Productivity and cost analysis of manual felling and skidding in Oriental spruce (*Picea orientalis* L.) forests

E. Çalışkan


Abstract. Cost and productivity are major factors when considering which type of harvesting system to operate. Observations were conducted on felling and skidding harvesting operations, in the Blacksea region of Turkey, Pazinçığı spruce forest sites, in order to obtain time study data. The performance of the Stihl chain saw, forest tractor (MB Trac900) skidder was studied for log methods. Production and cost analysis were conducted on the harvesting system data in order to compare the two systems. The productivity and gross-effective productivity of chainsaw for different diameters were 9.11 m$^3$/hour/man and 10.6 m$^3$/hour/man respectively. The unit costs with and without delay times were 1.30 $/m^3$ and 1.11 $/m^3$, respectively. The significant variables included diameter at breast height, and distance among harvested trees for the time expenditure model. The regression function is statistically significant at a level of 5%. The productivity and gross-effective productivity of forest tractor skidding for different diameters were 11 m$^3$ and 10.43 m$^3$ per hour, respectively. The unit cost per cubic meters was 3.81 $ for the with delay times while the unit cost without delay times was 3.54 $ per cubic meter. The significant variables included skidding distance, number of logs, and volume for the time expenditure model. This regression function is statistically significance level of 5%. Result of this research can be also useful for in harvesting planning.

Keywords: timber harvesting, felling, skidding, time study, productivity, unit cost, Turkey.

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Manuscript received November 18, 2011; revised October 15, 2012; accepted October 21, 2012; online first October 23, 2012.
Introduction

Turkey has 21.2 million hectare of forests, which constitute 27.2% of the country area. The yearly average growing stock is 11.3 million cubic meters (OGM 2006).

The forest operations are represented by the felling, processing primary and secondary transportation phases, felling (cutting and falling, branch cleaning, peak taking, bucking and debarking). The forest primary transportation is the transport from the felling areas to the landing points near the first available road. Secondary transportation is related to taking from roadside to store as wood processing centers (Karaman 2001).

Forest harvesting and transportation operations have been carried out by mostly forest villagers and rarely forest contractors throughout the world there are five harvesting methods employed: cut-to-length, tree length, full tree, whole tree method (completed tree) and chipping method (Pulkki 1997, Gerasimov 2006). Traditionally, cut-to-length harvesting method has been used in Turkish forestry. Cutting, delimbing, and bucking activities are performed in forest stand by means of chainsaw. Debarking with axe and/or log wizard is mainly operated in stand and rarely on roadside (Eker & Acar 2006). The extraction operations from stand to landing or roadside is mostly realized on the steep ground by means of gravity and human force as rolling, throwing, and sliding/skidding fashion. Animal force, agricultural and forest tractors or skidders have been rarely used. The forest skylines, various distanced, have been used on mountainous region. Loading operations on roadside or landing yard is carried out manual with human force, grapple loaders or hydraulic cranes. Hauling through forest roads and main roads is executed by truck and tractor trailer from roadside to main storage.

Time study is one of the most common practices of work measurements. It is used worldwide, in many types of production, to determine the input of time in the performance of a piece of work (Björheden 1991). Time study is defined as the analysis of the methods, material, tools and equipment used in the production process (Barnes 1968, Gonzales 2005) or as time measurement, classification and analysis of the data in order to increase the efficiency of work (IUFRO 1995). A detailed time study is comprised of the time consumption for each work element. This refers to determining the influencing factors, the time consumption, and the method of data collection (Samset 1990).

Time measurements are done by using either direct or indirect methods, depending on the required accuracy. Direct timing can be classified as continued timing and repetitive timing. In continued timing, the time is recorded continually and the element are the differences between recorded times. In direct timing, the time for each work element is measured with a stopwatch or a handheld computer.

The main application of a time study is in the calculation of the productivity. According to Hanula (1993), productivity is the ratio between output (volume of wood) and input (time consumption or fund). One of the most important issues in appraisal of productivity is how to bring factors like weather conditions and operator motivation into the calculation. Time studies are also important in identifying critical areas within a harvesting system or operation that require improvement, leading to minimization of work time, increased production and reduced costs. Time study results also enable the evaluation of the effect of changing work patterns on productivity (Gullberg 1997) and have been used successfully in forest harvesting operations (FAO 1998b) to investigate the level of efficiency which operations were conducted.

