

Productivity Analysis of Front-end Loader in Timber Harvesting*

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Abstract

In this study, the productivity of front-end loader (Liebherr L 514 Stereo), which is one of the most used mechanized harvesting equipment in the production of forest products, was analyzed using time-study method. Factors influencing loader productivity were also evaluated by statistical analysis. Time measurements were carried out during forest harvesting operations in Topçam Forest Enterprise Chief in the city of Giresun. The results indicated that the most time-consuming stage of the loading operation was moving loaded to the logging truck, followed by moving unloaded to the side of the logs. According to the results, the average productivity of the loader was 34.27 m³/hr. Correlation test results showed that there was a positive correlation between productivity and log diameter and log volume, while there was no significant relationship between productivity and log length. The regression model developed with respect to the loader's productivity and specified log parameters (i.e. log diameter and log volume) was found to be significant and adequately explained the productivity of the loader. It was found that there was a significant relation between loader productivity and diameter classes and volume classes. It was also found that loader productivity increased as log diameter and log volume increases.

Keywords: Forest harvesting, mechanized loading, front-end loader, productivity

1. Introduction

The increasing demand of the population and society has increased the pressure on natural resources, thus the products and services provided from the forests should be planned effectively and continuously. For this reason, the forests which are among the top natural resources should be planned considering the optimum efficiency, minimum environmental impact, and economic factors (Kovacsova and Antalova, 2010). Considering that the need of the society, especially for wood-based forest products, will increase gradually, it is foreseen that the inclusion of modern techniques and technological tools and equipment in the work of forest harvesting will be of increasing importance.

Production stages of wood-based forest products include felling, delimiting, debarking, bucking, timber extracting, loading, hauling, unloading and stacking (Eker and Acar, 2006). These stages are implemented with different applications which are developed to reduce costs, simplify the work and ensure the time efficiently (Coskun et al., 2010). When modern techniques and technological tools are not put into practice, they are improperly planned or applied, production stages can be not economic, take much longer than usual, damage the residual stand and

forest soil, and reduce quality of the product (Acar and Senturk, 2000; Akay et al., 2007; Eroglu, 2012). Loading, which is one of the production stages, is of great importance in transporting the products reaching from the forests to the landing without losing time. The efficiency of this stage depends on the harmony of planning of its sub-phases.

In this study, it was aimed to investigate the performance of mechanical loading operation in mountainous terrain based on hourly productivity. In this context, precision forestry tools were utilized in the data collection and data analysis stages. The hourly productivity of loading operation carried out using the Liebherr L514 Stereo loader was investigated by using the time study during loading of a logging truck (Mercedes-Benz AXOR 3240). In addition, the factors affecting the productivity (diameter, length, volume) were analyzed using statistical methods. The study was carried out in Mesudiye Forest Enterprise Directorate (FED) in the city of Ordu in Turkey. The slope of the terrain (almost flat) in the landing area and the number of pieces (mostly one log a time) were not taken into account as they did not vary in the field study.

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2. Material and Methods

2.1. Study Area

The study area is located within the boundaries of Topçam Forest Enterprise Chief (FEC) in Mesudiye FED in Giresun Forest Regional Directorate (FRD) (Figure 1, 2). The dominant tree species in the study area are Eastern

Spruce (*Picea orientalis*) and Eastern Beech (*Fagus orientalis*). In this study, the loading of East Spruce logs, extracted from the forest compartments 137 and 138 in Topçam FEC, on the log truck located on the landing was examined.

