Evaluation of full tree skidding by HSM-904 skidder in patch cutting of aspen plantation in Northern Iran

R. Mousavi[1], M. Nikooy[2], A. E. Nezhad[2], M. Ershadfar[2]

[1]*Faculty of Natural Resources, Urmia University, Urmia, Iran*

[2]*Faculty of Natural Resources, University of Guilan, Somea Sara, Iran*

ABSTRACT: This paper presents research results of the performance of HSM-904 grapple skidder using a full tree harvesting method in a non-native aspen *Populus deltoides* plantation in even terrain conditions in Shafaroud, Northern Iran. Patch cutting as a silvicultural method was used in the plantation (2,000 ha). To evaluate the newly introduced machine to a ground skidding system in the aspen plantation and the possibility to increase the production rate, an empirical time study was conducted. The elements of the skidding work phase were identified and 58 cycles were recorded for the study. The models for effective time consumption, total productivity and work phase models are calculated. The average load per cycle was 2.2 m^3, the average one-way skidding distance was 253 m. The average travel speed of unloaded skidder was 5.53 $km \cdot h^{-1}$ and the average speed of loaded skidder was lower than the speed of the unloaded one by 2.94 $km \cdot h^{-1}$. The average output in the study was 7.1 m^3 per effective hour and the unit cost was 13.9 $USD \cdot m^{-3}$.

Keywords: time consumption; HSM-904 skidder; skidding; cost

In the north of Iran, there are several small patches of aspen plantations which are established by forest wood companies and forestry organizations. Due to the new forest policy in Iran aimed at decreasing the wood removal from natural forests, these plantations are a 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 forests. In 2010, a number of these plantations reached the target diameter and were ready for harvesting.

Information on the productivity, cost and application of the logging system is a key component in the evaluation of management plans of the Caspian forest (Sobhany 1991). Ground-based harvesting systems are common types of equipment used in primary transportation by all these companies. Limited financial capacity and high costs of highly efficient multi-operational machinery prevent the use of special machines for harvesting in plantations, therefore, forest companies use the same ground-based machines and equipment for extracting wood. Rubber-tired skidders such as Timberjack C-450 and TAF E-655 are the most commonly used logging equipment in the mountainous forests of Iran.

For many years, cable skidder was the only equipment for ground-based skidding. Recently, a number of these companies such as Mazandaran Wood and Paper Company (CHOKA) and Shafaroud Company bought HSM-904 skidders for skidding operations. HSM skidders are used for primary transportation in mountainous forests and plantations in Iran.

Numerous studies about skidding have been done in different countries and different terrain and stand conditions. Kluender et al. (1997) studied the productivity of rubber-tired cable and grapple skidders in southern pine stands 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 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 northern Iran. The study showed that the travelling time depended on skidding distance and number of logs skidded in each turn. The production rate was 6.53 m^3 and the production cost was 52.7 USD·m^{-3}. Howard (1987) had a different approach than the time study for estimating timber harvesting production and costs with skidders by collecting shift-level data on fuel consumption, repairs, maintenance and other operating costs. Productivities of grapple skidders were investigated in extracting trees by the full tree method of southern pine trees. He suggested that the principal variables affecting the skidding cycle time were skidding distance, machine power, number of bunches grappled and number of trees per turn.

Naghdi et al. (2010) evaluated hourly production and wood extraction costs of HSM-904 and Timberjack C-450 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 and 8.7 m^3 per hour and skidding costs included were 8.45 and 12.32 USD·m^{-3}, respectively.

Estimating the productivity of forest equipment is necessary for forest managers to assess skidding of tree length logs by HSM-904 from patch felling forests. This kind of information is important for decision-making and choosing the right method for wood extraction. Several studies about HSM-904 skidder in normal conditions in the forest were done but no study documented to show the results of applying the machine in the plantation and patch cutting, therefore the study was necessary. Moreover, the study shows different elements of skidding work phases and factors influencing each phase.

The aims of this study were: (1) analysis of a continuous time study of HSM-904 grapple skidder in an aspen plantation; (2) calculation of production rates and unit costs of the machine.