Time consumption of felling and productivity depends on several variables, such as harvesting intensity, DBH (or stump diameter) and inter-tree distance (Koger 1983, Kluender & Stokes 1996). Time studies of felling in different areas showed that felling, delimbing, bucking, and finding the tree are the most time-consuming operations.
consuming elements (Sickler 2004). Many factors can affect the productivity of chainsaws. Jones (1983) conducted a time study on a 60-acre tract with three thinning treatments in northern West Virginia. The three treatments were defined as 45%, 60% and 75% of the residual stocking. The harvest consisted of manual felling with a chainsaw. Time studies showed that hourly felling production increased while skidding productivity decreased from the treatments 45%, to 60% and to 75% of residual stocking. Regression equations were later developed based on the above time-study data (Brock et al. 1986), which can be used for estimating production rates and costs for similar thinning operations.

Wang et al. (2004) developed a productivity model for chainsaw felling, which included variables such as diameter at breast height and the distance among harvested trees. Holmes et al. (2002) conducted a time study on the forests of eastern Amazon, they found that the productivity and cost of manual felling were 20.46 m³/h and 0.46 USD, respectively. Nikoie (2007) developed a productivity model for chainsaw felling in Caspian hardwood forests, which included variables such as diameter at breast height and the distance among harvested trees.

A detailed time study about skidding was done by Wang et al. (2004). They found that the skidding cycle time was mainly affected by payload size and skidding distance. They also tried interaction between different variables in the different components of skidding.

The cost of skidding is typically the most expensive component in whole tree harvesting operation and directly depends on skidding distance (Mitchell 2000). Skidding distance is perhaps the single most important variable affecting skidding cost and productivity (Conway 1979, Feghhi 1989, Pilayer 1996, Naghd 1996, Javadpour 2006, Nurminen et al. 2006).

Many studies were carried out on productivity and cost of harvesting and logging operation and factors affecting the machine performance (Miyata 1980, Meng 1984, Legault 1985, Lanford et al. 1990, McDonald 1999, Egan & Baumgas, 2003). Akay (2004) studied the productivity of mechanized harvesting machines such as: skidder, fellerbuncher, harvester, loader and forwarder in Turkey.

The objectives of this study are (i) to find the production rates (m³/hour) and costs ($/m³) of harvesting operations on the basis of the log methods in the Turkey conditions; (ii) to develop a model for time consumption and productivity of felling, skidding, operation in each method, to determine the partial model of the work phases, and to find the most influencing factors in each work phase.

Materials and methods

Study area

This study was carried out in compartment 131 in the Paşakonağı forest management city of Giresun, in the Blacksea region of Turkey. The altitude ranged from 1650 to 1750 m above sea level and the average annual precipitation was 1.350 mm. The forest was an uneven-aged spruce (Picea orientalis) stand with the average growing stock 300 m³/ha. The slope of the compartment was 40 to 60 % and the aspects of the slopes were northern. Trees to be removed were felled, delimbed, topped, and bucked into logs motor-manually. The logs were skidded by forest tractor (MB Trac 900) to the roadside landings. The skidder type used in this study was a Forest Tractor (MB Tract 900), with the power of 85 HP and the weight was 6000 kg. Dominant canopy species include Picea orientalis, Fagus orientalis, Carpinus betulus. The manual harvesting system examined consisted of felling with a chainsaw. Felling was performed using a Stihl chainsaw with 4-horsepower (hp) engine and bar length of 80 centimetres. The field study was conducted in July 2010 in Paşakonağı forests, in the north of Turkey.
Data collection

During normal harvest operations, detailed records of felling, skidding, were kept (Figure 1). The time study of felling was conducted, skidding in the same study area and working group were studied in the summers of 2010. Time studies were conducted to assess timber harvesting performances, productivity and costs of log timber harvesting. The study covered regular working hours of the machines and operators. Field studies concentrated on collecting operational and financial data that are essential for subsequent evaluation.

Different variables were measured in each work phase. In felling, time consumption, inter-tree distance, tree species, logs volume were recorded. A total of 33 cycles for chainsaw felling were observed in the field. The work cycle for each operation consisted of certain elemental functions and factors. The time for each function and the value of each factor were recorded in the field. Elemental time functions for chainsaw felling were defined as:

- Walking time ($y_1$)
- Preparation time ($y_2$)
- Removing obstacle time ($y_3$)
- Chain cutting time ($y_4$)
- Felling action time ($y_5$)
- Delay time ($y_6$)
- Branching topping time ($y_7$)
- Bucking time ($y_8$).

