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ORIGINAL PAPER

Time consumption, productivity, and cost analysis of the motor manual tree felling and processing in the Hyrcanian Forest in Iran

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Abstract: An empirical time study was conducted to evaluate the performance of the current felling and tree processing methods used in Northern Iran's Hyrcanian forest. Motor-manual felling is done mostly in winter, while tree processing starts when the felling season ends. We identified the elements of felling and processing work phases, and 142 cycles and 110 cycles were respectively recorded for felling and processing. On the basis of data analysis (time study), we developed statistical models of effective time consumption in the respective work phase and for its total productivity. The production rate of felling with and without delay time was 9.7 and 11.65 trees per hour (0.17 USD·m^{-3} and 0.21 USD·m^{-3}), and the average production cost with and without delay was 1.21 USD and 1.45 USD per tree, respectively. The average productivity of processing was 35 m^3 per effective hour and the average unit cost of processing was 0.22 USD·m^{-3}.

Keywords: Motor-manual felling; time study; chainsaw; processing; cost; forest work study

Introduction

Uneven-aged management is used in most Iranian forests, which means that the harvesting methods used are single tree or group selection. The chainsaw is the most common tool used for felling and processing trees in Iran. Trees felling is performed by private contractor in Iran and it need to be qualified by the department of natural resources' regional office. Tree processing includes several elements, of which delimbing is the most tedious and hazardous part of tree processing and cross-cutting is the most important elements of processing from technical point of view.

The time consumption in motor-manual felling and tree processing is studied for mainly finding out the most important factors influencing work productivity to rationalize work performance and to set a base for payment or for the cost calculation (Nurminen et al. 2006). In the present study we calculated the production rates (m^3·h^{-1}) and costs ($·m^{-3}) of felling and tree processing under Iranian conditions and developed time consumption and productivity models for felling and processing. Additionally, the most influential factors respective to each work phase were also determined based on the data.

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Material and methods

The study was conducted in the Nav Watershed of the Hyrcanian Forest in Northern Iran. This area is located between latitude 37°61' N–37°20' N and longitude 48°39' E–48°44' E.

Data collection

During normal harvest operations, we did detailed records of felling and processing. An electronic chronometer and video camera (Sony HC62) were used for data collection. A Stihl MS 880 model chainsaw was used in felling and tree processing. Total effective time and mean log volume (number of cut tree) per cycle in felling and processing were calculated, and then put into relation and yielding productivity per hour in each work phase. Total effective time was converted into productivity.

SPSS 17.0 for Windows was used as a statistical package for data analysis. As statistical parameters were used for selecting the best-fit model, the *p*-value, *F*-value and R^2 were chosen. The null hypotheses were rejected if the test results indicated *p*-values was larger than 0.05 (Nurminen et al. 2006). Different transformation and curve types were also tested to obtain the residuals as symmetrical as possible and to achieve the best values for determination coefficient.

Work phase classification

All activities associated to felling were broken into several time elements. **Cutting activities** include (1) moving: begins when feller walks toward the tree to be cut and ends when feller reaches the tree; (2) Clearing: begins when feller clears around tree and ends when feller is ready to cut tree; (3) sink-cut: begins when the operator starts to cut marked point, and ends when he has sawed out a pie-shaped piece of wood facing in the falling direction; (4) back-cut: begins when the operator starts to cut 2.5–5 cm above sink-cut in opposite direction, and ends when the tree falls on the ground; (5) miscellaneous time: every work which is a part of work phase, but is not placed in the above mentioned category (e.g.: fuelling). **Processing activities** include (1) moving: begins when the operator starts to move and ends when the operator reaches felled tree; (2) clearing begins when the operator start to remove some unwanted small tree and disturbing undergrowth and ends when the operator starts to next activity; (3) measuring: begins when the helper measures from the bottom and ends when measuring finishes; (4) delimbing and topping: begins when the operator starts to cut the top and branches and ends when all branches are cut; (5) cross-cutting (bucking): when the operator cross-cuts the felled tree and ends when the cross-cutting finishes. **Delay** includes (1) personal delay: any interruption during working time (e.g.: rest and personal breaks); (2) technical delay: any breaks related to failure in tools (e.g.: tearing chain of chainsaw); (3) operational delay: somehow related to inappropriate planning (e.g.: when there is no fuel in access).

