Productivity and cost of farm tractor skidding

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ABSTRACT: In this study, productivity rate and operation cost of farm tractor were evaluated in a mountainous natural forest. Data for the study came from a detailed time study in the Research and Educational Forest of Tarbiat Modares University (REFTMU) and was used to develop a multiple linear regression model to predict the skidding cycle time. The results showed that effective independent variables of skidding time were skidding distance and slope of skid trail (P = 0.01). Average productivity rate ranged from 2.43 to 2.60 $m^2 \cdot h^{-1}$. Total time and effective time, respectively. Total cost of the system was 10.24 USD$\cdot h^{-1}$ whereas 4.58% of the cost of skidding resulted from personal delay. The cost and productivity resulting from this study emphasized the importance for foresters to consider a farm tractor when designing skidding operations in young stands or prescribing a combination of two machines in mature stands.

Keywords: skidding operation; continuous time study; regression model; forest system efficiency; Iranian forest

In forest management, transportation is a rather difficult, expensive and time-consuming activity (Eroglu, Acar 2000). The basic requisite for correct management of a felling site in a wooded area is the knowledge of suitability of the machine to be used in the various operations (Curro, Verani 1990). To remain viable in the wood market, woodland owners are seeking logging systems that are cost-effective in meeting standards for timber stand improvements, cuts and water quality. At the same time, loggers face tremendous economic pressures and typically work under conditions of intense competition and narrow profit margins. Thus, it is important to evaluate the performance of various harvesting systems to ensure a profitable operation (Ledoux, Huyler 2000). A ground-skidding system is the process of moving trees or logs from the cutting site to a landing or roadside where they will be processed into logs or consolidated into larger loads for transport to the processing facility or other final destination (Jour Gholami, Majnounian 2008).

With the disappearance of traditional harvesting, with the expansion of mechanization and need for suitable forest mechanization systems, it is necessary to determine machine efficiency in skidding operations (Heinimann 1999) and to use suitable machines with high efficiency in the proper place.

Many studies were carried out that were aimed at productivity and cost of felling and skidding operations and effective factors influencing the machine performance (Klepac, Rummer 2000; Najafi et al. 2007).

Some independent factors affect the cycle time and consequently the machine productivity (Najafi et al. 2007). Studies indicated that the skidding cycle time was mainly affected by skidding distance (Behjou et al. 2008), skid trail slope and by the number of logs in each cycle (Jour Gholami, Majnounian 2008), volume in each cycle (Naghdi 2004) and interaction between them (Behjou et al. 2008).

Currently, farm tractors are used in Iranian mountainous forests to extract logs from the cutting site to a landing.

This small tractor has been proved to be an efficient and manoeuvrable machine to extract logs in a gentle slope area. Its system may also be able to operate effectively in a stand while minimizing residual damage and soil compaction (Bennett 1993).

The loaded tractor can travel on a skid trail up to 15% (uphill direction). Foresters prefer to use this kind of farm machine owing to lower investigation, spare parts price and good manoeuvrability. The tractor is manoeuvrable over most types of terrain in dense, small-diameter stands. It operates efficiently in stands with small or medium stems. This tractor should be considered in pole and sawtimber stands on small parcels where large equipment would not be cost effective and/or would pose a high risk of soil disturbance and residual stand damage.

Most of the previous studies were focused on skidders and forest tractors while the farm tractor had previously received scant attention from researchers.

The aims of the present study were (*i*) to determine productivity rates and logging costs per unit volume for a farm tractor skidding system, (*ii*) to develop a regression model, because by means of this model and by determining the average values of variables significant in the model it would be possible to predict skidding time and costs and to estimate the number of labour, machines and rate finance.

MATERIAL AND METHODS

In July 2009 a field study was conducted in the Research and Educational Forest of Tarbiat Modares University, located in a temperate forest in the north of Iran between 36°31'56"N and 36°32'11"N latitudes and 51°47'49"E and 51°47'56"E longitudes. The elevation ranged from 600 to 80 m above sea level. Average annual rainfall recorded at the closest national weather station, located 20 km far from the research area, was 860 mm.

