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Productivity Analysis of Mid-Size Cable Yarding Operation based on UAV-captured Video Sequences

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Abstract

Cable yarding is one of the most preferred timber extraction methods in steep and mountainous terrain conditions. In recent years in Turkiye, mid-size cable yarders have begun to be used frequently in steep forest areas where intensive forestry is carried out. In order to make more effective use of cable yarders and achieve maximum productivity, timber extraction operations must be planned most appropriately and implemented in the field accordingly. The productivity of mechanized equipment used in harvesting operations is mainly determined by using time study analysis. In traditional methods, time measurements are carried out by observing the work stages with time recording devices (stopwatches) in the area where the machine operates. Since timber extraction by using a cable yarder occur in steep and rugged terrain conditions, difficulties may be encountered in applying time analysis in the field. In this study, it was aimed to obtain high-resolution digital video images of the activities of cable yarding operation with an Unmanned Aerial Vehicle (UAV) and to calculate productivity through time study analysis on these images. For the study, the Tajfun MOZ 500 GR model mid-size cable yarder was evaluated during a timber extraction operation in Köyceğiz Forest Enterprise Chief (FEC), located in Muğla City, Turkiye. Besides, statistical analysis was performed to estimate the effects of factors such as average product length, product diameter, lateral yarding distance, number of pieces, and total product volume per turn on the productivity of the cable yarder. The results indicated that UAV video images can be an effective alternative method to conduct time study analysis and productivity estimations. It was found that the productivity of the mid-size cable yarder was 11.76 m^3/hour. During the operation, the pulling mainline to the product and choker setting were the most time-consuming work stages, followed by the time-loaded carriage reaching the landing. The statistical analysis indicated a significant relationship ($p<0.001$) between product length, product diameter, total volume and productivity of the cable yarder. The results showed that there was a negative relationship between lateral yarding distance and productivity. The regression model regarding the productivity of the cable yarder and the independent variables was also significant.

Keywords: Forest operations, Cable yarding, Productivity, Time study, UAV imagery

1. Introduction

Production of wood-based forest products consists of cutting-felling, delimbing, debarking, bucking, extracting, loading, distant transportation, unloading, and stacking stages (Eker and Acar, 2006). One of the most challenging and costly stages in timber production is transporting the cut trees from the stump to the landing areas using timber extraction methods. In Turkiye, the process of extracting wood-based forest products is carried out mostly using conventional methods involving human-animal power techniques, while mechanized extraction methods partly do it. Instead of conventional methods, which are technically, economically, environmentally, and ergonomically problematic, mechanized methods provide higher potential results.

The main advantages of the mechanized extraction methods are reducing the cost of log production, providing organic matter to the forest ecosystem by leaving the logging residues in the forest at the end of the production process, reducing the stand damage by limiting the area of timber production units, and increasing the workforce potential in timber production activities (Akay and Sessions, 2004). On the other hand, mechanized extraction works that are not well planned and properly organized increase costs, cause loss of time and value, and result in negative effects on the forest soil and the residual trees (Akay et al., 2007; Eroğlu, 2012; Gülci et al., 2015).

Recently, mechanized timber extraction methods have been used, particularly in regions where intensive forestry is practiced in Turkiye (Akay et al., 2016). It is seen that mid-size yarders are used more frequently, especially in steep and mountainous forest areas. In fact, cable yarding is the main solution for steep terrain with a more than 40 % slope where ground-based harvesting

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systems cannot provide effective solutions (Spinelli et al., 2015). In this context, the General Directorate of Forestry (GDF) purchased Tajfun MOZ brand cable yarders in 2019 to be used in timber extraction activities in regions with rough terrain. They provided the necessary practical training for the logging crew. This investment has been an important step in supporting the mechanization and precision forestry approach in timber extraction in terms of being economical in producing of wood raw materials and minimizing stand damage.

Spinelli et al. (2015) examined the mid-size tower yarder for uphill and downhill timber extraction operations in the Italian Alps. They analyzed the potential correlation between productive time consumption and some parameters, including yarding distance, lateral extraction distance, mean log size, and number of logs per turn. It was reported that all the parameters, except number of logs, were useful predictor variables for the productivity of the cable yarder. Yılmaz et al. (2022) conducted a study to estimate the productivity of the Tajfun MOZ 500 GR cable yarder during the timber extraction operation in the city of Artvin, Turkiye. They reported that load volume, yarding distance, and carriage speed were the main factors that influenced the productivity of the cable yarder. In a recent study, Emir et al. (2023) investigated the fixed costs and variable costs of Tajfun MOZ 500 GR cable yarder for the conditions of Turkiye. They found that fixed and variable costs for operating the yarder were 18.94 USD/hour and 16.23 USD/hour, respectively.