MATERIAL AND METHODS

Study area

The study was carried out at the Haftdaghanan plain in the Shafaroud forest, Guilan province (Fig. 1). In the study area the terrain is located in a plain and runs on a gentle slope.

The study area covered 2,000 hectares of a 23-years-old plantation of the aspen *Populus del-*

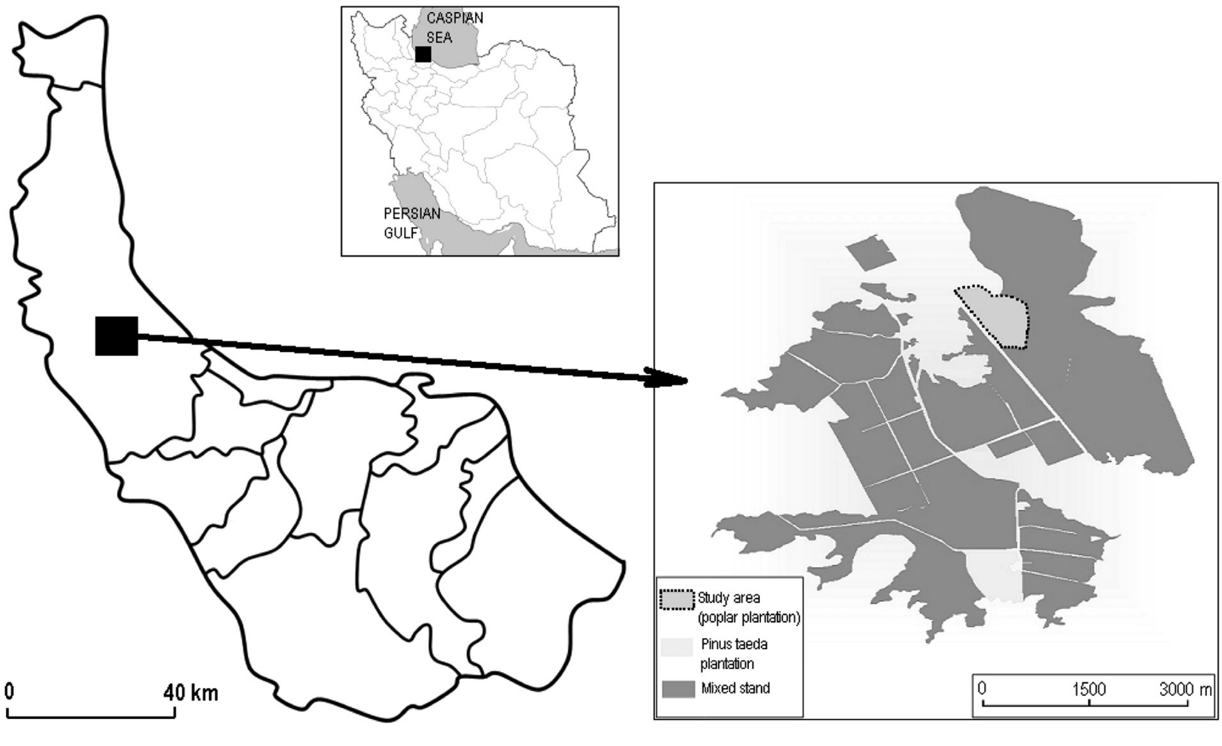

Fig. 1. Location of the study area in Guilan province and in Iran

toides, a poplar native to North America (Fig. 1). The trees were planted at a spacing of 4 × 3 m. The average number of trees per hectare was 625 trees. The plantation is harvested in rotation usually every 25–30 years. The study was carried out in September 2010. During the study the skid trail was dry and covered with leaves and branches of felled trees.

All trees were felled and delimbed with a chainsaw and delivered to the landing by HSM-904 grapple skidder. Diameter of the tree at breast height (DBH) was measured on sample plots before logging, and the average volumes were calculated using a local tree volume table which was available at the company. All cut trees were skidded to the roadside and piled on both sides of landing. A total of three workers were operating in the skidding systems. The skidder operators had several years of experience and the driver performed all services and most of the repair works.