In skidding, for each trip, time consumption, log size, number of logs skidded, terrain slope, skidding distance, and winching distance were recorded. The time elements considered in the skidding (forest tractor) work cycles include:

- Travel unloaded ($t_1$), releasing the winch ($t_2$), hooking ($t_3$), travel loaded ($t_4$), delay ($t_5$), winch ($t_6$) and unhooking ($t_7$).

In addition to measuring skidder working cycle time with a deci-minute stop watch, independent variables expected to affect on skidder productivity were documented. Variables included skidding distances (meter), slope of trails (%), number of logs per turn and of load volume. Finally, 33 work cycles were collected for forest tractor (MB trac 90). Delay times are time that is not related to effective working time. During this time study, technical, personal and operational delays were recorded. Delay time is unwanted time consumption in each work phase. There are three kinds of delay time: (i) personal delay time, any interruption or non-working time such as resting or any other breaks related to the personnel were placed in this category, (ii) technical delay has different types including chain saw chain breaking and replacing with a new one, sharpening of chain, pinching chain, down time of skidder which was put in this category, (iii) operational delay is related to inappropriate planning. For example, when

Figure 1 Typical conditions of wood procurement felling (a) and skidding (b)
there was no accessible fuel in working time and therefore should be brought from another place, or required spare parts are unavailable, it was put in this category. In skidding, when the log was not ready for skidding or the operator had to wait for preparing logs, it was put in this category.

Working time on the study operation was eight hours per day, but the effective hours differed in each working phase. Nevertheless, at least 1 hour lunch break and rest should be considered.

Data analysis

Time study analysis and calculation of productivity

Total effective time in all work phases in log method were recorded and mean log volume per cycle were calculated and included in the Equation (1). Yielding productivity per hour in each work phase. Total effective time was converted into delay-free productivity and gross-effective productivity by using the formula below:

$$ P_e = \frac{60 \cdot Xvl}{T_{top}} $$

$$ P_{ge} = \frac{60 \cdot Xvl}{T_{top} + T_{delay}} $$

where $Xvl$ = log volume (m$^3$), $P_e$ = productivity (m$^3$/effective hour), $P_{ge}$ = gross-effective productivity (m$^3$/gross-effective hour), $T_{top}$ = total time consumption (min/cycle), $T_{delay}$ = delay times (min/cycle).

Modeling

In the study, multivariate regression was used for modeling. Regression analysis with appropriate transformation of variable was used in those elements, in which the time consumption can be explained by an independent variable, for example, diameter. Other elements of the model were formed by using average time consumption value. The time consumption model was created by combining the elements. With this technique, a regression model was formed to estimate the total time consumption of the work cycle directly as a function of the most influential factor.

The SPSS 14.0 statistical programme has been applied for developing regression equation of the work cycle. SPSS 14.0 was used as the statistical packages for the study analysis. The response variables were tested by Duncan’s multiple range test at 0.05 level. As statistical parameters used for selecting the best-fit model the $P$-value, $F$-value, and $R^2$ were chosen. The $F$-value and the $P$-value are statistical measures used to determine the amount of influence that an independent variable has on the dependent variable.

The stepwise regression model was applied to develop a model. In this method, if any variable has a significant effect on the RMS (Residual Mean Squares) of the model, it would be used in the model.

Unit cost

Unit cost of production in different work phases was calculated by dividing the system cost by the average productivity per hour. System cost is a sum of machine and labor costs. Machine cost is obtained by totaling fixed costs and variable costs. All costs are reported for productive machine hours. Estimates of hourly costs of the chainsaw and forest tractor were computed using the machine rate method (Björheden et al. 1995, Wang 2003, Eker 2004).

Unit cost:

$$ \text{Unit cost} = \frac{\text{System cost ($/hour)}}{\text{Av. productivity (m$^3$/hour)}} $$
Results

Distribution of time consumption of felling and unit cost

Total time consumption model of felling; the delay free work cycle was defined by totaling the time consumption of the elements [Eq. 3].

\[ Y_{top} = y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7 + y_8 \]  

(3)

where \( Y_{top} \) - total effective time consumption for felling, \( y_1 \) - time consumption for walking, \( y_2 \) - time consumption for preparation, \( y_3 \) - time consumption for removing obstacle, \( y_4 \) - time consumption for chain cutting, \( y_5 \) - time consumption for felling action time, \( y_6 \) - time consumption for delay, \( y_7 \) - time consumption for branching and topping, \( y_8 \) - time consumption for bucking time.

