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Comprehensive Productivity Models for Tracked and Wheeled Skidders in the Hyrcanian Forests of Iran

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Abstract: The goals of the study were to develop comprehensive productivity models of skidders for the Hyrcanian forest areas of Iran and to compare the productivities of two existing skidding machine types in order to select the most profitable ones under various operating conditions. Estimating productivity of forest equipment is imperative for forest managers to estimate production costs of logging and for developing a cost efficient logging plan. This study deals with the performance of ground based harvesting systems (tracked and wheeled skidders) in the mountainous forest of the northern part of Iran. Two regression models for each skidding machine type (one equation for uphill and another for downhill skidding) were developed. In addition, related times for each element of skidding cycle and delay times were determined.

Key words: Hyrcanian forests, productivity, tracked and wheeled skidders, uphill and downhill skidding, regression models

INTRODUCTION

The Hyrcanian forests of Iran, composed of mixed broadleaved species are the only commercial forests of Iran that have an important economic value in addition to their ecological role. Timber harvesting is the most expensive element of the operations in theses forests, therefore improving their efficiency is an important duty of forest managers.

Estimating productivity of forest equipment is imperative for forest managers to estimate production costs of logging and to develop a cost efficient logging plan (Bavaghar *et al*., 2008). The need for accurate information about machine productivity is essential for improving project economics for forestry managers and forest contractors (Brown *et al*., 2002). Primary transportation in logging is defined as the process of wood transport from the felling site (stump) to a road that can be accessed by long-distance transportation systems (usually trucks) (Conway, 1982).

In Iran, ground based harvesting systems (wheeled and tracked skidders) are common types of equipment used in primary transportation. Therefore, Iranian harvest planners must optimize the deployment of skidding machines in order to achieve successful harvesting operations. Developing productivity models for harvesting equipment should help managers achieve greater operational efficiency.

Single-machine harvesting models focus on the activity of a machine and how it is influenced by the environment and stand in which it is working (McDonagh *et al*., 2004). These models normally involve detailed activity modeling to determine the factors affecting productivity. Many research has been undertaken in this field including, for example by

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Roger and McDonald (1989), Eliasson (1999), Wang *et al.* (1998), Elisasson and Lageson (1999), Egan and Baumgas (2003), Akay *et al.* (2004), Davis and Kellogg (2005), Merence and Kosir (2007), Eberhardinger (2007) and Gluschkov and Markoff (2007). Mismatching of harvesting systems to operating areas was estimated to be a significant problem for 40% of all logging contractors (McDonagh *et al.*, 2004).

This study deals with the performance of tracked and wheeled skidders in the mountainous forests of northern part of Iran. Some studies of skidder productivity were conducted in operations within these forests in the past, but no comprehensive models of skidder productivity had been developed. The goals of this study were to develop comprehensive productivity models of skidders for the Hyrcanian forests of Iran and to compare productivities of two existing skidding machine types in order to select the most profitable one under various operating conditions. The hypothesis is that the productivity of tracked and wheeled skidders is dependent on skidding distance, skidding slope, load volume and the number of logs skidded per turn in uphill or downhill skidding.

MATERIALS AND METHODS

Study Area

The study site was located in the northern forests of Iran, which are known as the Hyrcanian forests (Fig. 1). These forests cover the southern coasts of the Caspian Sea and have a total area of 1.8 million ha that can be regarded as commercial forests. Hyrcanian forests are predominantly composed of mixed hardwoods that are uneven aged and have a multistoried structure. These forests can be found at altitudes ranging from sea level up to an elevation of 2800 m. Selection harvesting is the silvicultural method used and short wood and tree length harvesting systems are employed in theses forests. This study was carried on in areas that were harvested under the supervision of the natural resources offices of northern Iran.

