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An evaluation of a fully mechanized forest harvesting operation in Bursa, Turkey

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Abstract: In recent years, the use of mechanized harvesting technology in forestry has gradually increased in Turkey. There are a number of private contractors who fell and extract timber in state forests by using mechanized harvesting equipment such as: harvesters, feller-bunchers and skidders. Performances of the mechanized harvesting systems are mainly influenced by features such as tree size, tree formations, terrain conditions, operator motivation and skill. In order to implement these systems effectively and efficiently, their applications should be well planned according to the sustainable forestry principles. Therefore, environmental, social and economic dimension as well as operational productivity of these systems should be evaluated. In this study, a single-grip harvesting operation was evaluated by using time and motion study analysis. Also, the main factors that affect harvesting operation were investigated. The study was implemented during a clear-cut operation of Brutian pine (*Pinus brutia*) stands in Osmangazi Forest Enterprise Directorate in the city of Bursa, Turkey. Three stages of harvesting operation were evaluated: a. moving harvester to the trees, b. gripping and felling trees, and processing (i.e. delimbing and bucking) trees. The average time of the work stages was examined and the results indicated that most of the time was spent on tree processing. The productivity of harvesting operation was estimated to be 23.91 m^3/hr. The productivity of mechanized harvesting system was mainly affected by the tree size, which directly influences the total processing time of the felled trees in the study area. The results from this study cannot be generalized but it suggested that mechanized harvesting using a harvester should be well planned and organized ahead of time in order to operate harvester with optimal efficiency. Optimum machine selection and machine combinations should be practiced based on site specifications and stand characteristics. Technical training and field training of the operators are also very important to maximize the harvesters' efficiency and minimize operational costs.
Keywords: Timber extraction, fully mechanized harvesting, time and motion study, single-grip harvester

1. Introduction

In recent years, the usage of mechanized harvesting systems has been increasing in Turkey, especially in Maramara region. The main reason for this trend is that private forest industry demands for large amounts of woods which can be only provided by the logging contractors using mechanized harvesting systems. Appropriately planned and implemented mechanized harvesting operations provide important advantages such as minimizing environmental effects, leaving logging residual as organic matter in the stand, and improving labour efficiency (Akay and Sessions, 2004). However, mechanized harvesting systems can be very costly operations due to very high ownership and operating costs in Turkey. Therefore, mechanized harvesting operations should be efficiently managed in order to ensure profitability (Hiesl and Benjamin, 2013).

The highly mechanized harvesting systems implemented in Turkey currently consist of harvester, feller-buncher, and grapple skidder. Harvested was the first highly mechanized equipment introduced to Turkish forestry in mid 2000s. The use of harvested in forest operations is still new in Turkey and there is only few studies focused on harvester productivity.

Enez and Arıcak (2012) conducted a study where productivity of single-grip harvester was evaluated for different species and tree sizes in Kastamonu region in Turkey. They stated that harvester productivity was maximized in harvesting firs (27.36 m^3/hr), followed by Yellow pine (20.82 m^3/hr), and Black pine (11.82 m^3/hr). For various dimeter classed, the maximum productivity was reached at the DBH of 36-52 cm (25.68 m^3/hr) and followed by 20-36 cm DBH class (23.1 m^3/hr).

Previous studies reported that the productivity of mechanized harvesting mainly depends on ground slope, tree size, tree form, numbers of trees per unit area, operator's motivation and skill (Jiroušek et al., 2007). Thus, the important site factors such as terrain conditions and stand characteristics should be studied and their effects on productivity should be considered during planning stages (Wang et al., 2004).

The productivity of mechanized forest equipment is generally computerized based on the operating time. In the time and motion studies, the duration of recurrent elements of work are measured by time recording devices (i.e. chronometer, watch) directly on a worksite (Szewczyk et al., 2014). There are three common time study methods including cumulative, repetitive, and random sampling (Ovaskainen et al., 2004). In this study, time and motion study analysis using repetitive approach was used to assess the productivity of a single-grip harvesting operation. Also, the main factors that affect harvesting operation were investigated. The study was implemented in Osmangazi Forest Enterprise Directorate in the city of Bursa, Turkey.