The skidding operation consists of several phases. Travel unloaded begins when the skidder leaves the landing and ends when the skidder arrives at the working site. Manoeuvring is the work phase when the skidder reaches the cutting area and ends when the skidder is getting ready for grappling. Preparing for loading (winching) is a work phase when the skidder operator winches cut trees toward the skidder and ends when a sufficient amount of trees is collected. Grabbing (grappling) begins when the grapple of the skidder opens and takes the cut tree in the grapple and ends when the grapple is closed. Travel loaded is the phase when the skidder moves to the landing and ends when the skidder reaches the landing area. The last phase, piling, starts when the skidder operator opens the grapple and piles the stems in the landing.

Data collection

During normal harvest operations, detailed records of skidding events were kept. Field studies concentrated on collecting operational and financial data that are essential for subsequent evaluation. A deciminute stop watch was used for recording the time of skidding elements. The Nordic Forest Work Study Council (NSR) time concept was used for data collection. Although the time concept introduced by IUFRO (1995) is comprehensive, due to practical difficulties in data collection the NSR time concept (Fig. 2) was used. However, delay time was taken in greater details and broken down into three elements as proposed by Naghdi (2005). It included technical, personal and operational delays. Technical delay (such as machine break down) is largely inevitable, while operational delay and personal delay can be avoided or significantly decreased.

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 a productivity model for the skidding machine, multiple regression analysis using the least square method was applied to test the correlation between the skidding cycle times and the variable under study. The model was used before by Pir Bavaghar et al. (2010). In order to determine the number of required samplings, a pre-inventory was done to specify the time variance of the skidding cycle time. Then the sample size required for a reliable estimate on average was calculated. The number of required samples for the study was 15; however 58 work cycles were collected for HSM-904.

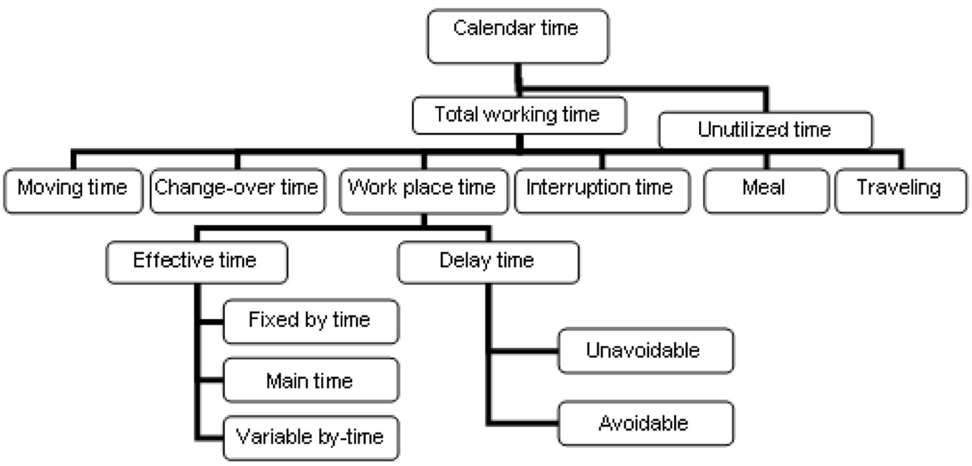

Fig. 2. Time concepts according to the NSR recommendation (Source: Harstela [1993])

Table 1. Time study and production data

Machine	Grapple skidder HSM
Study duration day (total observation time, h)	6
Productive time (valid observation, h)	18.7
Trees harvested	334
Volume harvested (m^3)	125.5

SPSS 17 as a statistical 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 coefficients, *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. In this case, the models were not statistically significant or applicable.

A summary of the time study and production is presented in Table 1. The stepwise regression analysis was applied to the time study data base to develop a delay-free cycle time equation for each element and overall time consumption and productivity. The significant variables included volume per turn in cubic meters, number of logs per turn and skidding distance in meters.

Cost calculation

The operation cost of the skidder was based on fixed cost and variable cost. Total costs were calculated by summarizing machine cost and labour cost (Table 2). For the calculation of the costs, instructions prepared for harvesting planning by Iranian forest organizations were used (Mousavi 2009). Fixed costs included the cost of 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 $l \cdot h^{-1}$. The lubricant costs were assumed to be 30% of the fuel cost.

