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Performance Analysis of a Harvester during Timber Extraction Activities in Bursa, Turkey*

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Abstract

In Turkey, the use of mechanized harvesting technology in forestry has recently increased due to demands of private forest industry for large amounts of woods. In order to implement these systems effectively and efficiently, their applications should be well planned considering the factors that affect the performance of harvesting equipment. Performances of the mechanized harvesting systems are mainly influenced by factors such as tree size, tree formations, terrain conditions, operator motivation and skills. 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 evaluated using statistical analysis. The study was implemented during a clear-cut operation in Brutian pine (*Pinus brutia*) stands located in Osmangazi Forest Enterprise Directorate in the city of Bursa, Turkey. Three stages of harvesting operation were evaluated; harvester moving to the trees, grabbing 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 the harvesting operation was found to be 24 m^3/hr ranging between 6 m^3/hr to 57 m^3/hr. This productivity was mostly affected by the tree size, which directly influenced the total processing time of the felled trees in the study area. According to the statistical analysis results, it was found that there is a significant relationship between tree volume and the time spent on tree processing stage. The results from this study cannot be generalized but it suggests that mechanized harvesting using a harvester should be well planned ahead taking into considering the volume and size of the felled material in order to operate the harvester with optimal efficiency. Optimum machines and configurations should be selected based on machine specifications and stand characteristics.

Keywords: Mechanized harvesting, harvester, time and motion study, productivity

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 the increase in wood demand from the private forest industries at a rate that can only be met by using mechanized harvesting systems. Appropriately planned and implemented, mechanized harvesting operations can help minimize the environmental impacts of extraction by retaining logging residue on the stand and improve 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, as mentioned in previous studies; mechanized harvesting operations should be efficiently planned and managed in order to ensure profitability (Hiesl and Benjamin, 2013).

The highly mechanized harvesting systems in Turkey consist of cut to length harvester, feller-buncher, and grapple skidder equipment. The cut-to-length harvester was first introduced to Turkish forestry in last decade. The use of this machine in forest operations is still new in Turkey and there are only a few studies that have analyzed its productivity. Enez and Arıcak (2012) conducted a study where the productivity of a single-grip harvester was evaluated for different species and tree sizes in the Kastamonu region of Turkey. The study demonstrated that the harvester productivity was maximized in harvesting firs (27.36

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m^3/hr), followed by Yellow pine (20.82 m^3/hr), and Black pine (11.82 m^3/hr). From different dimeter classes, the maximum productivity was reached at the DBH class 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 stand properties, topographical features, and operator's motivation and skill. Mederski (2016) detailed further that the stand conditions, tree characteristics, terrain conditions, and operator skills have direct impact on harvester productivity. Further, the stand density, thinning intensity, type of thinning operation, harvested timber volume per unit area, and density of the strip roads are found to be the main stand conditions that affect productivity (Eliasson, 1999; Suadicani and Fjeld, 2001; Mederski 2006). In the context of tree characteristics, efficiency of the harvesting operation is mostly affected by the size of the selected trees, tree species, tree shape, thickness of branches, and tree selection criteria for thinning (Visser and Stampfer, 2003; Spinelli et al., 2010; Bembenek et al., 2015; Suchomel et al., 2012; Glöde, 1999; Eliasson and Lageson, 1999).

The productivity of mechanized forest equipment is generally analyzed based on the time spent operating on the different work stages and cycles. Time and motion studies are commonly used to measure the duration of recurrent work stages by live time-recording devices (e.g. chronometer, watch, stopwatch) directly on a worksite (Szewczyk et al., 2014). There are three common time study methods that include cumulative, repetitive, and random sampling (Ovaskainen et al., 2004). In this study, the time and motion study analysis approach used repetitive sampling of harvesting cycles to assess the productivity of a single-grip harvesting operation. It was also aimed to determine the main factors that affect harvesting operation.

2. Material and Methods

This study was implemented in Osmangazi Forest Enterprise Directorate in the city of Bursa, in western Turkey. The study area is mostly covered by Brutian pine (*Pinus brutia*) stands and is located in 40° 19′ 06″ North, 28° 50′ 10″ East. (Figure1). The average ground slope and elevation were 25% and 225 m, respectively.