2. Material and methods

2.1. Study area

The study was conducted during harvesting operations taken place in Osmangazi Forest Enterprise Directorate within the boarder of Bursa Regional Directorate of Forestry in western Turkey. Study area, mostly covered by Brutian pine (*Pinus brutia*) stands, is located in Osmangazi province of Bursa (Figure1).

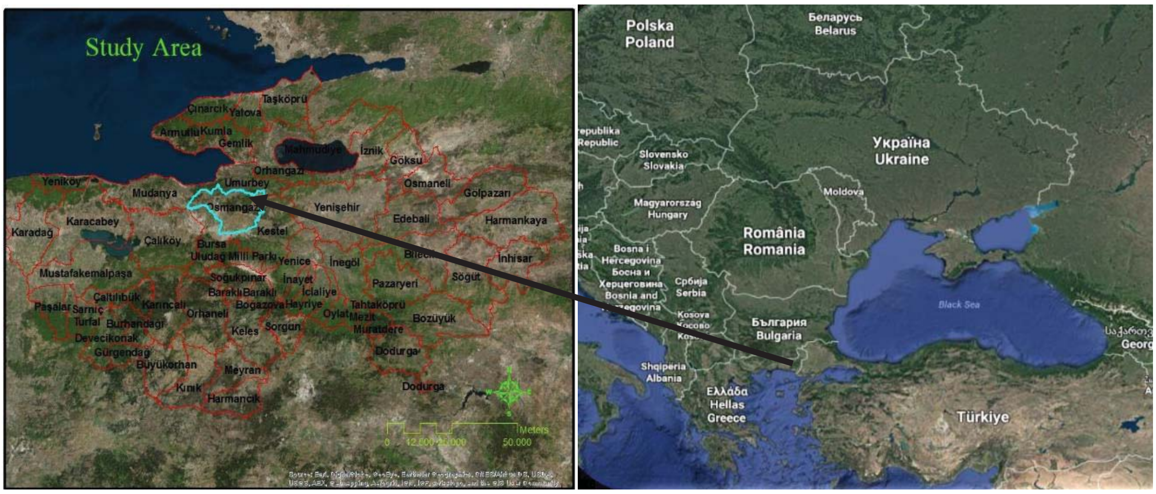

Figure 1. Study area

2.2. Time study

Mechanized cut-to-length (CTL) system was implemented in the field. Trees were cut and bucked by using single grip harvester, and then rubber-tired tractor was used for skidding logs from stump to landing area. The time study was implemented by using repetition approach in which chronometer was run for each work stage separately (Figure 2).

Figure 2. Single-grip harvester

In this study, the harvester operation was evaluated by timing the movement of equipment. The work steps measured include:

1. Moving: Begins when the harvester ends the previous cycle and includes the moving time to the next tree to be cut.
2. Grapping and cutting: Begins when the cutting-head is positioned on the tree and ends when the tree is completely severed from the stump.
3. Processing: Begins when the harvester moves from the stump with the felled tree and ends when movement is stopped.

2.3. Statistical analysis

In statistical analysis, SPSS 22 program was used for statistical analysis where average values and standard deviations were computed. The relation between tree volume and productivity was also analyzed by One-Way ANOVA at 0.05 confidence level. In order to determine if there is a correlation between total cycle time and main decision variable (timber volume), Pearson Correlation Test was implemented. Then, Linear Regression Analysis was used to determine mathematical models for dependent and independent variable. The potential effects of stand feature (tree volume) on productivity were investigated by the correlation analysis based on the timed data.

3. Results and discussion

A time series analysis was used to assess the productivity of a harvester and the effects of tree size on its performance. The total cycle time was computed by calculating three work steps including moving, grapping and cutting, and processing. The results indicated that that the most time-consuming step was processing stage, followed by grapping and cutting, and then moving the cut trees to the dump roadside area (Table 1, Figure 3).