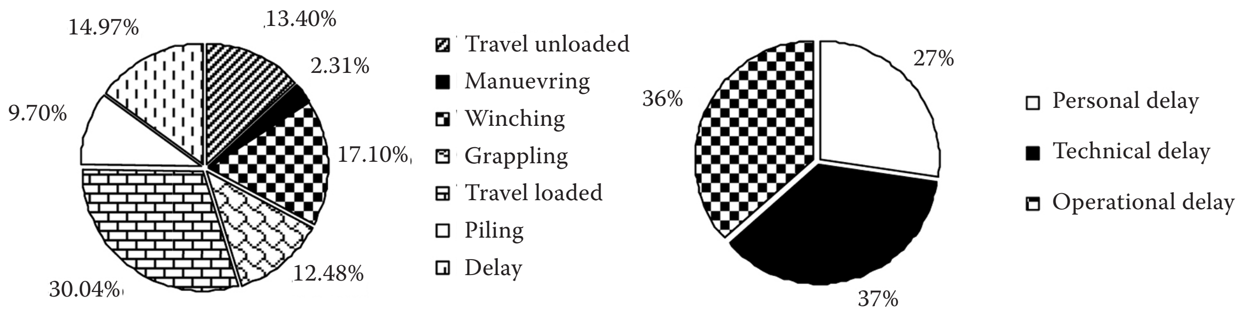

Fig. 3. Distribution of time consumption using a grapple skidder (a) and time distribution of delays (b)

Table 2. Detailed costs of skidding by HSM-904 grapple skidder

Cost factor	Cost	Cost factor	Cost
Purchase price (USD)	225,000	Interest ($USD \cdot year^{-1}$)	22,089
Salvage value (USD)	22,500	Deprecation ($USD \cdot year^{-1}$)	20,250
Economic life (years)	10	Tax and insurance ($USD \cdot year^{-1}$)	4,234
Tire life (hours)	4,000	Total fixed cost ($USD \cdot h^{-1}$)	51.75
Tire price (USD)	1,950	Maintenance and repair ($USD \cdot h^{-1}$)	20.25
Number of tires	4	Fuel and lubricate cost ($USD \cdot h^{-1}$)	9.1
Repair factor (f)	0.9	Tire cost ($USD \cdot h^{-1}$)	2.26
SMH (hours)	1,200	Total variable cost ($USD \cdot h^{-1}$)	31.61
PMH (hours)	900	Total labour cost ($USD \cdot h^{-1}$)	9.6
Utilization (%) Ut = (PMH × 100/SMH)	75%	Total cost (system cost) ($USD \cdot h^{-1}$)	92.96

Table 3. Characteristics of timber skidded by HSM-904 skidder (weight – 9,000 kg, HP – 170, width – 2.4 m, length – 6.4 m, height – 2.93 m)

Harvesting item	Effective time	Gross-effective time
Total volume skidded (m^3)	124.14	124.14
Total number of cut trees (average number of logs per turn)	334	334
Average number of logs per turn	5.75	5.75
Minimum number of logs per turn	3	3
Maximum number of logs per turn	9	9
Average volume of each stem (m^3)	0.371	0.371
Minimum volume of each stem (m^3)	0.236	0.236
Maximum volume of each stem (m^3)	0.458	0.458
Average DBH of each stem (cm)	23.7	23.7
Minimum DBH of each stem (cm)	19	19
Maximum DBH of each stem (cm)	31	31

RESULTS

Time consumption and productivity

Distribution of time consumption

The time distribution of different elements of skidding (HSM-904 skidder) is presented in Fig. 3a. Travel loaded took the longest time and it was followed by winching and delay. Fig. 3b shows the time distribution of different kinds of delay.

A summary of skidding operations with HSM-904 skidder during the time study is presented in Table 3. The time consumption of skidding was analyzed and is presented in Table 4. In this table average, maximum and minimum time consumption and productivity of skidding with and without delay are shown. The average delay-free time consumption of skidding was 17.4% lower than the time consumption with delay, while the average delay-free productivity was 14.08% higher than the productivity with delay (Table 4).