The time consumption distribution of the felling work phase is shown in Figure 2a. Bucking time (\( y_8 \)) is the most time-consuming element in felling, followed by branching and topping time (\( y_7 \)) and walking time (\( y_2 \)). The breakdown of the different types of delays is shown in Figure 2b. Operational delay is the most time-consuming delay time in felling.

Figure 3 shows the time consumption of felling and total time consumption of felling with different diameters. Average felling time includes only chain cutting time while total time consumption of felling includes the time consumption of all felling elements. Time consumption of felling increases with diameter. The relation between stump diameter and time consumption (without delay) constitutes an exponential model and these variables were medium correlated.

Table 1 shows the detailed time study results for the felling work phase for the methods applied. Table 1 shows the summary of time study variables for this Total Felling time. Diameter of felled trees varied from 26 to 85 cm and averaged 81.53 cm. The distance among harvested trees varied from 10 to 190 m with an average of 78.35 m.

The stepwise regression analysis was applied to the time study data base to develop a delay-free cycle time equation. The significant variables included diameter at breast height (\( D \)) in centimetres and distance among harvested trees in m (\( L \)). The cycle time equations calculated for the chainsaw took the following equation: 

\[ T = a + bD + cL \] 

where \( T \) is the cycle time, \( a \) is the constant, \( b \) and \( c \) are coefficients for diameter and distance, respectively.

Figure 2a Distribution of time consumption in manual felling (a) and delays (b)
form:

\[ T_{\text{total time}} = 6.943 + 0.135 \cdot D + 0.02 \cdot L \]  

(4)

The multiple correlation coefficient \( R^2 = 0.676 \) are interpreted as 67.6% of total variability, which are explained by the regression equation with chainsaw. The significant level of ANOVA shows that models are significant at \( P = 0.05 \) (Table 2).

The productivity and gross-effective productivity of chainsaw for different diameters were 9.11 m\(^3\) and 10.6 m\(^3\) per hour/one person, respectively. Total cost of felling per hour was 11.81 $. The unit costs with and without delay times were 1.30 $/m\(^3\) and 1.11 $/m\(^3\), respect-

![Figure 3 Time consumption of felling for different diameters](image)

Table 1  Descriptive statistics of different element of felling work phase

<table>
<thead>
<tr>
<th>Factor</th>
<th>Parameter</th>
<th>Mean</th>
<th>St. deviation</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking time (min)</td>
<td>y1</td>
<td>1.60</td>
<td>0.90</td>
<td>0.05</td>
<td>3.6</td>
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<tr>
<td>Preparation time (min)</td>
<td>y2</td>
<td>1.38</td>
<td>1.22</td>
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<tr>
<td>Removing obstacle time (min)</td>
<td>y3</td>
<td>0.50</td>
<td>0.65</td>
<td>0.00</td>
<td>2.3</td>
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<tr>
<td>Chain cutting time (min)</td>
<td>y4</td>
<td>1.55</td>
<td>0.72</td>
<td>0.50</td>
<td>3.5</td>
</tr>
<tr>
<td>Felling action time (min)</td>
<td>y5</td>
<td>0.38</td>
<td>0.49</td>
<td>0.00</td>
<td>1.7</td>
</tr>
<tr>
<td>Delay time (min)</td>
<td>y6</td>
<td>1.02</td>
<td>0.90</td>
<td>0.03</td>
<td>3.4</td>
</tr>
<tr>
<td>Branching and topping time (min)</td>
<td>y7</td>
<td>2.56</td>
<td>1.35</td>
<td>1.00</td>
<td>6.4</td>
</tr>
<tr>
<td>Bucking time (min)</td>
<td>y8</td>
<td>3.52</td>
<td>1.54</td>
<td>1.90</td>
<td>7.2</td>
</tr>
<tr>
<td>Total time (min)</td>
<td>Ytop</td>
<td>12.52</td>
<td>3.50</td>
<td>7.70</td>
<td>21.6</td>
</tr>
<tr>
<td>Diameter</td>
<td>D</td>
<td>81.53</td>
<td>13.01</td>
<td>26</td>
<td>85</td>
</tr>
<tr>
<td>Distance among felled trees (m)</td>
<td>L</td>
<td>78.35</td>
<td>39.22</td>
<td>10</td>
<td>190</td>
</tr>
</tbody>
</table>