Cost calculation

The production cost of every machine was based on fixed cost and variable cost. Total cost was calculated by adding up machine cost and labour cost (Table 1).

Table 1. Summary of detailed chainsaw cost calculation parameters

Cost factors	Felling (chain saw)	Processing (chain saw)
Purchase price (US$)	1045	1045
Salvage value (US$)	104.5	104.5
Economic life (year)	4	4
Chain life (hour)	240	240
Fuel cost (US$·h^{-1})	0.5	0.5
Repair factor (f)	0.6	0.6
SMH (hour)	320	880
PMH (hour)	160	740
Utilization (%)	75.0	75.0
Total fixed cost (US$·(PMH)$^{-1}$)	0.41	0.41
Total variable cost (US$·(PMH)$^{-1}$)	0.92	0.92
Total machine cost (US$·(PMH)$^{-1}$)	1.33	1.33
Total labor cost (US$·h^{-1})	12.80	6.40
Total cost (US$·(PMH)$^{-1}$)	14.13	7.73

*The same chain saw has been used for felling and processing.

Results

Distribution of time consumption of felling

The time consumption distribution of the felling is shown in Fig. 1. Back cut was the most time consuming elements of felling The breakdown of delays time showed that the percentage of operational delay was 62%, while the percentage of technical delay and personal delay was 19%.

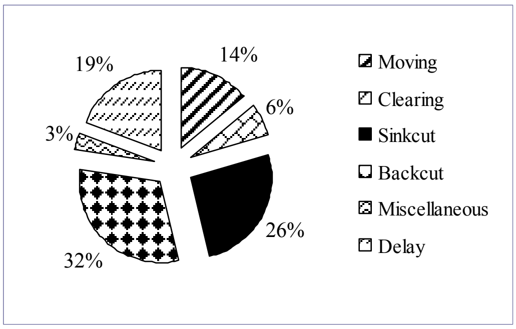

Fig. 1 Distribution of time consumption in manual felling

Time consumption of felling in different diameters is shown in Table 2. The average productivity of felling was 11.6 trees per hour. Average felling time includes only sink-cut and back-cut and the effective time includes time consumption of all elements

Time consumption model for the felling elements

The models are presented here for walking, felling, sink-cut, and back-cut to estimate the effective time consumption as a function of independent variables (Table 3). Other work phase including clearing and miscellaneous time was calculated as a mean value which is 24.7 s·tree^{-1} and 13.0 s·tree^{-1}, respectively.

Distribution of time consumption of processing

The time consumption distribution of the processing was calculated as moving (10%), clearing (10%), delimbing and topping (28%), measuring (9%), bucking (25%), miscellaneous time (3%), delay (15%). Technical delay was found to be the most time-consuming delays time in processing. The time consumption and productivity of processing are presented in Table 4.

The statistical characteristic of regression models of elements are presented in Table 5. *F*-value and *p*-value show that the presented models are statistically significant.

Production cost of work phases

The production cost of manual felling and processing was calculated as:

Cost factors	Felling (USD·tree^{-1})	Processing (USD·m^{-3})
Avg. unit cost	1.21	0.22
Min. unit cost	0.23	0.09
Max. unit cost	4.41	0.89

Table 2. Time consumption and productivity of felling at different diameters (without delay)