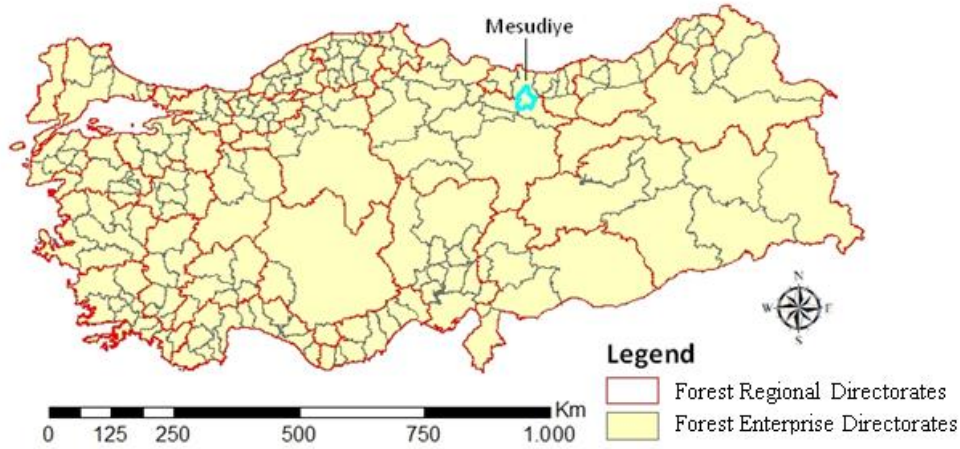


Figure 1. The location of Mesudiye on the map of Turkey

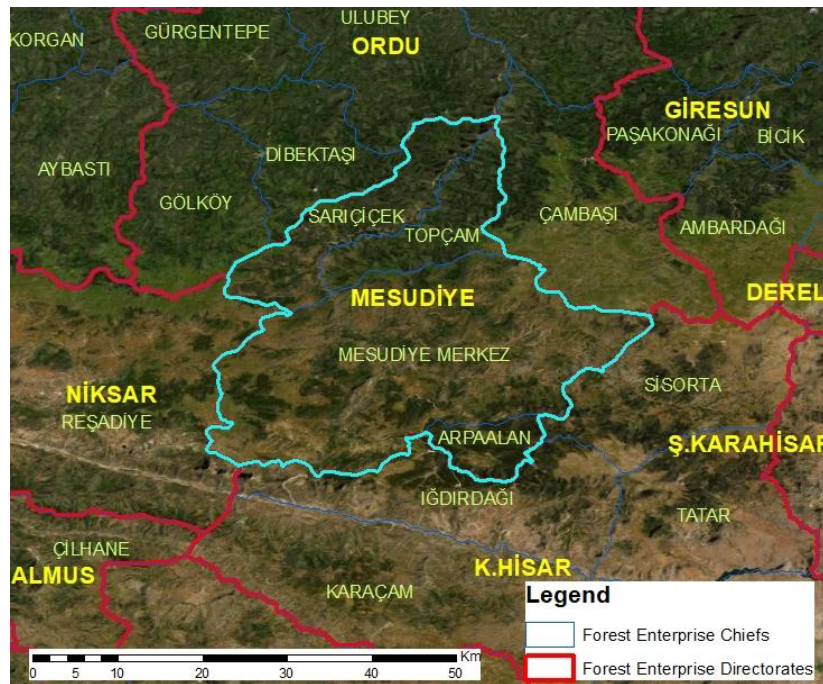


Figure 2. The location of the Topçam FEC

2.2. Time Study

In this study, the productivity of a front-end loader (Liebherr L514 Stereo), a common loader used in the loading wood-based products to the logging truck, was analysed by using time study method (Figure 3). During the loading operation, a total of two people were employed; one loader operator and one worker doing the product stacking in the truck. Two Selex 7064 chronometer was used during time measurement in the field. The average diameters and lengths of the logs were measured with the help of MANTAX

Precision Meter and Weiss brand tape, respectively. Before starting field surveys, a time study form was developed to record time measurements for each work stage in the loading study (Table 1). The work stages evaluated in the loading operation are; loader moving to logs on the ground, loading the logs by grapples, moving to logging truck, and unloading logs to the truck. In addition, the delay time (mechanical and personnel-induced delays) during the study was also recorded.



Figure 3. Loading operation

Table 1. Time study form

Date:		Truck Model:			Weather:					
FED		Loading Model:			Altitude and Aspect:					
FEC:		Truck capacity:			Slope (%):					
Compartment number:		Loading capacity:			Workers:					
		1	2	3	4	5	6	7	8	9
Key Factors	Diameter (cm)									
	Height (m)									
Stages	Loader moves to logs on the ground									
	Loading the logs by the loader									
	Loader moves to logging truck									
	Loader Unloads logs the Truck									
Others	Delay time									

2.3. Productivity Analysis

By using the total time obtained by time measurement, the hourly productivity (m³/h) of the loading was determined. The following formula was used in productivity (P) calculation:

$$P = (V/t)60 \tag{1}$$

V = Average product volume in a cycle (m³)

t = Average total time in one cycle (min)

60 = Coefficient used to convert time from minute to hour

One of the commonly preferred formulas in technical forestry applications, the Huber Formula, was used to calculate the volumes of products. In this formula, the product volume in each cycle was calculated based on medium log diameter (d) and length (L) (Carus, 2002):

$$V = \pi d^2 L / 40000 \tag{2}$$

di = Medium diameter of the product (cm)