Table 5 shows the average time consumption values for manoeuvring (t_2) and preparing for loading (t_3). The average value was applied for constructing a total time consumption model for elements that were not statistically proved to be related to any variables. The overall time consumption and productivity models are presented in order to estimate the time consumption and productivity of skidding as a function of independent variables. The average number of logs was 6, the average skidding distances was 253.3 m, and the average volume was 2.2 m^3.

The statistical characteristics of the regression models for skidding are presented in Table 6. *F*-value and *P*-value show that the presented models are statistically significant. Overall, the time consumption models of skidding for both the methods were also checked by graphical statistical measures and the models were proved to be statistically significant (Fig. 4).

Table 4. Productivity of HSM skidder in the study area

Harvesting item	Effective time	Gross-effective time
Average skidding time (min·cycle^{-1})	18.40	21.6
Minimum skidding time (min·cycle^{-1})	13.00	13.1
Maximum skidding time (min·cycle^{-1})	26.60	36.6
Average skidded volume (m^3)	2.20	2.2
Minimum skidded volume (m^3)	1.10	1.1
Maximum skidded volume (m^3)	3.63	9.0
Average productivity ($m^3·h^{-1}$)	7.10	6.1
Minimum productivity ($m^3·h^{-1}$)	4.28	3.28
Maximum productivity ($m^3·h^{-1}$)	11.0	9.29

Table 5. Descriptive statistics of mean values based on the work phase model

Element	Parameter	Mean (min·cycle^{-1})	Minimum (min·cycle^{-1})	Maximum (min·cycle^{-1})	Std. dev.	N
Manouvering	t_2	3.7	1.8	6.6	0.38	59
Preparing for loading (winching)	t_3	2.7	0.9	6.9	0.91	59

N – number of observation

The effect of the two most important variables in skidding (skidding distance and volume skidded) on its productivity is given in Fig. 5. An inverse relationship of productivity with skidding distance and a direct relation with volume skidded are shown. Therefore the highest productivity was found when the skidding distance was short and volume skidded was high. The figure is based on the productivity model.

Production cost

The production cost of skidding is presented in Table 7. The unit cost of skidding increased by 16.4% when delay time was included in the calculation. Maximum productivity was at a short skidding distance and high skidded volume per turn.

DISCUSSION

Due to different stand conditions such as stand composition, silvicultural methods, operations and terrain conditions, the results and models are applicable to areas with the same working conditions (summer season with good terrain conditions) and equipment. Methodologically, the emphasis of this study was put on the correlation time study. The main problem of the correlation study is the multi-

Table 6. Statistical characteristics of models based on regression analysis

Model	Dependent variable	R^2	F-test		N	Term	Constant/ coefficient	Estimated std. error	t-test	
			F-value	P					t-value	P
Travel unloaded	t_1	0.85	360.5	< 0.001	58	constant	0.277	0.392	0.707	0.483
						x_{sd}	0.010	0.001	6.995	< 0.001
Grabbing	t_4	0.52	44.6	< 0.001	58	constant	–0.927	0.647	–1.432	0.158
						x_n	0.414	0.092	4.486	< 0.001
						x_v	0.574	0.225	2.548	0.014
Travel loaded	t_5	0.73	110.6	< 0.001	58	constant	2.428	0.812	2.991	0.004
						x_n	0.688	0.134	5.136	< 0.001
Piling	t_6	0.75	48.703	< 0.001	58	constant	–0.468	0.562	–0.833	0.408
						x_n	0.256	0.080	3.191	0.002
						x_v	0.477	0.196	2.441	0.018
Overall time consumption	t_t	0.75	48.703	< 0.001	58	constant	3.159	1.414	2.234	0.030
						x_v	1.722	0.512	3.363	0.001
						x_n	1.227	0.182	6.734	< 0.001
						x_{sd}	0.017	0.04	4.150	< 0.001
Productivity	p_e	0.85	92.373	< 0.001	58	constant	5.885	0.638	9.219	< 0.001
						x_v	2.592	0.231	11.216	< 0.001
						x_n	–0.478	0.082	–5.807	< 0.001
						x_{sd}	–0.006	0.002	–3.426	0.001

x_{sd} – skidding distance, x_n – number of logs, x_v – volume skidded, N –number of observations