Mechanized cut-to-length (CTL) harvester system was implemented in the field. Trees were cut and bucked by using single-grip harvester, and then rubber-tired tractor was used to skid logs from stump to landing area. The harvester was equipped with AFM 60 model cutting head. The weight, optimum tree diameter, and feeding speed of the cutting head were 1500 kg, 15-35 cm, and 0-6 m/s, respectively. The time and motion study repeatedly used a chronometer for each separate work cycle (Figure 2).

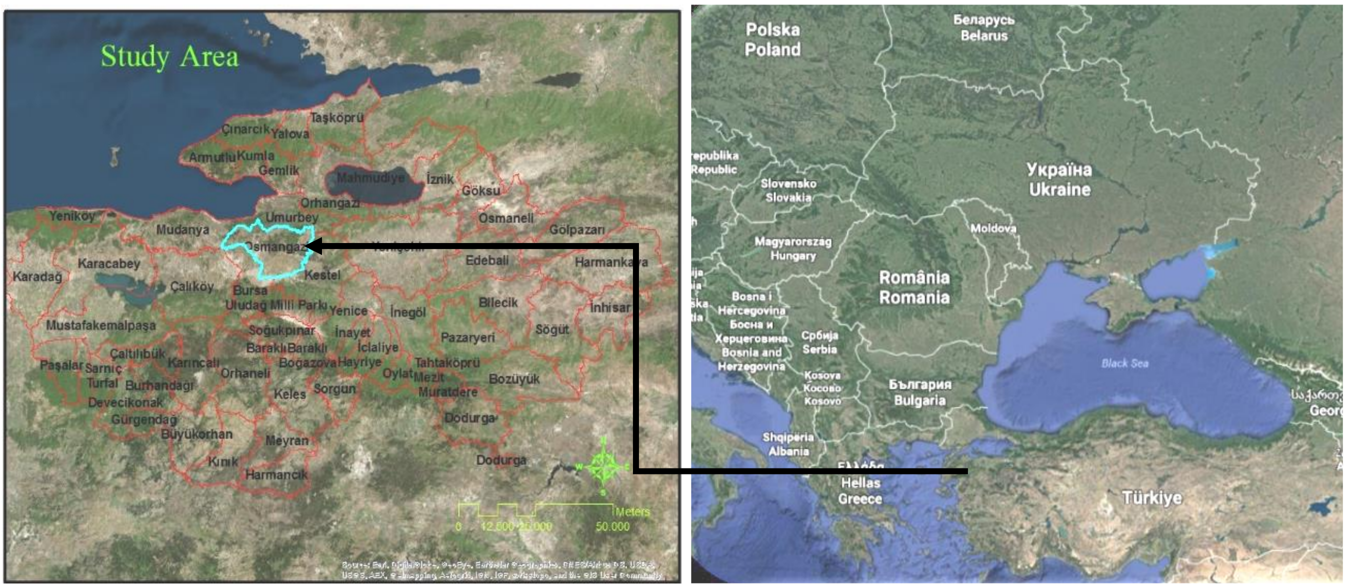


Figure 1. The study area

Figure 2. Single-grip harvester

The movement of equipment stages measured include:
1. Moving: Begins when the harvester completing the previous cycle and includes the moving time to the next tree to be cut.
2. Grabbing and felling: 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 the processing is stopped.

Operational or human caused delays were not significant, thus, they were not included into the total cycle time. The IBM SPSS Statistics 22.0 program was then used to determine basic average and standard deviation values. The relationship between the independent variables (tree volume) and productivity was analyzed by a One-Way ANOVA at 0.05 confidence level and Pearson correlation test. These test methods were used to determine the relationship between the volume removed in each working cycle.

3. Results and Discussions

A time and motion series analysis were used to assess the productivity of a harvester during a forest harvesting operation. The total cycle time was computed by calculating three work stages including moving, grabbing and felling, and processing. The results indicated that the most time-consuming stage was processing (43%), followed by grabbing and felling (31%), followed by moving the felled trees to the roadside dumping area (26%) (Table 1, Figure 3).

