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Productivity and cost analysis of skidding with Timberjack 450C in forest plantations in Shafaroud watershed, Iran

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ABSTRACT: We present research results of timber skidding by a Timberjack 450C skidder in the path cutting of pine trees in Shafaroud watershed. Time studies were conducted to quantify the productivity and perational cost of skidding by a skidder in a plantation in even terrain conditions in Shafaroud, northern Iran. A linear regression model was applied for finding the relation of dependent variables such as total time consumption and productivity with appropriate independent variables. The most influencing variable for skidding were skidding distance, number of logs in each turn and load volume. The results indicated that the total production with and without delays was 5.17 and 5.98 m^3·effective h^{-1}, while the production cost with and without delays was 13.7 and 11.91 USD·h^{-1}, respectively.

Keywords: forest operation; wood extraction; skidder; time study; Iran

Limited access to natural forest resources has promoted the use of short rotation woody crops by wood and paper companies in Iran as they are an important source of fibre and wood. One of the largest forest wood companies in the north of Iran (Shafaroud) manages approximately 135,000 ha of forest, in which 10,526 ha of forest is planted with species such as poplar, alder and some coniferous species in the plain area (Shafaroud 2012). Rubber-tired and tracked skidders such as Timberjack 450C, Caterpillar HSM-904, Ranger 66BDS, Caterpillar Bulldozer D6, D7 and Zetor are the most commonly used logging machines in the mountainous forests of Iran (Pir Bavaghar et al. 2010). Small areas of plantations and limited financial capacity prevent the use of special machines for harvesting, therefore, forest companies use the same ground-based machines and equipment for wood extraction. Wood harvesting in plantation areas is a vital source of fibre for wood and paper companies. Therefore, improvements in harvesting systems have an important role for the application of machines in future. Harvesting costs and information on the productivity are the main issues of logistics in short rotation species (Nikooy 2007); cost and application of the logging system are important factors in the evaluation of forestry management plans (Mousavi et al. 2011). Timberjack 450C is the most common machine used for mechanized forest operations throughout northern Iran. The skidder skids the felled trees in full-tree logs to the landing where they are loaded onto tree-length trucks. Previous studies addressed the production and cost of Timberjack 450C as a skidding machine in mountainous areas. Behjou et al. (2008) conducted a time study on the skidding capacity of a Timberjack 450C wheeled skidder in mountainous forests in northern Iran. They reported that the skidding cycle time was mainly affected by the skidding distance, winching distance and the interaction between them. The gross and net production rate of the skidder in this study was 20.51 and 22.93 m^3·h^{-1}, respectively. Jourgholami and Majnounian (2008) studied the productivity and cost of wheeled skidder (Timberjack 450C) in the same conditions. They analysed the production rate and cost of this machine in educational and experimental forests of Kheiroud. The results of the study showed that the production rate of this machine with and without delays was 8.22, 8.88 m^3·h^{-1} and the production cost of the ma-

chine was 7.41 and 6.86 USD·m^{-3}, respectively. Various researches on skidding operations have been done in different forest settings (Miller et al. 1987; Kluender et al. 1997; Wang 2004; Najafi et al. 2007; Mousavi et al. 2012). All these studies confirmed that independent variables such as skidding distance, number of logs per turn and load volume are the most significant factors influencing the productivity and cost of logging. However, many studies about skidding are done in Iran, but none of them addressed full tree skidding, therefore, the aim of this study was: to develop productivity models for a Timberjack 450C skidder in full tree skidding extraction in a typical clear cutting operation in Loblolly pine; to calculate the production rate and cost of this machine.

MATERIAL AND METHODS

The study was carried out at the Haftdaghanan plain in the Shafaroud forest, Guilan province, Iran (Fig. 1). This area is covered by 3,012 ha of eastern cottonwood (*Populus deltoides*), loblolly pine (*Pinus taeda*), and black alder (*Alnus glutinosa*) stands of different age. Only compartment 7 (Fig. 1)

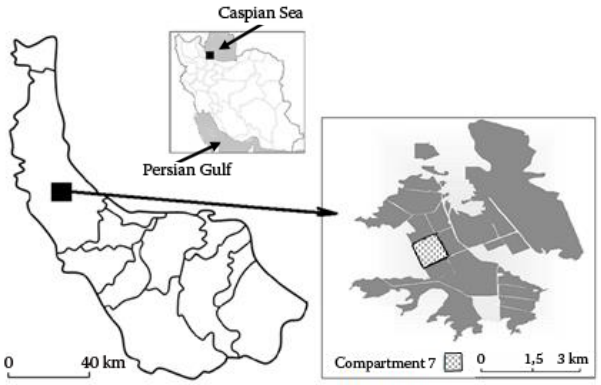

Fig. 1. Location of the study area in the north of Iran

covered by loblolly pine stand was selected for this study. Full tree skidding in this compartment was investigated in August 2012. The average number of trees per ha was 1,666 trees with a spacing of 2 × 3. Table 1 shows the information on the basic parameters of the trees. Harvesting in the plantation area was done every 25–30 years. During the study, the skid trail was dry and covered with leaves and branches of the felled trees. All trees were felled with a chainsaw and skidded to the landing by Timberjack 450C cable skidder and piled on both sides of landing.