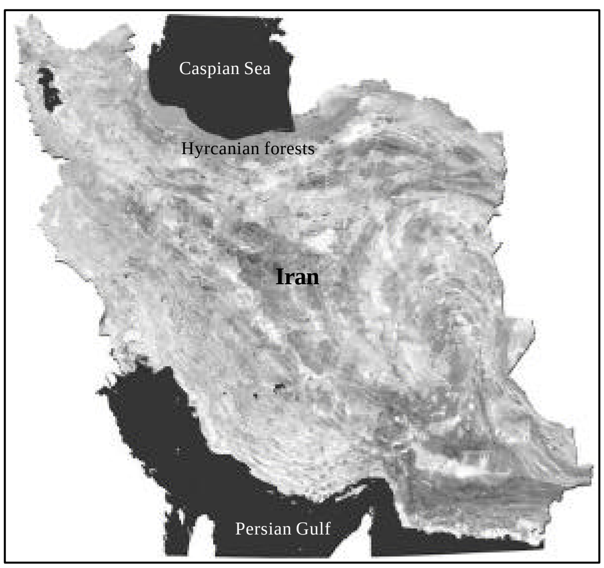

Fig. 1: The study area location in Iran

Study Procedures

Mechanized harvesting systems commonly used throughout the Hyrcanian forests include wheeled and tracked skidders. In order to assess skidder productivity, a time study method was used. Time study is one of the most common methods of work measurement. It is used worldwide to determine the times associated with work elements in the production process (Bjorheden, 1991).

Field work was conducted in spring, summer and early autumn of 2007. 501 skidding cycles of wheeled skidders (Timberjack 450C, Caterpillar, HSM 904 and Clark Ranger 66BDS), composed of 196 cycles of downhill skidding and 305 cycles of uphill skidding) and 130 skidding cycles of tracked skidders (Caterpillar Bulldozer D6 and D7 and Zetor), composed of 58 cycles of downhill skidding and 72 cycles of uphill skidding) were observed and. Continuous time recording techniques were used throughout the study, with elemental times read and recorded at each element of the machine cycle with a one hundredth second stop watch. As well, various delay times (technical, operational and personal delays) were recorded. The elements of the machines cycles were recorded as: travel empty, positioning, releasing winch, hooking, winching, travel loaded, unhooking and piling. In order to develop the productivity models for the two types of skidding machines, multiple regression analysis, using the least-squares method, was used to test the correlation among the skidding cycle times and the parameters under study. In this study, the parameters most likely to have an effect on cycle times (skidding distance, skidding slope, number of skidded logs and volume per turn), were measured.

RESULTS

Skidder Cycle and Setting Characteristic

The results of skidding cycle time and the primary factors expected to affect the skidding performance of wheeled and tracked skidders for both downhill and uphill skidding are shown in Table 1-4. The maximum skidding distances for wheeled skidders in downhill and uphill skidding were 1295 (Table 1) and 941 m (Table 2) and for tracked skidders were 308 (Table 3) and 509 m (Table 4), respectively, that were too long by most standards.

Average gross times per turn for wheeled skidders in downhill and uphill skidding were calculated to be 22.06 (Table 1) and 16.51 min (Table 2), respectively. In downhill and uphill skidding of wheeled skidders, only 69 and 64% of each machine cycle was devoted to productive activities, respectively. The results for tracked skidders in downhill and uphill skidding were 24.94 (Table 3) and 25.68 min (Table 4) for gross times and 77 and 65% for the

Table 1: Descriptive statistics for wheeled skidders in downhill skidding (N = 196)

Variables	Minimum	Maximum	Mean	SD
Productive time (min)	2.93	43.97	15.24	7.38
Distance (m)	11.50	1295.00	447.15	344.89
Slope (%)	-26.00	-2.50	-11.90	5.48
Volume (m^3)	0.16	6.91	3.11	1.56
Number of logs	1.00	5.00	1.65	0.83

Table 2: Descriptive statistics for wheeled skidders in uphill skidding (N = 305)

Variables	Minimum	Maximum	Mean	SD
Productive time (min)	2.01	30.34	10.62	5.42
Distance (m)	3.00	941.00	204.46	185.17
Slope (%)	1.00	25.19	11.44	5.03
Volume (m^3)	0.27	6.23	2.51	1.33
Number of logs	1.00	5.00	1.46	0.79

Table 3: Descriptive statistics for Tracked skidders in downhill skidding (N = 58)

Variables	Minimum	Maximum	Mean	SD
Productive time (min)	7.01	41.30	19.22	8.72
Distance (m)	73.00	308.30	180.27	55.48
Slope (%)	-32.85	-0.50	-16.34	8.37
Volume (m^3)	1.12	7.59	3.34	1.50
No. of logs	1.00	6.00	2.78	1.43

Table 4: Descriptive statistics for Tracked skidders in uphill skidding (N = 72)

Variables	Minimum	Maximum	Mean	SD
Productive time (min)	1.34	40.02	16.74	7.18
Distance (m)	0.00	508.80	163.62	115.84
Slope (%)	0.00	28.79	18.16	7.80
Volume (m^3)	0.47	7.99	3.14	1.76
Number of logs	1.00	4.00	1.51	0.67