Table 1. Average time per work steps

Work Steps	Min. (sec)	Max. (sec)	Average (sec)
Moving	5	80	25
Grapping and cutting	8	93	29
Processing	13	98	40
Total cycle time	29	271	95

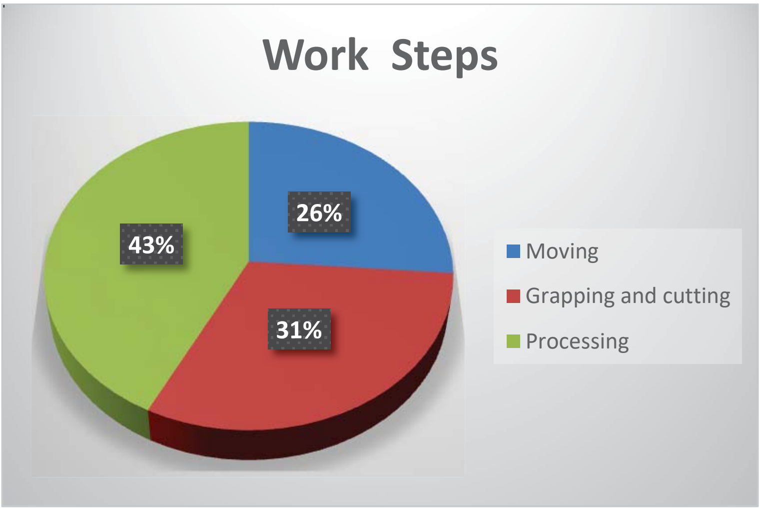

Figure 3. Average time per work steps

Pearson correlation method was used to determine the relationship between productivity and tree size factors (volume), using SPSS 22 program (Table 2). Statistical analysis indicated that there was a significant relationship ($p<0.01$) between productivity and tree size at the confidence interval of 99%.

The significant relation between tree size factors (volume) and productivity was also proven by a One-Way ANOVA at 0.05 confidence level (Table 3). The regression analysis graphic showed a normal distribution (Figure 4). In this study, it was found that there was a significant relationship between tree volume and harvester productivity (Figure 5).

Table 2. The correlation analysis between productivity and tree volume

Correlations

		Productivity	DBH
Productivity	Pearson Correlation	1	0,479(**)
	Sig. (2-tailed)		0,000
	N	32	32
Volume	Pearson Correlation	0,479(**)	1
	Sig. (2-tailed)	0,000	
	N	32	32

** Correlation is significant at the 0.01 level (2-tailed).

Table 3. The summary table of One-Way ANOVA test

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1655,388	1	1655,388	8,913	0,006(a)
	Residual	5571,794	30	185,726		
	Total	7227,182	31			