Table 2  ANOVA table for regression equation in Chainsaw

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual</td>
<td>98.689</td>
<td>3</td>
<td>49.344</td>
<td>30.053</td>
<td>0.000</td>
</tr>
<tr>
<td>Total</td>
<td>49.257</td>
<td>30</td>
<td>1.642</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regression</td>
<td>147.946</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Manual tree felling is a highly variable operation. There are many complicated factors affecting felling productivity. The methods introduced by Conway (1979) regarding the proper way to fell trees as well as by FAO (2002) about reducing the impact of logging and directional felling would help to increase the productivity of felling and improving the potential of the future stand.

Distribution of time consumption of skidding and unit cost. Total time consumption model of skidding; The total time consumption model of a delay free work cycle was determined by adding up the time consumption of all individual elements.

\[ T_{\text{stop}} = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7 \]  

where \( T_{\text{stop}} \) - total effective time consumption for skidding, min/cycle, \( t_1 \) - time consumption for travel unloaded, min/cycle, \( t_2 \) - time consumption for releasing, min/cycle, \( t_3 \) - time consumption for hooking, min/cycle, \( t_4 \) - time consumption for travel loaded, min/cycle, \( t_5 \) - time consumption for delay, min/cycle, \( t_6 \) - time consumption for winching, min/cycle, \( t_7 \) - time consumption for unhooking, min/cycle.

Time consumption distribution of different elements of skidding are calculated and presented in Figure 4a. In the log method travel loaded (\( t_4 \)) took 22% of the gross-effective time. This was the highest followed by travel unloaded (\( t_1 \)), unhooking (\( t_7 \)), releasing (\( t_2 \)), hooking (\( t_3 \)), winching (\( t_6 \)) and delay (\( t_5 \)). The breakdown of the different types of delay is shown in Figure 4b. Operational delay is the most time-consuming delay time in felling.

Delay time was calculated as a mean time consumption value for methods. In the log method, time consumption for personal, technical and operational delay was 5.8, 8 and 6.2 seconds per payload.

Table 3 shows the summary of time study variables for this forest tractor. Regression analysis with the stepwise method between independent variables was performed on time study data to develop an operational cycle time equation for this machine. The dependent variable is skidding time per cycle without delay.

Table 3 shows the summary of time study variables for this total skidding time. Volume of skidding trees ranged from 0.10 to 2.90 m\(^3\) and averaged 1.04 m\(^3\). The skidding distance varied from 10 to 65 m with an average of 29.70 m. Equation 6 shows the regression equation
of time consumption using forest tractor.

\[ T_{stop} = 2.443 + 0.925V + 0.031D + 0.562N \]  

where: \( T \) - skidding time without delays (min/cycle), \( D \) - skidding distance (m), \( N \) - number of logs per cycle, \( V \) - load volume per cycle (m³).

However, in wood extracting with forest tractor skidding distance, number of logs, and volume per cycle were entered in model at significant level \( P = 0.05 \). The multiple correlation coefficient \( R^2 \) 0.892 are interpreted as 89.2% of total variability, which are explained by the regression equation with forest tractor. The significant level of ANOVA shows that models are significant at \( P = 0.05 \) (Table 4).

The productivity and gross-effective productivity of Forest Tractor skidding for different diameters were 11 m³ and 10.43 m³ per hour, respectively. Total cost of skidding per hour was $39.8. The unit cost per cubic meters was $3.81 for the with delay times while the unit cost without delay times was $3.54 per cubic meter.

The effect of each variable factor on skidding time and cost was studied by changing one variable while holding the other variables constant at their mean value.

### Discussion

The results of this study reveal that the diameter of the tree was the most significant factor affecting time consumption and productivity of felling, while inter-tree distance also influences the time consumption and productivity of felling. The productivity of felling large diameter trees was higher than in felling trees with a small diameter.