Table. 1. Information on the basic parameters of trees in average values

Basic parameters of trees			
diameter (cm)	dominant height (m)	basal area (m^2)	volume (m^3)
19.27	15.67	0.2123	0.2723

The total volume of production in the compartment was 28,000 m^3 and a Timberjack 450C cable skidder was used in the study (Table 2).

The working group consisted of two persons including choker setter and skidder operator. They had several years of experience with that type of machine and performed all service and most of repair works. The operator drives the skidder from roadside to stump area, then he releases the cable for hooking. Loads are winched toward skid trails and the machine moves to the landing area. During a normal logging operation, detailed information on skidding components was recorded. Continuous time study to the nearest second with stop watch was used in the study. Different types of delays (such as technical, operational, and personal delays) were also recorded (Pir Baveghar et al. 2010). The extraction cycle was divided into several elements (Spinelli, Hartsough 2001; Wang et al. 2004) as below:

(1) travel unloaded: begins when the machine starts from the landing and ends when it reaches the stump area,
(2) manoeuvring: begins when the machine changes the direction of travel in order to approach the cut trees and ends when it is positioned and ready to grab it,
(3) winching (hooking): 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,
(4) travel loaded: begins when the machine moves to the landing and ends when it reaches there,
(5) unhooking: begins when the machine reaches the landing and ends when the load is unhooked.

Table 2. Specification of the Timberjack 450C skidder

Parameter	Value
Overall height (mm)	3,023
Power (HP)	177
Total weight (kg)	10,270
Front axle weight (kg)	5,682
Rear axle weight (kg)	4,588
Overall width (mm)	3,175
Number of cylinders	6

Table 3. Summary cost information of skidding by a Timberjack 450C cable skidder

Parameter	Cost	Parameter	Cost
Purchase price (USD)	125,000	Depreciation (USD·year^{-1})	11,250
Salvage value (USD)	12,500	Interest (USD·year^{-1})	12,271
Economic life (h)	10	Tax and insurance (USD·year^{-1})	8,664
Tire price (USD)	2,100	Total fixed cost (USD·h^{-1})	35.76
Tire life (h)	4,000	Total variable cost (USD·h^{-1})	19.64
Repair factor (f)	0.9	Total labour cost (USD·h^{-1})	15.83
Scheduled machine hour (SMH) (h)	1,200	System cost (USD·h^{-1})	71.23
Productive machine hour (PMH) (h)	900	Utilization (%)	75

A total of 61 cycles for the skidder were observed in the field. The variables recorded for the skidder were travel distance (m), number of felled trees per cycle, and load volume (m^3).

Diameter of the tree at breast height (DBH) was measured in the sample plots before skidding, and the average volumes were calculated using the local tree volume table (Mousavi et al. 2012) which was available at the company. A reversible metric tape was used for measuring the skidding distance in each cycle. In order to develop the 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 parameters under study (Pir Bavaghar et al. 2010). Instructions prepared for harvesting planning by the Iranian forest organization were used for the cost calculation (IFRWO 2006). The operation cost of skidding machine was based on fixed cost (included the cost of interest rate, depreciation, tax and insurance) and variable cost. The depreciation was calculated considering an economic life of 10 years. The interest rate was 16.5%, the fuel consumption rate was 191 USD·h^{-1}, and the lubricant costs were assumed to be 30% of the fuel cost. Total costs were calculated by summarizing the machine and labour cost (Table 3).

RESULTS

Summary of log skidding with Timberjack 450C in the study area is shown in Table 4. A regression model developed from the detailed time study of log skidding in the study area was as follows:

$$y = -2.670 + 1.161n + 0.033d + 4.517v$$

where:
y – skidding time (min),
n – number of logs per turn,
d – skidding distance (m),
v – volume per turn (m^3).

The coefficient of determination (R^2) was 0.74, which shows that 74% of total variability is explained by the regression equation. The significance level of ANOVA shows that the model is significant at $\alpha = 0.01$ (Table 5). Skidding model was checked by graphical statistical measures and the model was confirmed to be statistically significant (Fig. 2).