Table 5: The distribution of elemental times per machine cycle

Elemental times (% of gross time)	Wheeled/downhill	Wheeled/uphill	Tracked/downhill	Tracked/downhill
Travel empty	18	12	10	12
Positioning	2	2	3	2
Releasing winch	7	6	12	5
Hooking	6	6	8	5
Winching	7	9	16	9
Travel loaded	22	19	20	23
Unhooking	2	3	3	3
Piling	6	6	5	5
Personal Delay	16	21	13	15
Technical delay	3	2	4	15
Operational delay	11	14	6	6

percent of productive activities. The remainder of the cycle times was related to various kinds of delays (personal, technical and operational delays). Personal delays in both types of machines constituted the greatest proportion of delay time. The technical delays for tracked skidders were greater than those for wheeled skidders. Most tracked skidders used in Iran have surpassed their normal economic lives and this is a major reason for their technical delay times being greater than for wheeled skidders.

Personal and operational delays could be decreased by better management of operators and stages of operation. The distribution of elemental times per machine cycle is shown in Table 5. The travel loaded element took the most time, while positioning and unhooking consumed the least amount of time.

Regression Analysis

After determining the relation of each measured parameter (average skidding distance, skidding slope, winching distance, number of skidded logs per turn and skidded volume per turn (including bark)) with the cycle gross (Table 6) and productive (Table 7) times, by drawing dot plots, regression analyses were undertaken. It should be noted that some of time study data samples, were set aside randomly, in order to assess the validity of the models (12 samples for wheeled skidders in downhill, 10 samples for wheeled skidders in uphill, 7 samples for tracked skidders in downhill and 10 samples for tracked skidders in uphill skidding) and the regression analysis was undertaken using the rest of data. Multiple regression analysis of the skidding cycle times and related parameters revealed that gross times (total cycle time minus personal delays because of the expanded range of the personal delays changes in the different cycles) were positively associated with skidding distance, winching distance, the interactive variable DS (multiply skidding distance and slope) and the number of skidded logs per turn (i.e., gross times increased as skidding distances increased)

Table 6: The relation of each measured parameter with gross time

Type of vehicle	General slope	Distance	Volume	N. of logs	Slope	W. Distance
Wheeled skidder	Downhill	$R^2 = 0.48$	$R^2 = 0.18$	$R^2 = 0.28$	$R^2 = 0.02$	$R^2 = 0.01$
		S = 6.55	S = 8.18	S = 7.67	S = 8.94	S = 8.05
	Uphill	$R^2 = 0.18$	$R^2 = 0.08$	$R^2 = 0.15$	$R^2 = 0.02$	$R^2 = 0.00$
		S = 8.32	S = 8.82	S = 8.45	S = 9.08	S = 9.54
Tracked skidder	Downhill	$R^2 = 0.38$	$R^2 = 0.01$	$R^2 = 0.40$	$R^2 = 0.24$	$R^2 = 0.04$
		S = 7.49	S = 9.43	S = 7.33	S = 8.25	S = 9.30
	Uphill	$R^2 = 0.44$	$R^2 = 0.18$	$R^2 = 0.08$	$R^2 = 0.12$	$R^2 = 0.00$
		S = 5.87	S = 6.56	S = 7.52	S = 6.91	S = 7.83

Table 7: The relation of each measured parameter with travel time

Type of vehicle	General slope	Distance	Volume	No. of logs	Slope
Wheeled skidder	Downhill	$R^2 = 0.87$	$R^2 = 0.26$	$R^2 = 0.20$	$R^2 = 0.07$
		S = 2.00	S = 4.80	S = 4.98	S = 5.36
	Uphill	$R^2 = 0.78$	$R^2 = 0.16$	$R^2 = 0.07$	$R^2 = 0.00$
		S = 2.01	S = 3.92	S = 4.12	S = 4.28
Tracked skidder	Downhill	$R^2 = 0.36$	$R^2 = 0.01$	$R^2 = 0.37$	$R^2 = 0.28$
		S = 3.39	S = 4.22	S = 3.36	S = 3.60
	Uphill	$R^2 = 0.87$	$R^2 = 0.20$	$R^2 = 0.09$	$R^2 = 0.10$
		S = 2.16	S = 5.61	S = 5.99	S = 5.96

