

Productivity Analysis of Timber Skidding Operation with Farm Tractor

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Abstract

Farm tractors equipped with necessary attachments have been widely used in skidding of forest products in Turkey. There are farm tractors of different types and sizes used in forest operations. For appropriate logging plans and better machine selections in mechanized forest operations, it is important to analyze the efficiency of farm tractors during skidding operations. In this study, it was aimed to analyze the productivity of timber skidding operation with farm tractor. Time study was used to estimate productivity and then the effects of specified factors (volume and number of piece) on productivity were investigated by using statistical analysis. Logging operation took place in a black pine (*Pinus nigra*) stand located in the province of Köyceğiz in Muğla. Time data of work stages (i.e. move-out from landing to stump unloaded, choker setting at the stump, skidding loaded from stump to landing, and unloading at the landing) during uphill skidding operation were collected for two skidding trails with different slope classes (20% and 30%) while average skidding distance was kept constant at 100 m. It was found that the average productivity for two slope classes were 5.72 m³/hr and 4.30 m³/hr, respectively. The results indicated that the productivity increased as the volume of skidded logs per turn increased for both slope classes. On the other hand, increasing number of pieces transported in each turn caused reduction in productivity of skidding operation by farm tractor. The most time consuming work stage was skidding followed by move-out unloaded and choker setting stages.

Keywords: Forest transportation, skidding by farm tractor, productivity, time study analysis

1. Introduction

As Extraction of forest products from stump to landing areas is one of the most difficult and time consuming forest operation activities. Mechanized harvesting equipment has been used in timber extraction operations due to their important advantages such as high productivity, labor efficiency, and worker safety (Akay and Sessions, 2004). In Turkey, forest harvesting activities are generally conducted by forest villagers or small contractors who cannot afford this harvesting equipment since they have very high purchase price and their variable costs are related with the fuel price (Akay, 2005). Farm tractors equipped with appropriate forestry attachments are often used for timber extraction because they are versatile and cost effective (Spinelli and Baldini, 1992).

When the terrain conditions and the size of the forest operation are suitable, modified farm tractors can be used in various forest operation techniques including skidding, forwarding, cable logging, and loading in Turkey (Öztürk and Akay, 2007). Modified farm tractors are one of the widely used means of timber extraction not only in Turkey but also in other European countries such as Italy, Croatia, etc. (Zimbalatti and Proto, 2009; Stanki'c et al., 2012; Gülci et al., 2017a; Proto et al., 2018). In a study conducted by Turk and Gumus (2010), unloaded and loaded time of farm tractor was investigated during skidding by farm tractor operation. They reported that slope, log volume, number of logs, and terrain conditions were the most important factors influencing efficiency of skidding with farm tractors.

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Öztürk (2010) investigated the productivity of farm tractor skidding in beech stands in the city of Ordu in Turkey. Time study analysis was carried out by using time data recorded during skidding operation. A regression model was developed to investigate the effects of independent variables (i.e. skidding distance, load volume, and number of loads) on total cycle time. The results indicated that increasing skidding distance increased total cycle time which leads to reduction in productivity. In another study conducted in the same year, Gilianipoor et al. (2010) determine the production rate and harvesting costs per unit volume for farm tractor skidding. A regression model was also developed to estimate total cycle time and costs of the skidding operation. They reported that the most effective independent variables were skidding distance and slope of the skid trails.

In Turkey, most of the mechanized forest harvesting operations are performed by skidding forest products from stump to landing areas with farm tractors. Thus, it

is crucial to analyze the productivity of farm tractors during skidding operations. In this study, the productivity of timber skidding operation with farm tractor was analyzed for various slope classes by using time study. Besides, statistical analysis was run to determine the effects of specified factors (volume, number of piece) on skidding productivity.

2. Material and Methods

2.1. Study Area

The study was carried out in a black pine (*Pinus nigra*) stand (unit no 209) of Köyceğiz in Muğla, Turkey (Figure 1). Time study was implemented in two worksites having different average slopes (i.e. 20% and 30%). In the worksites, trees were felled with a chainsaw and forest products with various lengths and diameters were skidded uphill to the landing area by Türk Fiat 450 model farm tractor (Table 1). In both worksites, the timber skidding operations involved two workers including tractor operator and a choker setter.