The natural vegetation is a deciduous forest with dominant species of hornbeam (*Carpinus betulus* [L.]) and beech (*Fagus orientalis* Lipsky) (Agherkakli et al. 2010). Soils have developed from the cretaceous rock and the texture of soil was clay, clay silt and clay loam. Skidding of the processed timber was performed by farm tractor harvesting systems. All skidding was favourable (loaded downhill) and at < 15% slope.

Time study data were collected during spring and summer of 2009 in REFTMU. Detailed time studies were conducted to collect data on skidding activity cycles, delays, and productivity rates.

The time study of typical forest operations begins with the identification of a set of functional elements comprising the work cycle of the machine being evaluated. In performing a time study, observers watch for these elements as the machine works and note the duration of the event (elemental time) and any other factors that influence the performance of the machine (for example skidding distance, log volume, slope, etc.). Data were collected continuously throughout the skidding for each cycle from start to finish. The skidding element times include: travel empty, position, hook, loaded travel, unhook and technical delay. Recorded data included productive cycle time elements and other independent variables associated with each activity.

SPSS ver. 17 was used to complete forward stepwise multiple linear regression to develop regression equations for predicting skidding cycle times based on significant (P = 0.05) independent variables. Random 10% of the detailed time study data was witheld from regression equations in order to validate the regression models. Individual logs were identified by painted numbers before the skidding began. Data recorded for each log included species, diameter at the beginning and end of logs and length.

Skidding costs were calculated for owning and operating and labour cost associated with the farm tractor. Skidding cost was divided by the productivity rate to determine cost per unit (USD·m^{-3}).

The following components were used to calculate productivity rates and costs for skidding:

– *effective hour* (min·hr^{-1}): productive time, determined from the % of time lost in delays;
– *delay-free cycle time*: determined by inserting the average values for the observed independent variables into the skidding regression equation formulated for the machine. Units for skidding are min·turn^{-1};
– *volume per cycle*: volume per piece type (log), determined from diameter and length measurement, and total pieces per cycle, determined from the detailed time study. Units for skidding are CCF/turn;
– *owning, operating, and labour costs* (USD·hr^{-1}): determined from a cost appraisal of the specific equipment and personnel used at skidding operation.

Table 1. Technical specifications of tractor model 8502 four wheels drive vehicle

Length	3.8 m
Width	2.1 m
Height	2.52 m
Distance from earth	0.36 m
Engine power	80.5 kwt

Table 2. Total skidding cycle determined from the detail time study

Time	Travel empty	Preparation	Hook	Travel loaded	Unhook	Piling	Technical delay	Total time
Minute	961.88	51.13	72.13	1,073.16	39.68	26.23	101.066	2,325.13
Percent	41.37	2.20	3.10	46.15	1.70	1.12	4.34	100

Table 3. Breakdown of delays from the detail time study

Time	Personal delay	Operational delay	Technical delay	Total delays
Minute	113.85	43.28	101.06	258.2
Percent	44.09	16.76	39.14	100.0

Table 4. Summary statistic for independent variable

Variables	Average	Median	Maximum	Minimum
Skidding distance (m)	665	738	1234	70
Slope (%)	–20.68	–13.89	–35	0
Load volume (m^3)	1.506	1.39	3.73	0.43
Number logs	1.17	1	2	1

Table 5. Time and limit confidence

Cycle	Distance	Slope	Estimated skidding time	Real skidding time	Limit confidence
1	234	–15	20.40	17.18	$10.65 < t < 25.95$
2	743	–11	28.67	35.43	$21.184 < t < 36.172$
3	865	–28	48.36	45.12	$35.45 < t < 61.28$
4	457	–24	34.63	25.88	$25.26 < t < 43.99$
5	1,043	–18	42.78	34.02	$31.55 < t < 54.00$
6	512	–17	29.05	28.78	$21.28 < t < 36.81$

RESULTS

Productivity

Summary for the total skidding cycle is shown in Table 2. The average total cycle time was 34.70 min, whereas the two most time-consuming components of the total skidding time were travel empty and travel loaded. The average technical delay, the third time-consuming component, was 4.34% (Table 3). Delays were 10.4% of the average skidding cycle time; delays ranged from 44.09% in personal delay to 39.14% in technical delays (Table 3).