The Pearson correlation method was used to determine the relationship between productivity and tree size (volume) using IBM SPSS Statistics 22.0 (Table 2). The statistical analysis indicated that there was a significant relationship ($p<0.01$) between the productivity and tree size felled at the confidence interval of 99%. Bulley (1999) also reported that the harvester's productivity is closely related to the tree size and stand characteristics.

Table 1. Average time per work cycle

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

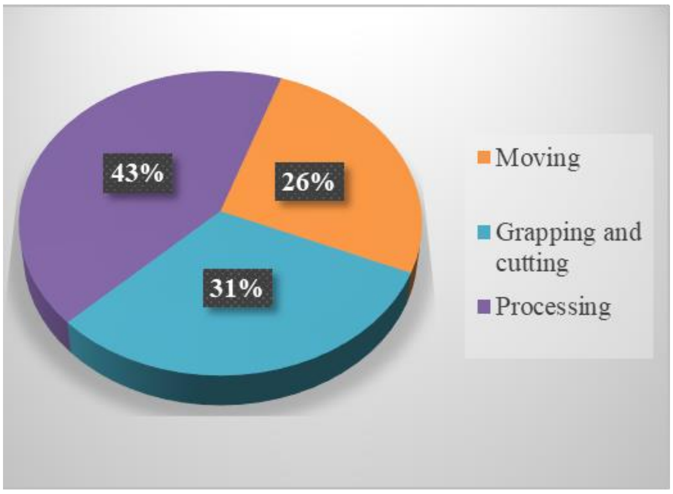


Figure 3. Average time spent on work cycles

Table 2. The correlation analysis matrix between productivity and tree volume

		Productivity	Volume
Pearson Correlation	Productivity	1	0.479(**)
	Volume	0.479(**)	1
Sig. (2-tailed)	Productivity		0.000
	Volume	0.000	

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

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. In this study, it was found that there was a significant relationship between tree volume and productivity of the harvester (Figure 4).

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 studies. Andersson (1994) reported a harvester productivity of 22.2 m^3/hr for the average tree volume of 0.34 m^3. In a similar study, 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) conducted a study where productivity of a harvester ranged from 13.5 m^3/hr to 60.5 m^3/hr with a fairly large stem size (0.1 m^3-1.0 m^3).

In statistical analysis, a correlation analysis was performed to evaluate the productivity of the harvester in each working stage. It was found that there was generally positive linear relationship between work stages and tree volume (Table 4). Nakagawa et al. (2007) reported that there is almost linear relationship between harvester productivity and piece volume of the harvested tree. As indicated in Table 4, volume does not affect productivity in moving stage and there was also no statistically significant relationship. The most impactful work stage on productivity was found to be in the processing stage, followed by grabbing and felling (Figure 5). Previous studies also stated that processing time (especially delimbing) was affected by the size of the felled tree which reflects the machine productivity (Hanell et al., 2000; Suadicani and Fjeld, 2001; Wang and Haarlaa, 2002). One-Way ANOVA test indicated that there was a significant relationship between work cycles and productivity (Table 5).

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

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1655.39	1	1655.39	8.91	0.006(a)
	Residual	5571.79	30	185.73		
	Total	7227.18	31			