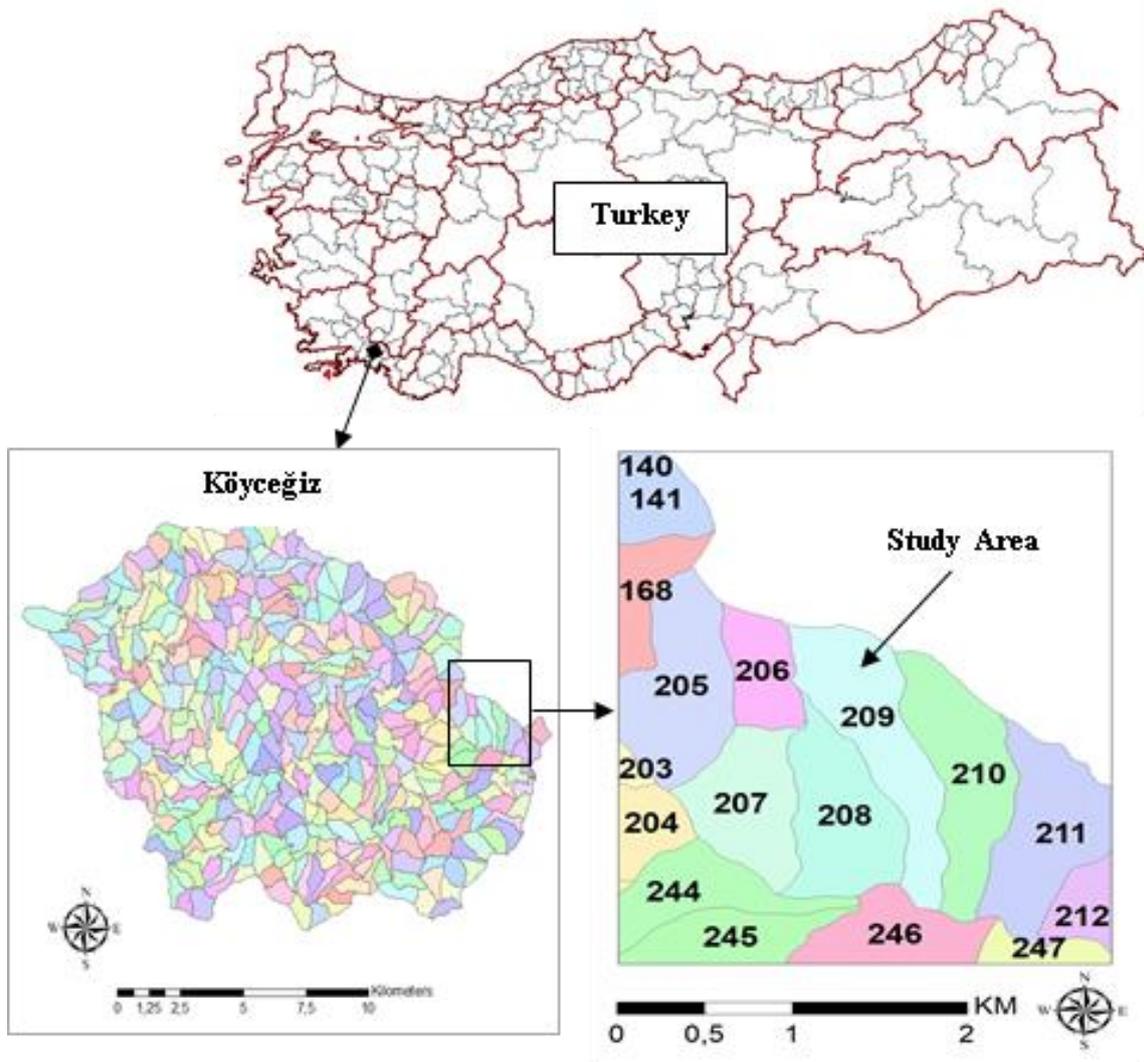


Figure 1. Study area

Table 1. Technical specifications of Türk Fiat 450 model farm tractor

| Features | Values |
|------------|--------------------------|
| Frame | 4x2 2WD/4x4 4WD optional |
| Axle width | 198 cm |
| Front Tire | 6.00-19 |
| Rear Tire | 12.4-28 |
| Weight | 2100 to 2400 kg |
| Length | 322 cm |
| Fuel | Diesel |
| Gears | 8 forward and 2 reverse |

2.2. Time Study Analysis

Time study analysis is commonly used to quantify the productivity of forest operations based on time measurements of work stages at the worksite (Spinelli and Magagnotti, 2011; Szewczyk et al., 2014; Gülci et al., 2017b). In this study, chronometer was used to implement repetitive time study method which is an effective method for time and motion studies (Ovaskainen et al., 2004). Time study data were collected for two skidding trails with different slope classes (20% and 30%) while average skidding distance was constant (100 m) in both worksites.