67 skidding cycles were studied to develop a validated linear regression ($P < 0.10$). The result of independent variables is shown in Table 4.

A regression model developed from the detailed time study was as follows:

$$Y = 0.024D + 0.986S, R^2 = 0.62$$

where:
Y – skidding time (min),
D – skidding distance (m),
S – slope (%).

The results showed that the effect of the volume of logs per cycle on the skidding time was not significant. Average productivity rate was calculated as 2.60 $m^3 \cdot h^{-1}$.

The developed model was validated by comparing observed results (time study) with estimated

Table 6. Cost of farm tractor system (USD·h^{-1})

Cost parameter	Cost (USD)
Fixed costs	
Depreciation	1,178
Interest	1,168
Insurance and taxes	234
Total fixed cost in the useful hours	1.43
Total fixed costs in the hours scheduled	1.07
Operating costs	
Repair and maintenance	3.20
Fuel and lubricant	0.8
Tires	0.1
Total operating cost	4.11
Labor cost	4.69
Total cost of system	10.23

Skidding cost for delay free skidding time and delay skidding time was calculated 4.21 USD and 3.9 USD $m^3 \cdot h^{-1}$.

results (model output) for six cycles. To validate the model, prior to the model development, six cycles were selected randomly. The observed data were entered into the model to estimate the cycle time, then the observed and estimated values were compared (Table 5).

Productivity rate for delay-free skidding time and delay skidding time was calculated to be 2.6 and 2.43 $m^3 \cdot h^{-1}$. Table 6 shows the costs of the system, including owning, operating and labour costs. The most costly component of the system cost was labour cost.

Sensitivity of skidding time to skid trail slope and skidding distance

The regression model and actual volume per log were used to generate information on the sensitivity of skidding time to increased skidding distance and skid trail slope (Figs. 1 and 2). Skidding time increased as the trail slope and distance increased. Fig. 3 shows the interaction effect of skid trail slope and skidding distance on cost. Both the skid trail slope and skidding distance affected skidding cost (Fig. 3). A log volume standard of 1.76 m^3 was used in regression equation.

DISCUSSION

During the farm tractor skidding operation, travel empty and travel loaded collectively dominated the cycle time (Table 2). There is little doubt that skidding distance significantly affected skid cycle time and production rate (Liu, Corcoran 1993). Fig. 3 showed that the farm tractor productivity was affected by skidding distance. The only other component that required a significant percentage of time was the skid trail slope. A farm tractor usually works on the farm on a slope of up to 15%, thus the skid trail slope (20%) influenced travel time. It has been documented that skidding time increases rapidly with increasing skid trail slope (Najafi et al. 2009). The tractor, loaded logs on the downhill trail slope, inevitably to maintain balance, then the machine travelled slower and the skidding time increased. This discrepancy could be further magnified if productivity declined with an increase in skidding distance (Fig. 3).