Table 8: Gross time equations (regression models) per skidding cycle

Type of vehicle	General slope of skid trail	Regression model	R^2 (%)	R^2_{adj} (%)	S
Wheeled skidder	Downhill	$G_T = 2.45 + 0.02\ D + 0.21Dw + 3.08\ N$	55.8	55.0	5.42
	Uphill	$G_T = 4.84 + 0.02\ D + 3.86\ N$	26.3	25.7	8.23
Tracked skidder	Downhill	$G_T = 5.40 - 0.002\ DS + 2.93\ N$	70.5	69.4	5.20
	Uphill	$G_T = 5.35 + 0.06\ D$	43.9	42.9	5.87

G_T: Gross time in minutes (without personal delay times); D: Average skidding distance (m); Dw: Average winching distance (m); N = No. of skidded logs per turn

Table 9: Travel time equations (regression models) per skidding cycle

Type of vehicle	General slope of skid trail	Regression model	R^2 (%)	R^2_{adj}(%)	S
Wheeled skidder	Downhill	$T_T = 4.11 + 0.0150\ D$	87.1	87.0	2.00
	Uphill	$T_T = 2.89 + 0.0204\ D$	77.9	77.8	2.01
Tracked skidder	Downhill	$T_T = 5.69 - 0.00171\ DS$	69.3	68.7	2.37
	Uphill	$T_T = 2.43 + 0.0623\ D$	87.5	87.3	2.16

T_T: Travel time in minutes (without winching and delay times); D: Average skidding distance (m); DS: Average skidding distance (m) multiply by Slope (%)

Table 10: Productive and gross time equations per skidding cycle

Type of vehicle	General slope of skid trail	Productive time equation ($P_T = T_T + W_T$)	Gross time equation ($C_T = P_T + D_T$)
Tracked skidder	Downhill	$P_T = T_T + 4.41$	$C_T = P_T + 6.81$
	Uphill	$P_T = T_T + 3.56$	$C_T = P_T + 5.89$
Wheeled skidder	Downhill	$P_T = T_T + 8.40$	$C_T = P_T + 5.72$
	Uphill	$P_T = T_T + 4.97$	$C_T = P_T + 6.35$

P_T: Productive time in minutes; W_T: Average winching time in minutes; C_T: Total skidding cycle time in minutes (gross time); D_T: Average delay time in minutes

(Table 8). Because of the weak validity of these models (low normality of residuals, high S, low R^2 and low validity results by witness data), the regression analysis for travel times was also undertaken. Travel time (productive cycle time minus the sum of time taken by releasing the winch, hooking and winching) were positively associated with skidding distances for the wheeled skidders in downhill and uphill skidding and tracked skidders in uphill skidding. For tracked skidder in downhill skidding, the interactive variable DS (multiply skidding distance and slope) was entered in the model (Table 9). The regression models were validated using the data samples that had been set aside earlier in this process. Results showed that all of presented equations had a reliable validation, statistically. In order to estimate the productive time and gross time, as we use the travel time equations, average winching and delays times should be added to the results (Table 10).

System Productivity

Systems productivity based on gross time were measured as 8.46 and 9.12 $m^3 h^{-1}$ for wheeled skidders and 8.04 and 8.16 $m^3 h^{-1}$ for tracked skidders in downhill and uphill skidding, respectively.

Systems productivity based on productive time were calculated to be 12.24 and 14.18 $m^3 h^{-1}$ for wheeled skidders and 10.42 and 11.25 $m^3 h^{-1}$ for tracked skidders in downhill and uphill skidding, respectively. The greater productivity in uphill skidding was caused by shorter skidding distances and gentler slopes in this skidding direction.

DISCUSSION

Time studies of existing wheeled and tracked skidders were undertaken under various operating conditions in the Hyrcanian forests of Iran. Comprehensive productivity models of skidders (two regression models for each skidding machine type (in uphill and downhill skidding) were developed. Because of the expanded range of the winching time and personal delay changes in the different cycles, the regression analysis for travel time was undertaken. Regression analysis showed that only skidding distance was correlated to travel time for the wheeled skidders in downhill and uphill skidding and tracked skidders in uphill skidding. For tracked skidder in downhill skidding, interactive variable DS (Skidding distance and Slope of skid trails) was used in the regression model. These results are in support with other researches (Naghdi and Bagheri, 2007; Davis and Kellogg, 2005; Akay and Sessions, 2004; Egan and Baumgas, 2003; Sobhany, 1991). The skidding distance and trails slope are the most effective parameters in timber skidding.

By using this information, forest managers could predict the time required for tracked or wheeled skidders to extract the felled timber from a compartment.

Better information about the likely productivity and cost of harvesting equipment and systems is a necessary for improved management planning aimed at rehabilitation and utilization of the Hyrcanian forests (Sobhany, 1991).

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