The main work stages in work cycle of tractor skidding were move-out from landing to stump unloaded, choker setting at the stump, skidding loaded from stump to landing, and unloading at the landing (Figure 2). Mechanical and human-caused delays were also recorded for each cycle. The volume of each

forest product transported during a skidding trip was computed by medium surface approach (Huber Formula):

$$V_i = \frac{\pi}{40000} d_i^2 L_i \quad (1)$$

V_i = volume of the timber i (m^3)

d_i = medium diameter of the timber i (cm)

L_i = length of the timber i (m)

And then, productivity of tractor skidding for each trip was computed based on total cycle time and timber volume.

$$p = \frac{v}{t} * 60 \quad (2)$$

v = total timber volume (m^3)

t = cycle time (minutes)

2.3 Statistical Analysis

Statistical analysis of One-Way ANOVA, Pearson correlation test, and linear regression were implemented based on the time data using SPSS 16 statistical program. One-Way ANOVA at 0.05 significance level was used to investigate the effects of tree volume on productivity. In order to evaluate the effect of timber volume on productivity, timber volumes skidded in each cycle were divided into three classes: low ($<0.50m^3$), medium ($0.50-0.80 m^3$), and high ($>0.80 m^3$). Pearson correlation was used to investigate the relation among timber volume (X_1), number of pieces (X_2), and skidding productivity (Y). Finally, linear regression model was developed to search for the effects of independent variable (i.e. timber volume and number of pieces) on the dependent variable (i.e. productivity).



Figure 3. Unloading timber from farm tractor at landing area

3. Results and Discussion

Based on the time measurements recorded during uphill skidding of forest products by farm tractor, basic statistical data were generated for each work stages within the skidding operation including delay time. The average data about skidded timber (i.e. diameter, timber length, and number of piece for each trip) were given in Table 2. The average load per cycle was 0.56 m³ and 0.55 m³ for uphill skidding on 20% slope and 30% slope, respectively.

Table 2. The data about skidded timber (i.e. diameter, timber length, and number of piece)

| | 20% slope | 30% slope |
|------------------------------|-----------|-----------|
| Average timber diameter (cm) | 31.0 | 32.0 |
| Average timber length (m) | 2.31 | 2.85 |
| Average number of pieces | 2.90 | 2.05 |

Table 3 indicates the average time spent on each work stage for two worksites. In both worksites, it was found that skidding operation was the work stage that caused the highest time consumption, followed by move-out unloaded from landing to stump. Delay time caused by operational, technical, or human related factors was the third most time consuming work stage. Comparing two worksites, it was also found that time of every work stage increased depending on the gradient increase. The results indicated that the time of skidding on 30% ground slope increased about 47%. Previous studies reported that total skidding cycle time was adversely affected by slope (Jour and Majnounian, 2008; Gilanipoor et al., 2012).

The efficiency analysis indicated that the average production rate of the tractor skidding was 5.72 m³/hr and 4.30 m³/hr for the worksites with 20% slope and 30% slope, respectively. Mousavi and Nagdi (2014) reported that the average tractor skidding productivity was 1.07 m³/hr in a study where the average skidding distance and volume per cycle was 233 m and 0.5 m³, respectively. Another study indicated that

the productivity of a farm tractor was 4.38 m³/hr for a skidding distance of 50 m at the mountainous region in Turkey (Acar, 1997). In a study conducted by Öztürk (2010), the productivity of a farm tractor was 7.70 m³/hr while skidding average load of 1.63 m³ for the skidding distance of 320 m.

Considering that the average skidding distance was the same (i.e. 100 m) and the average load per cycle was very similar in both worksites (i.e. 0.56 m³ and 0.55 m³), about 25% reduction in productivity was mainly effected by the ground slope at the worksites. On the other hand, skills and experiences of the tractor operator are the other important factors that affect total cycle time and therefore productivity of the tractor skidding (Mousavi and Naghdi, 2014).