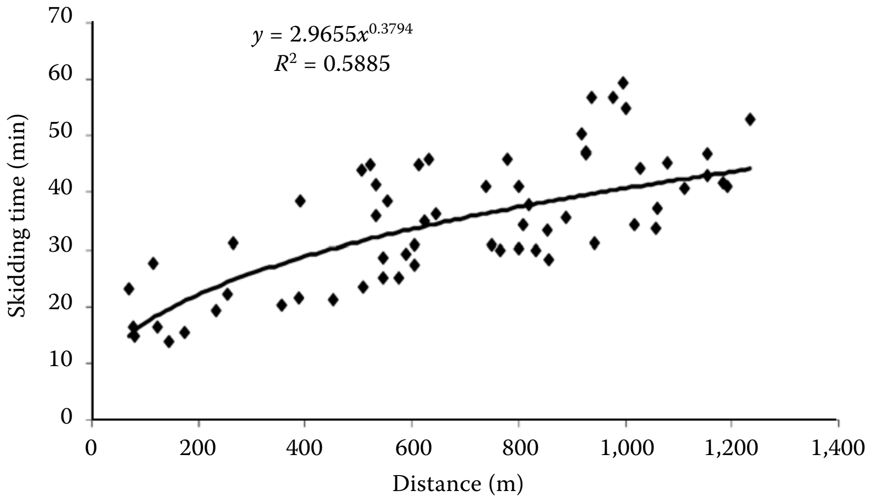

Fig. 1. Effect of distance on skidding time

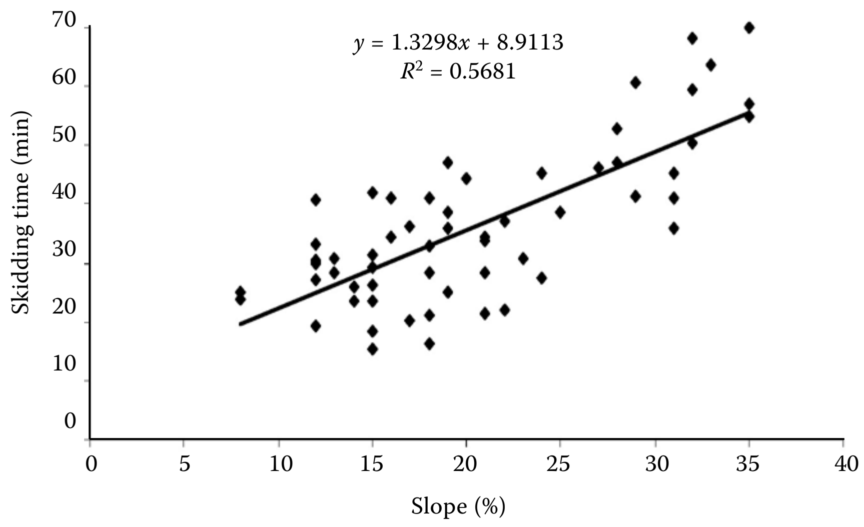

Fig. 2. Effect of slope on skidding time

Previous research showed that skidding productivity is affected by the number of logs per cycle (Abeli 1992). However, we found evidence that the system productivity was not strongly influenced by the number of logs per turn. This fact could be explained that the engine power of the tractor is lower than that of other skidders and then the tractor extracted one log in each cycle. For this reason the number of log per cycle was the same and the volume of logs was close to each other.

That technical delay was the third most time-consuming component of skidding time could probably be explained by the fact that the crew applied a used and short cable to winch logs.

As shown by the results, three types of delays – personal, technical and operational – have been identified during tractor skidding. Maximum time of delays was related to personal delay, the main reason it can be attributed to talk to the driver.

Fig. 2 shows that the effect of slope on skidding time is higher than that of distance. This could be explained by the fact that the machine is a speedy rubber tractor and low engine power. Therefore it is recommended that these tractors be used on long distances and gentle skid trails in thinning operations with low diameter. The system cost is much lower compared to skidders, future studies will be required to compare the efficiency of farm tractor and skidder in thinning operations.

References

Abeli W.S. (1992): Optimal road spacing for manual skidding sulkies. Journal of Tropical Forest Science, ***6***: 8–15.

Agherkakli B., Najafi A., Sadeghi S.H. (2010): Ground based operation effects on soil disturbance by steel tracked skidder in a steep slope of forest. Journal of Forest Science, ***56***: 278–284.