L = Product length (m)

2.4. Statistical analysis

Within the scope of statistical analyzes; firstly, the duration of the work stages, product dimensions (diameter, length, volume) and the basic statistical values (average, maximum, minimum and standard deviation) of hourly productivity were determined. The Pearson Correlation Test was used to investigate the relationships between the variables (diameter, length, volume) and the variables and productivity. Then, taking into account the correlation test results, Linear

Regression Analysis was used to develop a mathematical model for dependent variable (productivity) depending on independent variables (diameter, length, volume). In order to examine the effect of log diameters and volumes on productivity, the logs were classified into three diameters (small: <30 cm, medium: 30-39 cm and large: ≥39 cm) and three volume classes (low: <0.30 m³, medium: 0.30-0.49 m³ and high: ≥0.49 m³). One-way ANOVA (0.05) was used to evaluate the relationship between diameter and volume classes and productivity.

3. Results and Discussion

3.1. Basic Statistical Results

The basic statistical values (average, maximum, minimum and standard deviation) obtained for the variables (diameter, length, volume) related to the product dimensions affecting the productivity in the loading operation are given in Table 2. The average log diameter, length and volume were determined as 34.07 cm, 3.90 m and 0.38 m³, respectively.

The basic statistical values (mean, max, min and standard deviation) of the time measurements of the work

stages, delay time and loader productivity are given in Table 3. According to the results, it was found that the most time consuming stage in a loading cycle was the time for the loader to move to the truck (31.15%), followed by the time for the loader to move to the log on the ground (30.52%). When the mechanical and personnel delays are taken into consideration, it was determined that the delay time constitutes 25.29% of the total cycle time

Table 2. Basic statistical findings of the variables affecting the loading productivity

Variables	Unit	Average	Minimum	Maximum	Standard Deviation
Diameter	cm	34.07	20	50	7.87
Length	m	3.90	3	4	0.31
Volume	m ³ /cycle	0.38	0.13	0.98	0.19

Table 3. The basic statistical findings in loading

Phases	Average	Minimum	Maximum	Standard Deviation
Loader moves to logs on the ground (sec)	9.77	6	14	2.05
Loading the logs by the loader (sec)	5.50	4	8	1.14
Loader moves to logging truck (sec)	9.97	5	15	2.76
Loader Unloads logs the Truck (sec)	6.77	3	13	1.87
Delay time (sec)	10.83	4	16	3.64
Yield (m ³ /h)	34.27	10.73	69.51	15.19

In the loading operation with the loader, the average productivity was determined as 34.27 m³/hour. In a similar study (Karaman, 1991), the average productivity in the operation of loading spruce logs with Liebherr 902 loader was determined as 48.67 m³/hour.

3.2. Correlation Between Variables Affecting Productivity

The Pearson Correlation Test was applied to determine the relationships between hourly productivity and variables (diameter, length, volume) (Table 4).

Correlation test results showed that there was a positive ($p < 0.001$) relationship between log diameter and log volume and productivity at 99% confidence level. There was no significant relationship between log dimensions and productivity at 99% confidence level ($p > 0.5$). This is due to the fact that the lengths of the log evaluated in the study are very close to each other. In similar studies in which the loader's productivity analysis was carried out, it was stated that log volume and log dimensions were effective factors on productivity (Javadpour, 2006; Kewilaa and Tehupeiori, 2015).

Table 4. Findings of correlation analysis

		Diameter	Height	Volume	Productivity
Pearson correlation constant	Diameter	1	-0.083	.919**	0.823**
	Height	-0.083	1	0.134	0.141
	Volume	0.919**	0.134	1	0.851**
	Productivity	0.823**	0.141	0.851**	1
Sig. (2-tailed)	Diameter		0.662	0.000	0.000
	Height	0.662		0.479	0.457
	Volume	0.000	0.479		0.000
	Productivity	0.000	0.457	0.000	

3.3. Regression Analysis Results

Taking into account the correlation test results, Linear Regression Analysis was used to reveal the relationship between independent variables (diameter and volume) and dependent variable (productivity). The regression model was found to be significant at 99% confidence level ($p < 0.001$) (Table 5). The obtained R^2 value (0.74) showed that the regression model explained the loader efficiency sufficiently.