The effect of load volume classes per cycle on productivity was investigated within each worksite. The results showed that various volume classes had significant ($p < 0.01$) effects on productivity of the tractor skidding. For the both worksites, it was found that the average productivity increased from low volume class to medium and high volume classes (Table 4, Table 5). While productivity was increasing with increased load volume per cycle, it was found that it decreased when the number of loads per cycle increased during the skidding operation (Figure 3). Previous studies also found that the skidding productivity is affected by the number of logs per cycle (Abeli, 1992; Borz et al., 2015).

Pearson correlation test was used to investigate whether there is a statistically meaningful relationship among productivity, volume classes, and number of piece. According to the results of correlation tests for both worksites, there was a statistically significant and positive relationship between productivity and volume per cycle at the confidence level of 99% ($p = 0.000$, $p < 0.01$). On the other hand, relationship between productivity and number of pieces per cycle was again significant, but negative at the confidence level of 99% ($p = 0.000$, $p < 0.01$) (Table 6).

Table 3. Statistical summary of work stages in total cycle time (minutes) for two worksites

| Work stages | 20% Slope | | | | 30% Slope | | | |
|-------------------|-----------|------|------|------|-----------|------|------|------|
| | Min. | Max. | Mean | Std. | Min. | Max. | Mean | Std. |
| Move-out unloaded | 1.18 | 1.50 | 1.33 | 0.10 | 1.37 | 2.50 | 1.79 | 0.27 |
| Choker setting | 0.65 | 1.62 | 1.17 | 0.27 | 0.78 | 1.77 | 1.19 | 0.27 |
| Skidding | 1.25 | 2.75 | 1.65 | 0.36 | 1.98 | 2.93 | 2.43 | 0.27 |
| Unloading | 0.17 | 0.71 | 0.45 | 0.16 | 0.37 | 0.95 | 0.62 | 0.15 |
| Delay Time | 1.00 | 1.70 | 1.26 | 0.19 | 1.14 | 2.12 | 1.58 | 0.21 |
| Total work time | 4.67 | 7.24 | 5.86 | 0.64 | 6.27 | 8.69 | 7.61 | 0.78 |

Table 4. The effects of load volume classes on productivity for the worksite with 20% slope

| Volume classes | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Min. | Max. |
|----------------|----|------|----------------|------------|----------------------------------|-------------|------|------|
| | | | | | Lower Bound | Upper Bound | | |
| Low | 10 | 4.60 | 0.88 | 0.28 | 3.97 | 5.23 | 3.37 | 6.19 |
| Medium | 6 | 5.37 | 0.49 | 0.20 | 4.86 | 5.89 | 4.92 | 6.25 |
| High | 4 | 9.03 | 0.30 | 0.15 | 8.56 | 9.51 | 8.61 | 9.29 |
| Total | 20 | 5.72 | 1.86 | 0.42 | 4.85 | 6.59 | 3.37 | 9.29 |

Table 5. The effects of load volume classes on productivity for the worksite with 30% slope

| Volume classes | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Min. | Max. |
|----------------|----|------|----------------|------------|----------------------------------|-------------|------|------|
| | | | | | Lower Bound | Upper Bound | | |
| Low | 10 | 2.79 | 0.22 | 0.07 | 2.63 | 2.95 | 2.52 | 3.22 |
| Medium | 6 | 5.18 | 0.33 | 0.13 | 4.84 | 5.53 | 4.86 | 5.70 |
| High | 4 | 6.74 | 0.56 | 0.28 | 5.85 | 7.62 | 6.30 | 7.53 |
| Total | 20 | 4.30 | 1.67 | 0.37 | 3.52 | 5.08 | 2.52 | 7.53 |