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

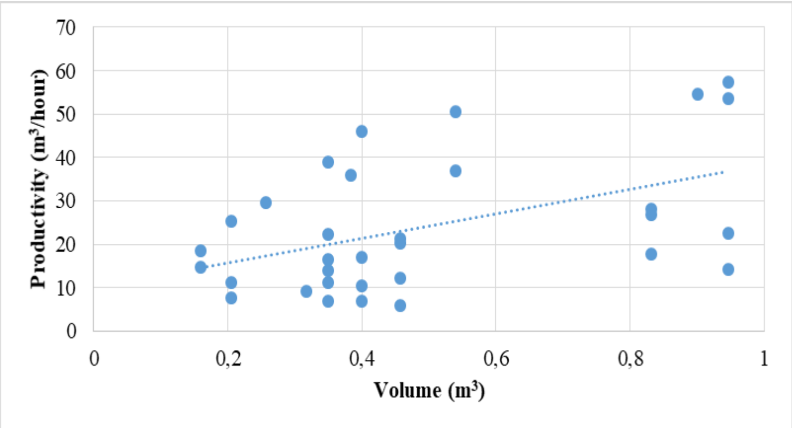
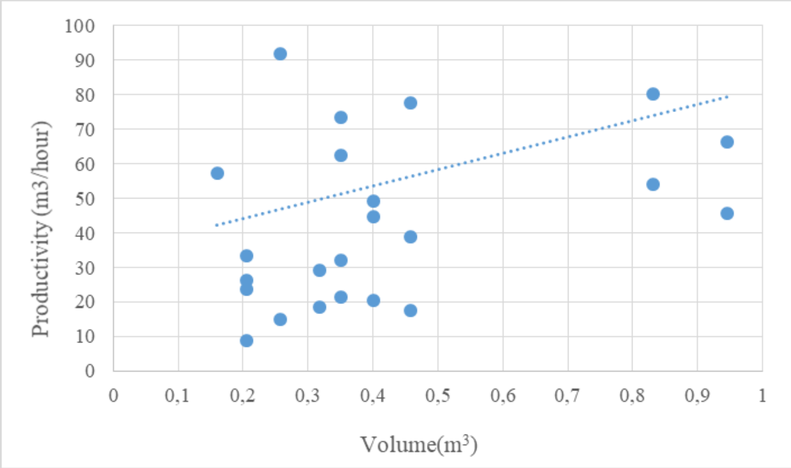


Figure 4. Tree volume vs. productivity

Table 4. The correlation between each work cycle, productivity and tree volume.

		Volume	Moving step	Grabbing and cutting step	Processing step
Pearson correlation	Volume	1.000	0.380	0.464	0.576
	Moving stage	0.380	1.000	0.981	0.907
	Grabbing and cutting stage	0.464	0.981	1.000	0.935
	Processing stage	0.576	0.907	0.935	1.000
Sig. (1-tailed)	Volume	.	0.019	0.005	0.000
	Moving stage	0.019	.	0.000	0.000
	Grabbing and cutting stage	0.005	0.000	.	0.000
	Processing stage	0.000	0.000	0.000	.



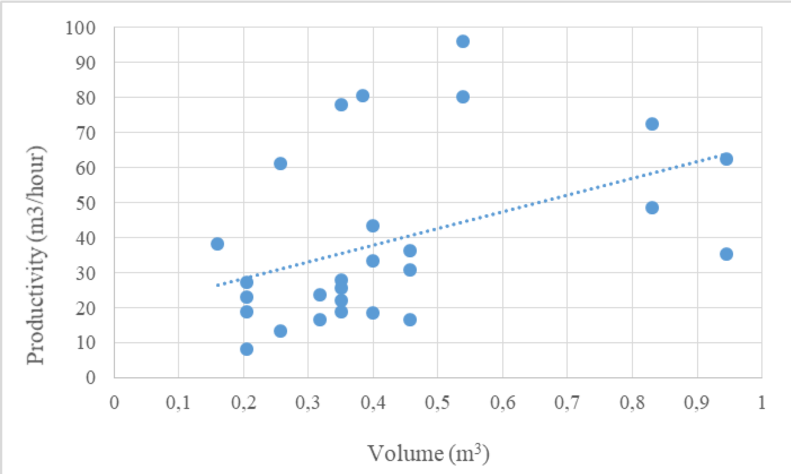


Figure 5. Tree volume vs. productivity for work stages: processing (top), grabbing and felling (below)

Table 5. The summary table of One-Way ANOVA test

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.854	3	0.285	8.312	0.000(a)
	Residual	0.890	26	0.034		
	Total	1.744	29			

a Predictors: (Constant), Moving stage, Grabbing and cutting stage, Processing stage

b Dependent Variable: Volume

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. In this study, productivity analysis was conducted on a single-grip harvester and the results revealed that there is a meaningful relationship between the volume of tree and productivity. According to previous studies, one of the important factors affecting productivity was also specified as the size of the felled tree. Therefore, the effect of tree volume on productivity should be carefully examined and machine selection and harvesting planning should be performed accordingly. The relationship between productivity and volume for three work cycles time were also investigated. The tree processing stage was found to be of the highest impact from all three cycles calculated. The results from this study suggested that optimum machine selection and machine combinations should be practiced based on not only terrain conditions but also stand and tree characteristics.

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