Fig. 3 shows the influence of the number of logs per turn, skidding distance and volume per turn on the time consumption of skidding. The time consumption of skidding increases when the number of logs, skidding distance, and volume per turn increase.

The time distribution of different elements of skidding (Timberjack 450C) is presented in Fig. 4. Winching took the largest share and it was followed by travel loaded and travel unloaded. Approximately 86% of each skidding was devoted to productive activities. The percentage of all kinds of delays is also shown in Fig. 4 as a percentage of total gross-effective time.

The system cost (net value) including the sum of machine cost and labour cost is 71.23 USD·PMH^{-1}.

Table 4. Summary of log skidding with Timberjack 450C in the plantation area

Machine	Timberjack 450C
Total number of cycles	61
Study duration (day)	6
Total study time (h)	20.77
Productive time (h)	17.96
Delay time (h)	2.81

Table 5. ANOVA table for regression equation

Factor	Sum of squares	df	Mean square	F	Significance
Regression	1625.59	3	541.86	28.010	00.00
Residual	1102.69	57	19.34		
Total	2728.28	60			

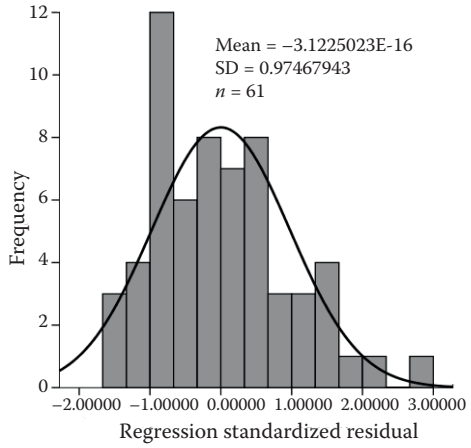

Fig. 2. Histogram of standardized residuals of the overall time consumption model in skidding

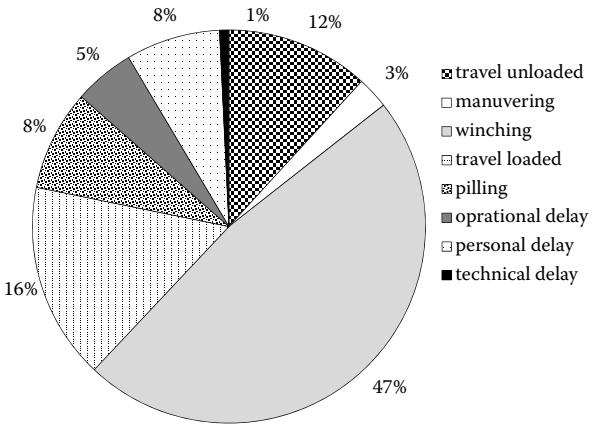

Fig. 4. Distribution of time consumption using a Timberjack 450C wheeled skidder

The fixed cost accounted for 35.76 USD·PMH^{-1} and is higher than the variable cost with 19.64 USD·PMH^{-1}. The labour costs were 15.83 USD·PMH^{-1} and it was the least costly component of the system cost. The unit costs with and without delay times were 13.7 and 11.91 USD·m^{-3}, respectively. The production rate of skidding in effective and gross effective hour was 5.98 and 5.17 m^3·h^{-1}, respectively. Fig. 5 shows the interaction of the number of logs per turn and skidding distance on the production cost. Production cost increases when both the number of logs and skidding distance increase.

DISCUSSION

Work and time study of full tree skidding by Timberjack 450C in the plantation area in northern Iran was performed and the relation between the time consumption and independent variables was introduced as a model. A regression equation was developed for the total cycle time, and the results indicated that the total cycle time was related to the number of logs per turn, skidding distance, and volume per turn. The regression equation developed in this study provided a basis for computing skidding time and cost from stump to landing for full tree treatment. A small diameter of felled trees leads to an increase in their number in each turn and also in winching time. The number of logs per turn was the most influencing factor on the time consumption of winching and total time consumption. Previous research showed that skidding productivity is affected by the number of logs per cycle (Abeli 1992; Jourgholami, Majnounian 2008; Pir Bavaghar et al. 2010; Mousavi et al. 2012). Some variables such as inappropriate felling time (felling just a few days before skidding), poor design of skid trail, keeping workers in pressure, have an influence on the time consumption of winching and skidding (Jourgholami 2005; Naghdi 2005; Pir Bavaghar et al. 2010). Directional felling can be useful to diminish winching time and improve skidder production. Behjou et al. (2008) and Ershadifar et al. (2011) reported that directional felling has an important role in reducing skidding time and production costs. Their study also highlighted the role of skidding distance as another significant variable that affects skidding time. Skidding distance is the most significant variable for the productivity as it was reported in many studies (Kluender et al. 1997; Wang