Behjou F.K., Majnounian B., Namiranian M., Dvorak J. (2008): Time study and skidding capacity of the wheeled

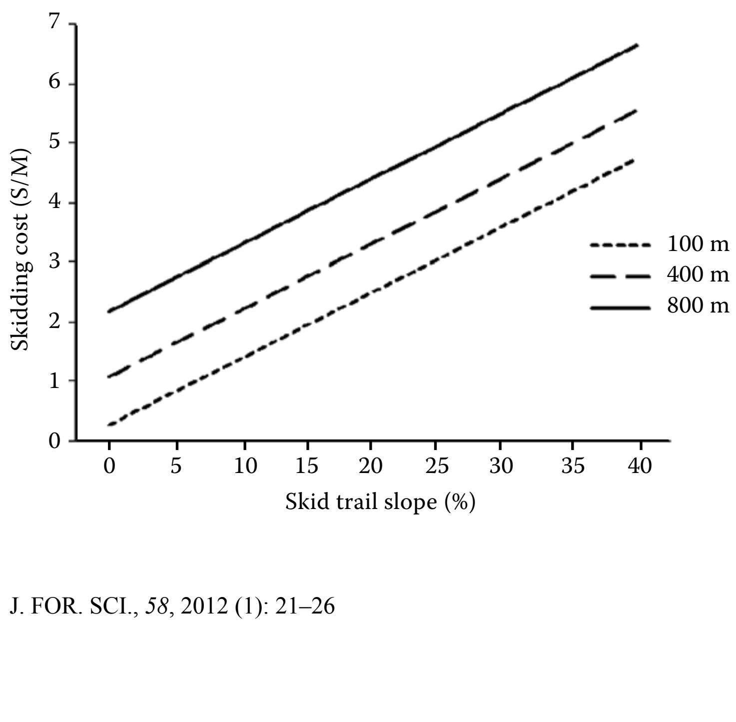

Fig. 3. Relative effect on cost as skid trail slope and skidding distance

skidder Timberjack 450C in Caspian forests. Journal of Forest Science, ***54***: 183–188.
Bennett D.M. (1993): Partial Cutting in a Second Growth Douglas-fir Stand in Coastal British Columbia: Productivity, Cost, and Soil Impacts. Technical Note TN-199, FERIC, Pointe-Claire.
Curro P., Verani S. (1990): On the maximum skidding output of the "Timberjack 380" forest tractor. Journal of Forest Engineering, ***1***: 35–39.
Eroglu H., Acar H. (2000): The comparison of logging techniques for productivity and ecological aspects in Artvin, Turkey. Journal of Applied Sciences, ***7***: 1973–1976.
Heinimann R. (1999): Ground-Based Harvesting Technologies for Steep Slopes. Corvallis, OR, Department of Forest Engineering, Oregon State University: 7.
Jour Gholami M., Majnounian B. (2008): Productivity and cost of wheeled skidder in Hyrcanian Forest. International Journal of Natural and Engineering Sciences, ***2***: 99–103.
Klepac J., Rummer B. (2000): Productivity and Cost Comparison of Two Different-Sized. Presentation at the 2000 ASAE Annual International Meeting sponsored by ASAE Midwest Express Center, Milwaukee: 10.
Ledoux Ch.B., Huyler N.K. (2000): Cost comparisons for three harvesting systems operating in northern hardwood stands. Research Paper NE-715.
Liu S., Corcoran T.J. (1993): Road and landing spacing under the consideration of surface dimension of road and landing. Journal of Forest Engineering, ***5***: 49–53
Naghdi R. (2004): Investigation and comparison of full tree and log utilization methods in order to presentation the best model forest roads network in Neka region (North of Iran). [Ph.D. Thesis.] Tehran, Tarbiat Modarres University: 238. (in Persian)
Najafi A., Sobhani H., Saeed A., Makhdoom M., Marvimohajer M.R. (2007): Time study of skidder HSM 904. Journal of the Iranian Natural Resource, ***60***: 921–930.
Najafi A., Solgi A., Sadeghi S.H.R. (2009): Soil disturbance following four wheel rubber skidder logging on the steep trail in the north mountainous forest of Iran. Soil & Tillage Research, ***103***: 165–169.

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