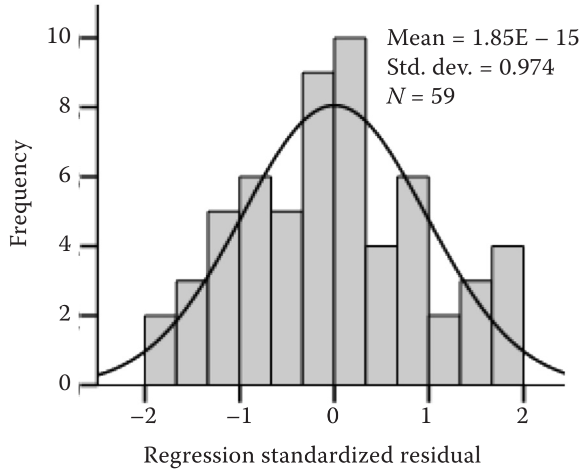

Fig. 4. Histogram of standardized residuals of the overall time consumption model in skidding

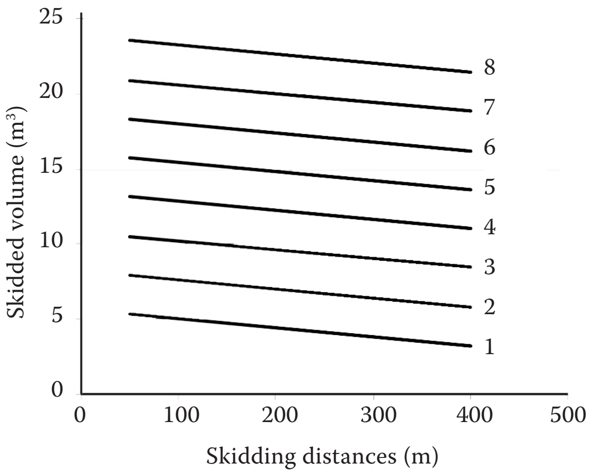

Fig. 5. Productivity of skidding as a function of skidding distance and volumes

Table 7. Unit costs of HSM-904 skidder

Unit cost	Effective time	Gross-effective time
Average unit cost (USD·m^{-3})	13.09	15.24
Minimum unit cost (USD·m^{-3})	8.23	10.01
Maximum unit cost (USD·m^{-3})	21.72	28.34

plicity of influencing factors which was controlled by a detailed division of harvesting work phases into elements (Bergstrand 1991; Nurminen et al. 2006).

According to Harstela (1993), the productivity of a harvesting system is the function of the qualities of the labour force, and the characteristics of conditions as well as other factors of production. One of the main problems regarding the generalization of the study is related to labour; therefore a standard crew was used in order to minimize and monitor the influence of workers on the study results. This is an important, although inadequate, approach to improve the ability to generalize the study results (Harstela 1993; Nurminen et al. 2006).

Two techniques were applied to create the models: work phase time consumption models and overall time consumption models. Both techniques appeared to fit well with the observations and are reliable to predict the time consumption and productivity, as previously found by Nurminen et al. (2006). The advantage of the work phase based model was, above all, the possibility to observe the harvesting work in greater detail, to decrease the variation of time consumption as well as to reduce the number of influencing factors. A work element is often influenced by few factors, while the total time is influenced by more factors. If the division into work elements is detailed enough, the work element might be affected only by a single factor or correspond to the average time.