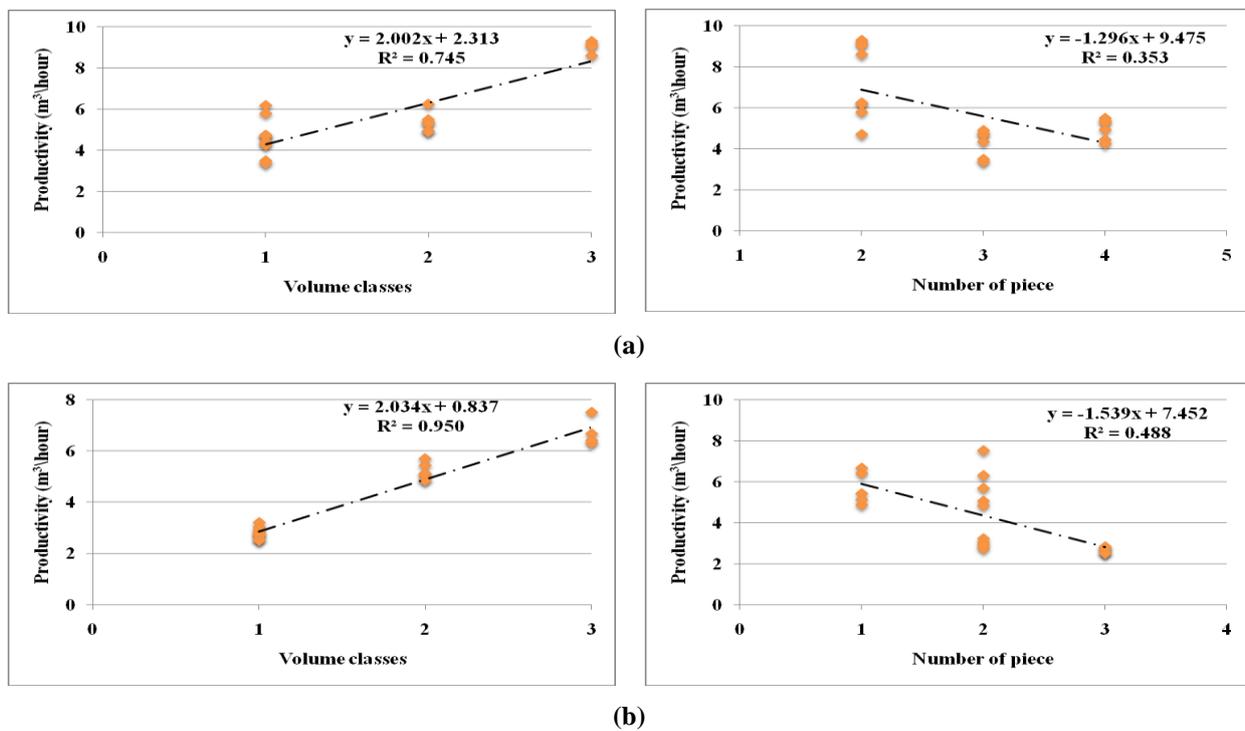


Figure 3. The productivity vs. volume classes and number of pieces for worksite with 20% (a) and 30% (b) slope

Table 6. Results of Pearson correlation tests

| Variables | | Productivity of Tractor Skidding (Y) | |
|----------------------------|-------------------------|--------------------------------------|------------------|
| | | 20% Ground Slope | 30% Ground Slope |
| Volume (X_1) | Correlation coefficient | 0.951** | 0.969** |
| | P | 0.000 | 0.000 |
| | N | 20 | 20 |
| Number of pieces (X_2) | Correlation coefficient | -0.595** | -0.699** |
| | P | 0.006 | 0.001 |
| | N | 20 | 20 |

At the final stage, linear regression model was developed to search for the effects of independent variables (i.e. timber volume and number of pieces) on the productivity. The R^2 values of the regression models were found to be 0.974 and 0.988 for the worksites with 20% slope and 30% slope, respectively. For the both worksites, regression model provided statistically significant results at the confidence level of 99% ($p=0.000$, $p<0.01$). The regression models generated based on volume (X_1) and number of pieces (X_2) were indicated below:

For ground slope of 20%:

$$Y = 3.106 + 7.246X_1 - 0.508X_2 \quad (p<0.001) \quad (3)$$

For ground slope of 30%:

$$Y = 2.113 + 5.900X_1 - 0.511X_2 \quad (p<0.001) \quad (4)$$

4. Conclusions

Harvesting systems utilizing farm tractors have been widely used in small-scale forest operations due to relatively lower capital investment and operating costs comparing with fully mechanized harvesting systems. In this study, the productivity of timber skidding operation with farm tractor was analyzed and the effects of load volume and number of piece on productivity were investigated. The results indicated that skidding operation should be well planned by considering the main factors such as load volume, number of loads, and slope of the skid trails. Besides, to improve the productivity of the tractor skidding operation, forest managers should implement directional felling which may also reduce labor cost, residual stand damage, and soil compaction. Prior to directional felling activities, skid trails should be planned and properly located in the worksite.

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