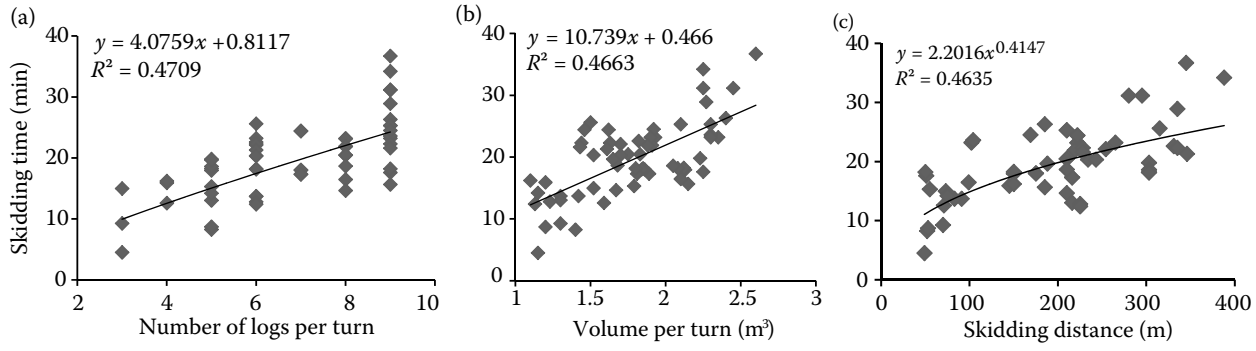

Fig. 3. Effect of the number of logs (a), volume (b) and skidding distance (c) on skidding time

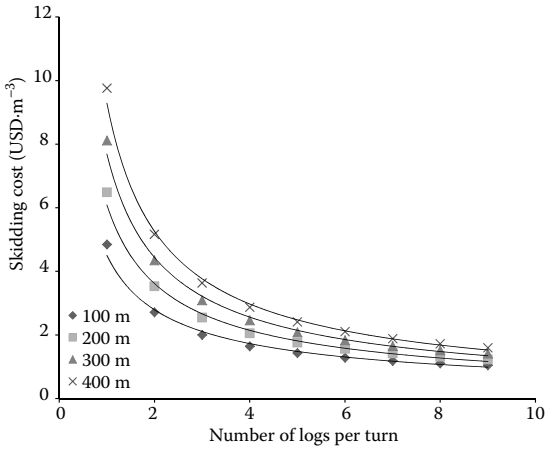

Fig. 5. Production cost of skidder as a function of skidding distance and number of logs per turn

et al. 2004). Winching time accounted for roughly more than 47% of the total time consumption, which was the highest. It was also mentioned by Jourgholami (2005). Using a choker, preparing the skid trail, and applying directional felling may reduce the time consumption of winching and skidding. Preparing the harvesting plan and planning the skid trail before skidding may help for applying directional felling and preventing operational delays such as hanging up to the residual stump and falling trees in unwanted direction (Conway 1984). The time consumption of travel loaded and unloaded directly depends on the travel distance. The average productivity of skidding for all cycles was 5.98 m^3 per effective hour and 5.17 m^3 per gross effective hour, respectively. Number of logs per turn is one of the most important variables influencing the cost and productivity of this machine. With a decrease in the number of logs per load, the volume of each cycle decreases, which has a significant influence on skidding productivity.

Few studies about production and cost of skidding machine in the plantation area have been reported. Mousavi et al. (2012) showed that the average output of skidding was 7.1 m^3 per effective hour for a grapple skidder (HSM-904) in patch cutting of an aspen plantation in northern Iran. The productivity of skidding in this study was lower than in the other studies which were done in the area with different conditions (Feghhi 1989; Pilevar 1996; Naghdi 2005; Nikooy 2007; Pir Bavaghar et al. 2010). Small size trees which have a low volume in the plantation area make it difficult to provide a full load of the machine, which is important for improving the productivity rate. Due to the small diameter of felled trees, it is essential to pre-bunch the logs by workers before the skidder arrival for the winching operation. It helps to provide a full load and reduce the time consumption of skidding.

CONCLUSIONS

The results of this study are valuable for forest harvesting planning, forest managers and loggers in comparing the potential applications of wheeled skidders like Timberjack 450C in plantation areas. The goal of this study was to find out the production rate and cost and also a suitable model for a Timberjack 450C skidder involved in full tree extraction in a typical clear cutting operation in loblolly pine. Number of logs per turn was the main factor affecting the skidder productivity, while skidding distance and volume per turn were also important. The wheeled skidder proved to have a great potential in skidding the short rotation biomass plantation in the same conditions. The results of this study can be used to calculate the total logging cost including felling and processing, loading, and hauling in a full tree harvesting system.

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