important element of skidding in both systems. It took 12 % and 20 % of the total time consumption using Timberjack C-450 and HSM-904 skidders, respectively. 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.

Unhooking time was recorded in Timberjack C-450 skidding. Time consumption of unhooking did not show any relevance to 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 4 % of total time using Timberjack C-450, and 8 % using HSM-904 skidder, respectively. Similarly to other harvesting work phases, time consumption of skidding involves delay times. Different types of delays were considered in skidding. Operational delay and technical delay accounted for almost 71 % of the delay time for HSM-904 skidder, while for Timberjack C-450 skidder it was 75 %. Percentage of personal delay was 29 % and 25 % for Timberjack C-450 and HSM-904 skidder, respectively. Delay time in this study took 16 % for HSM-904 skidder and 36 % for Timberjack C-450 skidder, which is significant in both cases.

In 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, and volume per turn. Time free delay was the dependent variable. In overall time consumption of skidding with Timberjack C-450, there was no relation between any variables and skidding time, while for HSM-904 skidder the number of logs and volume showed relevance with the independent variable.

Skidding productivity and cost of two systems might be affected by many variables, however, only a few of these variables such as number of logs and volume have been documented and shown. The percentage by which Timberjack C-450 skidding cost exceeded HSM-904 skidding cost is 37.6 %. Skidding costs was mainly affected by skidding distances, volume of load and number of logs per cycle.

Skidding distance is the most important variable affecting skidding cost and productivity. If other variables stay constant, the further a machine has to travel from the logs to the landing, the lower will be the productivity. Optimum skidding distance varies with terrain and other physical condition as well as with the type of machine being used (Conway 1979).

HSM-904 skidder is also new machinery which was recently introduced in harvesting system in Iran mostly for removing trees from plantations. In the case, only few studies are available for comparing the results. For example Naghdi (2010) calculated the production rate as 11.3 m^3/h for HSM-904 and 8.7 m^3/h for Timberjack C-450 skidder in the Wood and Paper Industries Company in Mazandaran. In the study by Naghdi (2010) the production rate of skidding was 56 % lower for HSM-904 skidder and 30 % lower for Timberjack C-450 skidder than in our study. Terrain conditions (macro- and micro topography), operators' skills, machine types and skidding distances might be the reasons for such ~~a~~ differences. Najafi et al. (2007) calculated production rate of 6.53 m^3/effective hour which is 10 % lower than in our study. In normal working conditions (mountainous conditions, enough volume of wood available, large size trees, cut-to-length method), the production rate of Timberjack C-450 skidder varies from 8.22 to 22.93 m^3/effective hour. In this study it was even lower that the production rate which has ever been recorded in Iran (6.67 m^3/effective hours).

One of the most important variables on the skidding productivity and cost is stem size. In small stem size skidding, the volume of each cycle decreases which can have significant influence on the productivity. It has been proved by Kahala (1982) and Jourgholami and Majnounian (2008). With small size skidding in a volume range of 1.11-3.64 m^3, skidding cost increases significantly, especially at longer distances. The highest productivity by HSM-904 is calculated by Mederski et al. (2010) in a skidding of large size trees with average trees volume of 2.16 m^3, however, in skidding very large trees with average tree size of 3.9 m^3 skidding productivity was 11.6 m^3/effective hour.

Currently cable skidding is more widely used in Iran than grapple skidding. Grapple skidding is applied only in plantations and when using full tree method. Up to now, there were no attempts to compare the productivity and costs for the two skidding systems in plantations. In this research both systems were evaluated from a technical and economical point of view.

It is proved that the stem size and number of logs are the most influencing factors on the skidding productivity. However, the skidding distance in many studies (e.g. Mousavi 2009, Naghdi 2010) is introduced as the most important variable affecting the skidding productivity but it has not been proved in this study.

The hypothesis that productivity of grapple skidding is higher than in the cable skidding is proved, although differences in the two systems are not statistically significant.

Overall, productivity of grapple skidding is higher than that of cable skidding. Consequently the unit cost of the cable skidding is lower than that of the grapple skidding. These results suggest that the grapple skidding system is more economically justified in plain conditions, while cable skidding system can be used in different terrain conditions from flat to steep area.

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