a-Predictors: (Constant) volume, b-Dependent Variable: Productivity

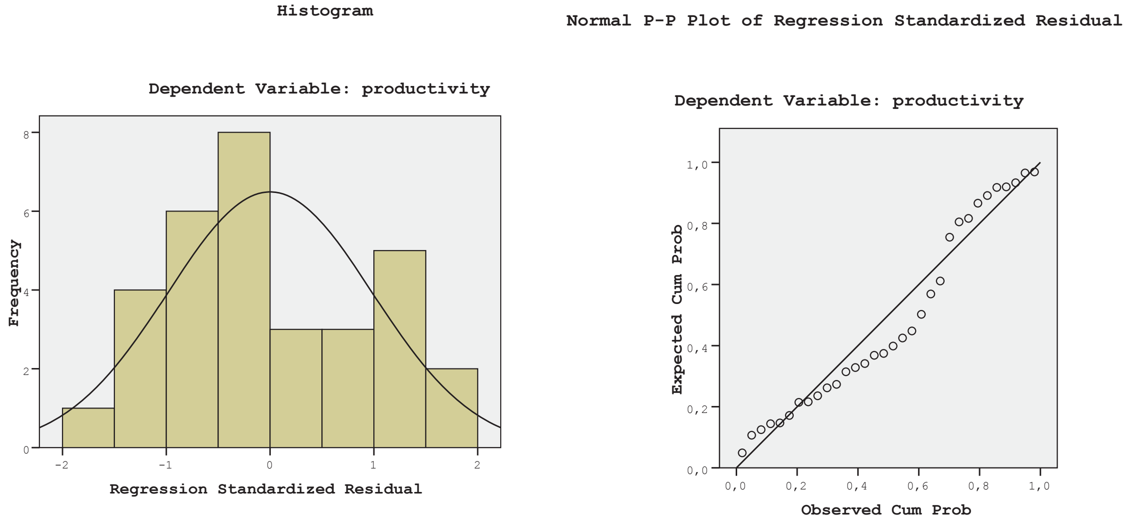

Figure 4. Regression analysis graphics

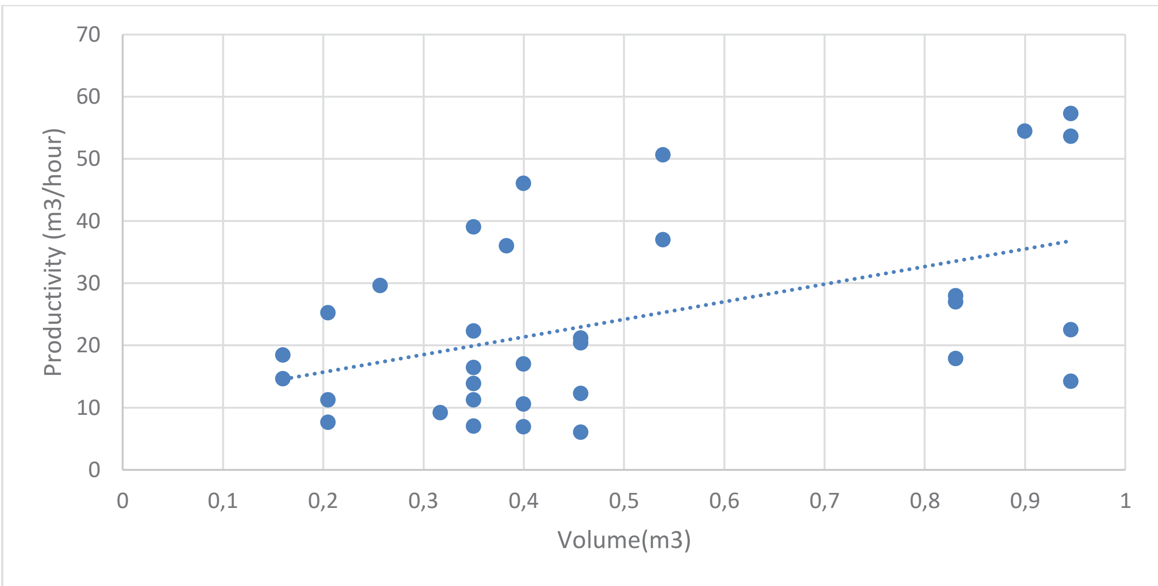

Figure 5. Tree volume vs. productivity

In this study, the average productivity was estimated as 23.91 m^3/hr, ranging between 6.02 m^3/hr to 57.26 m^3/hr. The average timber volume was 0.49 m^3 with the range of 0.16 m^3-0.95 m^3. The productivity was found very close to the values stated in previous works. Andersson (1994) reported a harvester productivity of 22.2 m^3/hr for the average tree volume of 0.34 m^3, which is less compared to Irish conditions. Lanford and Stokes (1996) reported an average harvester productivity of 21.0 m^3/hr using a Valmet 546 Woodstar harvester. Jiroušek et al. (2007) resulted in a productivity of 13.5 to 60.5 m^3/hr with a fairly large stem size (0.1 m^3–1.0 m^3).

4. Conclusions

Mechanized harvesting operations can be very costly especially when dealing with new equipment or the system is implemented for the first time. Thus, newly practiced operations should be well planned based on accurate estimation of the equipment productivity. One of the important factors affecting productivity in previous studies was specified as tree size. Therefore the effect of tree volume on productivity should be carefully examined. Productivity analysis conducted on a single-grip harvester revelaed that there is a meaningful relationship between the volume of tree and productivity. In this study, the effect of tree volume on productivity was studied, thus, other factors that may affect productivity need to be examined in future studies. All factors must be assessed for accurate planning of harvesting systems.

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