Diameter (cm)	Avg. felling time (s)	Avg. effective time (s)	Min. effective time (s)	Max. effective time (s)	Avg. productivity (tree·h^{-1})	Min. productivity (tree·h^{-1})	Max. productivity (tree·h^{-1})
<50	70	142	77	245	25.4	14.7	46.8
50	90	136	68	203	26.5	17.7	52.9
55	93	166	105	239	21.7	15.1	34.3
60	110	184	105	342	19.6	10.5	34.3
65	187	293	110	553	12.3	6.5	32.7
70	194	252	165	354	14.3	10.2	21.8
75	194	262	99	536	13.7	6.7	36.4
80	178	334	242	463	10.8	7.8	14.9
85	275	434	255	783	8.3	4.6	14.1
90	308	419	198	577	8.6	6.2	18.2
95	328	433	284	591	8.3	6.1	12.7
100	320	429	211	859	8.4	4.2	17.1
105	400	523	299	914	6.9	3.9	12
110	449	524	328	867	6.9	4.2	11
115	460	550	342	638	6.6	5.6	10.5
120	470	826	577	1126	4.4	3.2	6.2
125	507	513	378	760	7.02	4.7	9.5
130	283	329	253	406	10.9	8.9	14.2
135	595	773	690	856	4.7	4.2	5.2
140		-	-	-			
145	-	-	-				
150	328	536	-	-	6.7	-	-
155	392	518	198	577	6.9	-	-
160	-	-	-				
165		-	-	-			
170	619	757	-	-	4.7	-	-

Table 3. Statistical characteristics of the 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*
						Constant	7.341	4.511	1.628	0.107
Walking	t_{f1}	0.65	140.53	<0.001	101	x_{fd}	01.059	0.080	13.316	<0.001<0.00
						x_{ls}	0.586	0.138	4.254	1
						Constant	-9.063	23.133	-0.392	0.696
Sink-cut	t_{sc}	0.53	79.23	<0.001	142	x_d^2	0.003	0.004	0.881	0.380
						x_d	1.182	0.595	1.986	0.049
						Constant	-90.791	38.167	-2.379	0.019
Back- cut	t_{bc}	0.52	74.12	<0.001	142	x_d^2	-0.001	0.006	-0.193	0.847
						x_d	2.893	0982	2.945	0.004
						Constant	-99.854	57.657	-1.732	0.086
Felling	t_{f3}	0.55	85.79	<0.001	142	x_d^2	0.002	0.009	0.226	0.082
						x_d	4.075	1.484	2.746	0.007
						Constant	-60.130	22.986	-2.616	0.010
Overall	t_{of}	0.66	131.6	<0.001	135	x_d	3.932	0.301	13.049	<0.001
						x_{fd}	1.764	0.343	5.148	<0.001
						Constant	40.826	1.771	23.048	<0.001
Productivity	P_{ef}	0.64	253.5	<0.001	142	x_d	-0.254	0.022	-11.320	<0.001
							-0.118	0.026	-4.548	<0.001

x_{fd}= walking distance, x_{ls}= longitudinal slope, x_d= tree diameter at D.B.H

Table 4. Time consumption and productivty of processing at different diameters (without delay)

Diameter (cm)	<50	50	55	60	65	70	75	80	85	90	95	100	>100
Avg. processing time (s)	170	269	341	345	436	496	575	600	677	635	905	964	1021
Min. processing time (s)	122	181	280	241	316	333	423	384	569	391	-	875	894
Max. processing time (s)	263	349	420	484	616	612	805	807	764	758	-	1037	1209
Avg. volume processed (m^3)	0.81	1.60	2.40	2.98	3.53	4.86	5.93	6.21	7.37	7.90	9.45	10.82	12.07
Min. volume processed (m^3)	0.46	1.14	1.72	2.21	2.62	4.11	5.12	5.34	6.26	6.80	-	9.04	11.31
Max. volume processed (m^3)	1.08	1.92	2.65	3.40	4.10	5.33	6.95	7.24	8.59	9.58	-	12.01	12.60
Avg. productivity, ($m^3 \cdot h^{-1}$)	18.07	22.17	26.35	32.65	30.37	36.86	39.08	39.16	40.44	47.5	37.6	40.28	43.12
Min. productivity ($m^3 \cdot h^{-1}$)	9.73	16.02	15.44	22.12	19.79	25.70	23.04	23.8	29.49	35.15	-	37.2	35.87
Max. productivity ($m^3 \cdot h^{-1}$)	31.91	29.16	32.64	43.29	46.03	57.32	55.22	61.67	54.34	88.18	-	41.95	49.63
Number of observations	11 [13%]	5 [6%]	5 [6%]	13 [15%]	9 [10%]	7 [8%]	9 [10%]	10 [11%]	3 [3%]	8 [9%]	1 [1%]	3 [3%]	4 [5%]