The regression model which includes the dependent variable ($y =$ productivity) and the independent

variables ($x_1 =$ diameter; $x_2 =$ volume) representing the productivity is shown in the following equation:

$$y = -1.379 + (0.509) x_1 + (47.731) x_2 \quad (3)$$

The developed mathematical model showed that the most influential factor on productivity was the volume value. The graphs obtained as a result of regression analysis showed normal distribution (Figure 3, Figure 4).

Table 5. One-way ANOVA results

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	4914.78	2	2457.39	37.38	0.000 ^a
Residual	1775.02	27	65.74		
Total	6689.80	29			

a. independent variable: Diameter, Volume
b. dependent variable: Yield

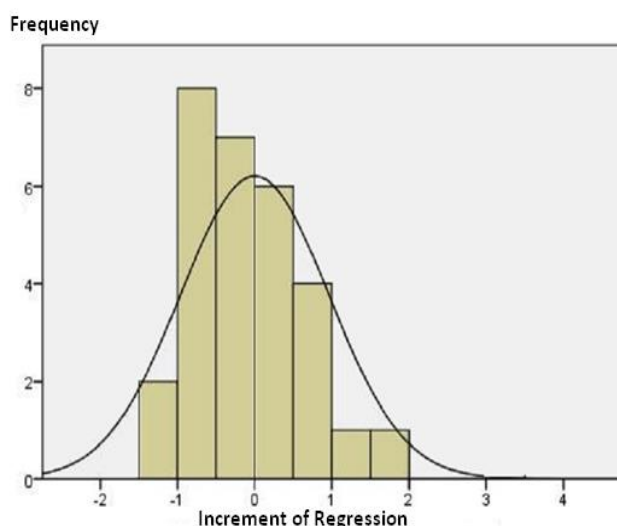


Figure 3. Regression histogram

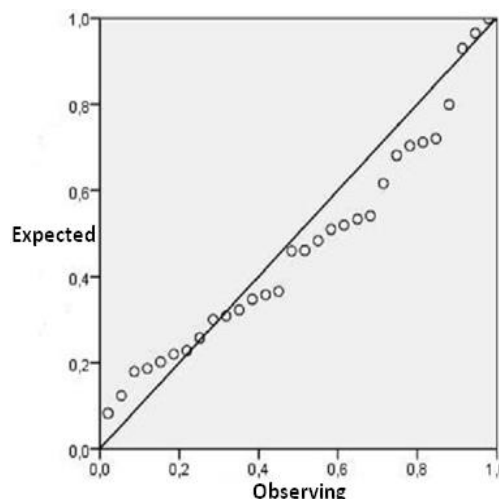


Figure 4. Normal probability graph

3.4. Diameter Classes Results

In order to examine the effect of measured product diameters on productivity, logs were divided into three diameter classes (small, medium, and large) according to the standard diameter classes of General Directorate of Forestry. Then, 0.05 significance level One-Way Analysis of Variance, using the relationship between the productivity of the diameter classes were evaluated (Table 6). According to the results obtained yield values increased from small diameter class, medium

and large diameter class increased (Table 7). In a similar study, Naghdi (2005) stated that the increase in log dimensions increases the productivity in loading studies.

By using Tukey multiple comparison test, yield values of diameter classes were compared among themselves. According to the results, it was determined that yield values belonging to diameter classes showed significant differences at 95% confidence level ($p < 0.05$) (Table 8).

Table 6. One-way ANOVA findings for diameter classes

	Sum of Squares	df	Mean Square	F	Sig.
Between-group	4225.01	2	2112.51	23.14	0.000
Within-group	2464.78	27	91.29		
Total	6689.79	29			

Table 7. Basic statistical values for diameter classes

Diameter Classes	N	Average	Standard Deviation	Standard Error	Minimum	Maximum
Small	8	16.43	4.95	1.75	10.73	25.23
Medium	14	36.35	9.82	2.62	22.79	63.70
Large	8	48.49	12.19	4.31	33.08	69.51
Total	30	34.27	15.19	2.77	10.73	69.51

Table 8. Multiple comparison results for diameter classes

(I)Diameter Classes	(J) Diameter Classes	Mean Difference (I-J)	Standard Error	Sig.	%95 confidence level	
					Lower limit	Upper limit
1	2	-19.92*	4.25	0.000	-30.42	-9.42
	3	-32.06*	4.78	0.000	-43.91	-20.22
2	1	19.92*	4.24	0.000	9.42	30.42
	3	-12.14*	4.25	0.021	-22.64	-1.64
3	1	32.06*	4.78	0.000	20.22	43.91
	2	12.14*	4.25	0.021	1.64	22.64