The variables such as distance between harvested trees, diameter at breast height (dbh), slope in the stump area, and slope between two harvested trees were entered into the general model for predicting felling time as significant variables, which can be applied in harvesting.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Summary of time study variables for forest tractor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor</strong></td>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>Travel unloaded (min)</td>
<td>t1</td>
</tr>
<tr>
<td>Releasing (min)</td>
<td>t2</td>
</tr>
<tr>
<td>Hooking (min)</td>
<td>t3</td>
</tr>
<tr>
<td>Travel loaded (min)</td>
<td>t4</td>
</tr>
<tr>
<td>Delay (min)</td>
<td>t5</td>
</tr>
<tr>
<td>Winching (min)</td>
<td>t6</td>
</tr>
<tr>
<td>Unhooking (min)</td>
<td>t7</td>
</tr>
<tr>
<td>Total time (min)</td>
<td>Tstop</td>
</tr>
<tr>
<td>Skidding distance (meter)</td>
<td>D</td>
</tr>
<tr>
<td>Turn volume (m³)</td>
<td>V</td>
</tr>
<tr>
<td>Number of log</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4</th>
<th>ANOVA table for regression equation in Forest Tractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of Squares</td>
<td>df</td>
</tr>
<tr>
<td>Residual</td>
<td>59.589</td>
</tr>
<tr>
<td>Total</td>
<td>7.187</td>
</tr>
<tr>
<td>Regression</td>
<td>66.776</td>
</tr>
</tbody>
</table>
planning. The felling cycle time per tree and felling productivity were mostly affected by dbh of the tree being felled but they were also affected by the distance between harvested trees. Increasing distance between harvested trees will increase felling time, but if dbh increases, the felling time decreases.

Manual tree felling is a highly variable operation. There are many complicated factors affecting felling productivity. The methods introduced by Conway (1979) regarding the proper way to fell trees as well as by FAO (2002) about reducing the impact of logging and directional felling would help to increase the productivity of felling and improving the potential of the future stand.

In felling with chainsaw; diameter at breast height and distance among harvested trees were entered in model at significant level $P = 0.05$. The multiple correlation coefficient ($R^2$) 0.676 are interpreted as 67.6% of total variability, which were explained by the regression equation with chainsaw. The productivity and gross-effective productivity of chainsaw for different diameters were 9.11 m$^3$ and 10.6 m$^3$ per hour/one person, respectively. Total cost of felling per hour was $11.81. The unit cost with and without delay times were 1.30$/m$^3$ and 1.11$/m^3$, respectively. Jones (1983) conducted a time productivity and cost of manual felling were 20.46 m$^3$/h and $0.46$, respectively.

Obviously, operational are the most frequent. After the operational delays, personal delays were the most frequent. Bucking time was the most time-consuming element in felling, followed by branching topping time and walking time.

In skidding with forest tractor; skidding distance, number of logs, and volume per cycle were entered in model at significant level $a = 0.05$. The multiple correlation coefficient ($R^2$) 0.892 are interpreted as 89.2% of total variability, which were explained by the regression equation with forest tractor(MBTrac 900). The productivity and gross-effective productivity of forest tractor skidding for different diameters were 11 m$^3$ and 10.43 m$^3$ per hour, respectively.

The productivity of skidding in the study was similar to the other studies conducted in the Hycranian forest. Feghhi (1989), Eghtesadi (1991), and Naghdi (2005) related 8.6, 10.4, 11.7 m$^3$/effective hour, respectively. Total cost of skidding per hour was $39.8. The unit cost per cubic meter was $3.8 for the with delay times while the unit cost without delay times was $3.54 per cubic meter.

Most of the time was spent travel load the logs in skidding with forest tractor (22% of total time). In addition 36% of skidding time was devoted to three working cycle as following: releasing the winch, hooking (choker setting) and winching. Although skidding distance was generally the most important variable since it effects cycle time more than other variables, in this study the number of logs per turn by using cut to length system was most important variable in forest tractor (MBTrac 900) and the most of the time spent in providing a sufficient volume in each cycle.

Conclusions

The developed models and production rate of manually felling and skidding are useful tools for logging planners in order to predict the time and cost of felling and skidding in the area of this study.

As a conclusion, the models and results provided in this study could, in general, help forest managers to better understand the influencing factors, on the productivity and cost in different work phases. It can be used for reorganizing and planning of forest work in order to meet the economic concerns.

The high rate of delays in both time studies is important to planners who want to increase the efficiency of felling and skidding diminish the logging costs.

The results of this study can be used to set
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