Travel unloaded is the first element of skidding. The modelling of travel unloaded showed that it was highly dependent on the skidding distance. Travel unloaded took 13.4% of the skidding time while in normal forest skidding in mountainous conditions it took approximately 26% (Mousavi 2009). Wang et al. (2004) found that the travel unloaded time depended on the travel distance. Manoeuvring of the skidder is the second element of skidding and it takes only 2.31% of the total time, which is not significant. Bringing a stem to the nearest distance or winching is an element of skidding which takes a relatively big share of the total time consumption (17.1%) and it is the second most time-consuming element. Grappling takes around 12% of the total time consumption and it is influenced by the number of logs and volume per turn. Travel loaded is the most time-consuming element of skidding. Similarly like travel unloaded, travel loaded is strongly related to skidding distances, and it is also influenced by skidded volume and the number of logs as it was mentioned in studies by Wang et al. (2004) and Mousavi (2009). Travel loaded took the longest time share among different elements of skidding (30.04%). Piling is the last element of skidding which took approximately 10% of the total time consumption of the work phase in both methods. Piling is the last element of skidding and it is influenced by the number of logs in each turn and skidded volume. It took around 15% of the skidding time, while cable skidding in normal conditions in the forest took around 10% of the total effective time (Mousavi 2009).

Similarly like 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 73% of the delay time. The percentage of personal delay was 27%, which can be decreased. In general, the delay time took 15% of the skidding time, which is a considerable proportion of the total time consumption.

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, and volume per turn. Other variables were not statistically significant. The dependent variable, time per skid turn, included productive time excluding delay time. Statistically, the standardized residuals of the models were quite symmetrical and normally distributed. According to the high level of the determination coefficient and the results of the *F*-test, models proved to fit well with the observation.

The average time consumption of skidding for all cycles was 18.4 min and the average productivity was 7.1 m^3 per effective hour. The productivity of skidding by HSM-904 grapple skidder in the study was similar to the other studies conducted in the Hyrcanian forest. Najafi et al. (2007) and Naghdi et al. (2010) calculated 6.53 m^3 per effective hour and 8.7 m^3 effective per hour in the mountain conditions, respectively. The stem size is one of the most important variables influencing skidding productivity and cost. In small stem size skidding, the volume of each cycle decreases, which can have a significant influence on productivity. It was proved by Kahala (1982) and Jourgholami and Majnonian (2008). With small size skidding in a volume range of 1.11 to 3.64 m^3, the skidding cost increases significantly especially at longer distances. The highest productivity by HSM-904 was calculated by Mederski et al. (2010) for the skidding of large trees with average tree volume of 2.16 m^3; however, for the skidding of very large trees with average tree size of 3.9 m^3 skidding productivity was 11.6 m^3 per effective hour.

Overall, the HSM-904 grapple skidder proved to have a high potential in skidding in aspen populations in the terrain with the same conditions (on gentle slopes). Using the skidder to develop a large size load can improve the efficiency of the skidding function. In this study the effective hour was more influenced by moving on different paths due to the treatment.

CONCLUSION

Currently, tree harvesting is done mostly in natural forests and forests in mountainous conditions. In the last decades, the forest company reforested many plain areas for harvesting. Aspen and other fast-growing species including coniferous species were planted, and currently many of these plantations are ready for harvesting. For the first time, a grapple skidder was introduced in this plantation for log skidding.

In this study skidding with grapple skidder was divided into several elements. Influencing factors on the time consumption of each element in skidding were analyzed. The time consumption of delay was 15%, which can be decreased by improved planning and work organization. Scheduling service and maintenance of machines can decrease the technical delay such as machine breakdown in working time and improve the production rate. The study showed that productivity of skidding depends on variables such as skidding distances, volume per turn, and number of logs per turn. The productivity of wheeled HSM-904 skidder was relatively low. The main reasons were small size trees (0.37 m^3), low load volume (2.14 m^3) and small amount of grappled stems (5.75) in each cycle. In order to improve the production rate, directional felling can be applied. This technique increases the volume and number of stems per turn or decreases delay time. The results of this study can be used to set piece rate, rationalization of work, work scheduling, and cost estimation.

Acknowledgements

First of all, I would like to say thanks to the managers of the study area, Mr. Nikkhah and the other personnel involved in the field experiment and data collection. Thanks to Dr. Nikooy Seyahkal (University of Guilan, Iran) for their help in the exhaustive data collection process.

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Received for publication October 5, 2011
Accepted after corrections December 14, 2011

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