3.5. Volume Classes Results

In order to investigate the effect of the measured product volumes on the productivity, the products were divided into three volume classes (low, medium and high). Then, 0.05 significance level of One-Way Analysis of Variance (One-Way ANOVA), using the relationship between the volume classes were evaluated (Table 9). According to the obtained results, productivity values increased from low volume class, medium and high volume class increased (Table 10). In a similar study in which Kewilaa and Tehupeiry

(2015) investigated the productivity and cost analysis of the grapple loader, a positive significant relationship was found between the average volume and weight of the products loaded in each cycle and the yield of the loading study. Tukey multiple comparison test was applied and the yield values of the volume classes were compared among themselves. According to the results, it was determined that the yield values of the volume classes formed showed a significant ($p < 0.05$) differences at 95% confidence level (Table 11).

Table 9. One-way ANOVA findings for volume classes

	Sum of	df	Mean Square	F	Sig.
Between-group	4494.94	2	2247.47	27.65	0.000
Within-group	2194.86	27	81.29		
Total	6689.79	29			

Table 10. Basic statistical values for volume classes

Volume	N	Average	Standard	Standard	Minimum	Maximum
Low	11	19,45	6,94	2,09	10,73	31,79
Medium	12	38,28	9,27	2,65	29,30	63,70
Hight	7	50,69	11,33	4,28	33,49	69,51
Total	30	34,27	15,19	2,77	10,73	69,51

Table 11. Multiple comparison results for volume classes

(I) Volume Classes	(J)Volume Classes	Mean Difference (I-J)	Standard Error	Sig.	%95 confidence level	
					Lower limit	Upper Limit
1	2	-18.83*	3.76	0.000	-28.16	-9.49
	3	-31.24*	4.36	0.000	-42.04	-20.43
2	1	18.83*	3.76	0.000	9.49	28.16
	3	-12.41*	4.29	0.020	-23.04	-1.78
3	1	31.24*	4.36	0.000	20.43	42.04
	2	12.41*	4.29	0.020	1.78	23.04

4. Conclusions

The loading operation has an important function to carry out the transportation of wood-based forest products smoothly. In this study, the grapple loader which is one of the most widely used mechanical production tools in the production of forest products has been analyzed in terms of productivity and the factors affecting the loader yield have been evaluated. When the average duration of the work stages in the loading study was examined, it was found that the most time consuming stage was the time of the loader moving to the truck (31.15%), followed by the time of the loader moving back to the logs on the ground (30.52%). In addition, it was found that lost time had a significant rate (25.29%) in total working time.

According to the results, the average productivity was 34.27 m³/hour. Correlation test results showed that there was a positive correlation ($p < 0.001$) between log diameter and volume and productivity at 99% confidence level, whereas there was no significant relationship between log length and productivity. It was determined that the regression model developed for loader productivity and log diameter and volume was significant at 99% confidence level ($p < 0.001$) and explained loader productivity in sufficient level ($R^2 = 0.74$).

It was found that there was a significant relationship between diameter classes and productivity values and loader productivity increased from small diameter class to large diameter class. It was determined that productivity values of diameter classes showed significant ($p < 0.05$) differences among themselves at 95% confidence level. Likewise, there was a significant relationship between volume classes and productivity values and loader productivity from low volume class to high volume class. It was determined that yield values of the determined volume classes showed significant ($p < 0.05$) differences among themselves at 95% confidence level.

In order to carry out the production of forest products effectively, a good harmony between loading activity and felling, unloading, stacking and hauling is required. Therefore, the use of high-performance mechanical loaders in the loading will contribute to the success of the production of forest products. In Turkey, manual loading method based on manpower is still preferred in the loading of logs in some regions, especially in the loading of small size (paper and firewood) forest products. However, the lack of economic use of manpower in recent years and the problems experienced in hiring experienced workers indicate that loaders will be preferred more in loading works. Furthermore, the necessity of transporting wood-based products in a short time, in certain periods and sometimes in severe weather conditions makes it necessary for the use of loaders operating in high efficiency in all weather conditions.

Operator performance is also of key importance for using loaders with optimum efficiency. Therefore, the necessary theoretical and practical training should be given to loader operators. The results obtained from this study indicated that it will be appropriate to investigate the productivity of loaders in different sizes and capacities in loading various forest products (i.e. industry wood, mining pole, paper wood, etc.).

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