Table 5. Statistical characteristics of the 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*
Walking	t_{p1}	0.81	219.4	<0.001	105	Constant	-0.33	3.951	-0.008	0.993
						x_{Pd}	1.197	0.058	20.720	<0.001
						x_{ls}	0.676	0.154	4.379	<0.001
Bucking	t_{p5}	0.84	275.12	<0.001	54	Constant	108.015	50.004	2.160	0.033
						x_{db}^2	0.075	0.010	7.206	<0.001
						x_{db}	-4.992	1.470	-3.395	0.001
Delimbing and topping	t_{p3}	0.46	90.19	<0.001	106	Constant	0.055	0.035	1.569	0.012
						x_{db}	1.862	0.152	12.255	<0.001
Overall time consumption	t_{opl}	0.76	166.09	<0.001	54	Constant	-13.224	113.692	-0.116	0.908
						x_{db}^2	0.061	0.024	2.596	0.012
						x_{db}	2.762	3.343	0.826	0.411
Productivity	p_{epl}	0.50	102.69	<0.001	54	Constant	0.496	0.203	2.442	0.016
						x_{db}	0.989	0.098	10.134	<0.001

x_{pd}= walking distance, x_{db}= diameter at tree butt

Discussion

The presented empirical time study provides information about the productivity and the cost of manual felling and processing in Iran. Due to the different characteristics of forest stand and operators, the results may not represent the time consumption of felling and processing in all Hyrcanian forest but provides time estimations for felling and processing with chain saw.

Methodologically, the emphasis of this study was on the correlation time study. 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). Since worker has significant effect on the productivity and cost of harvesting system, a standard crew was used in order to minimize the influence of the workers on the study results. This is an important step for generalization of the study.

Walking to the tree is the first element of the felling work cycle. There is a direct relation between walking and both distance and slope. Long et al. (2002) reported that time consumption of walking was mostly affected by inter-tree distances. Clearing time involves technical and safety issues. Tree should be felled in appropriate direction in order to prevent consequence problem to the residual stand, chainsaw operator and the tree being felled. In direction felling, most of the clearing time is spent deciding on the felling direction. The results of this study show that the chain saw operator spent only 6% of effective time for choosing the felling direction which is insufficient in comparison with directional felling which is 15% (Nikouy Seyahkal 2007). Other felling work phase including Sink-cut and back cut took 26% and 32 % of the gross-effective time, respectively.

Although, many factors such as stump diameter, inter-tree distance, terrain conditions, tree species, weather condition, quality of tools, and workers' skills affects the productivity of felling (Lynford 1934, Mann and Mifflin 1979, Koger 1983, Schmincke 1995) but tree diameter and inter-tree distance were found to be the most important influencing factors on the productivity of felling (Wang et al. 2004). Productivity was shown to be more sensitive to stem diameter than other variables. Time consumption of felling was increased by 7.1 times when the tree diameter increased from 30 to 150 cm, whereas, time consumption of felling was increased by 2.1 times when the distance increased from 5 to 100 m.

The unit cost of felling was mostly affected by labor cost. Labor costs accounted for 90% of the hourly cost, while only 10% was related to machine cost.

The main part of manual processing in Iran, including delimbing and topping, takes place in the stump area, but bucking is usually done in the forest and the landing. Since cross-cutting (bucking) is done in two places, time consumption of bucking in the landing is added to the time consumption of bucking in the forest.

Since felling and processing is done in different periods of time, the same distance must be traveled again in order to fell and process a tree. The relation between time consumption of walking and influencing variables was a linear function.

Delimbing and topping accounted for 28.8% of the gross-effective time for various tree species. Bucking a tree into logs is one of the most important issues in processing. However, the log length mostly depends on the tree size, cutting location and final production.

Similar to felling, an hourly cost of processing is mainly comprised of labor cost (83%). Hourly cost of processing took the lowest percentage among different work phases of harvesting. The results in our study can be applied to estimate the productivity and cost of harvesting performance as well as the required personnel, tools and equipment. The results can also be used for simulation and educational purposes.

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