The main factors influencing the increasing use of cable yarders in mountainous regions are the ecological and economic advantages they provide due to the need for less road networks. They do not cause compaction in forest soil because motor vehicles do not need to enter the land, and there is a low level of residual tree damage (Spinelli et al., 2010). In addition, the prominent features of cable yarding compared to other timber extraction methods are the practical use on steep terrains with low carrying capacity, low energy consumption, and deep pits that do not damage tree roots. On the other hand, cable yarding has potential disadvantages: the economic problems can be experienced in small amounts of timber production due to high fixed costs and the negative impact of production costs and productivity in the absence of expert and trained workforce.

The most appropriate approach to obtain maximum benefit from mechanized equipment, which has high hourly unit costs due to high purchasing costs and operation prices, is through comprehensive planning of mechanized harvesting activities (Eker and Sesison, 2020). In this study, the productivity of a mid-size cable yarder was evaluated using time analysis measurements based on digital video images obtained with a UAV. In the study, the effects of some parameters (product length, product diameter, number of pieces, total volume, yarding distance, lateral yarding distance) on the productivity of the cable yarder were also determined by statistical analysis.

2. Material and Methods

2.1. Study Area

The study area is located in Köyceğiz FEC within the border of Köyceğiz Forest Enterprise Directorate (FED) in Muğla Forestry Regional Directorate (FRD). The forest resources in Köyceğiz FED are indicated in Table 1 (GDF, 2023). In terms of forest conditions in Köyceğiz FEC, about 66.74% of the forest area was classified as productive, while 33.26% was degraded (Figure 1). The dominant tree species in Köyceğiz FEC were Brutian pine (*Pinus brutia* T.), Black pine (*Pinus nigra*), Stone pine (*Pinus picea*), and Oriental sweetgum (*Liquidambar orientalis*).

Table 1. The areal distribution of forests in Köyceğiz FED (GDF, 2023)

FECs	Productive (ha)	Degraded (ha)	Total Area (ha)
Ağla	13371.90	3218.80	16590.70
Akköprü	8421.70	1828.70	10250.40
Karaçam	14302.20	3659.30	17961.50
Beyobası	11457.30	3579.20	15036.50
Köyceğiz	**7109.60**	**3543.70**	**10653.30**
Sultaniye	9805.70	8195.10	18000.80
Marmaris	3090.78	4231.60	7322.40
Arboretum	201.50	176.40	377.90

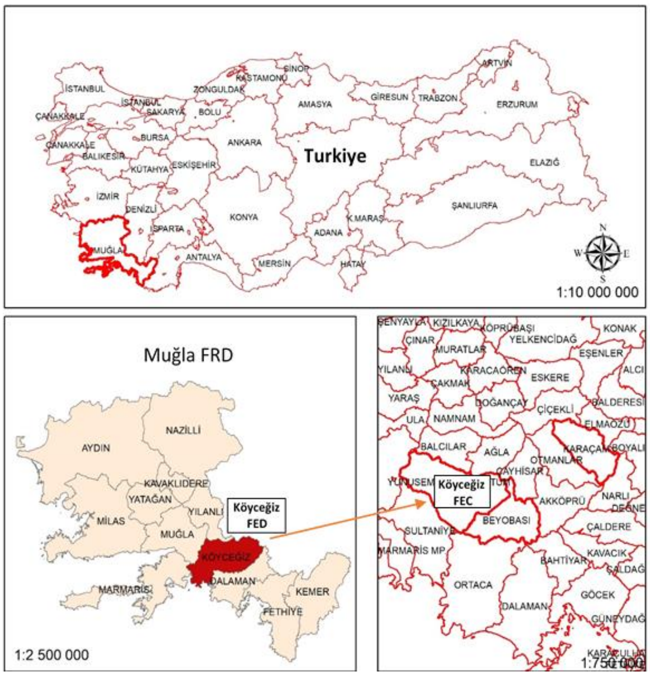

Figure 1. Köyceğiz FEC within the border of Köyceğiz FED

2.2. Skyline Operation

In the study area, the Tajfun MOZ 500 GR model mid-size cable yarder was evaluated during an uphill cable yarding operation in a Brutian pine stand that previously burned during the 2021 forest fire (Figure 2).

During the operation, the cable yarder received its power from the tail shaft of the Tümason 8105 model agricultural tractor. Tajfun MOZ 500 GR cable yarder has very functional features, such as a closed circuit hydraulic system supported by two hydraulic motors to provide full cable pull-back capability and to control the main line positioned with a separate pulley. The yarder has a foldable tower for easy hauling and positioning in the landing areas. Other features include two-way radio communication, a fully electric wagon, and a disc-brake to dissipate the heat generated during operation (Emir et al., 2023). The technical specifications of Tajfun MOZ 500 GR cable yarder are indicated in Table 2.

Figure 2. Tajfun MOZ 500 GR cable yarder and Tümason 8105 agricultural tractor

Table 2. Technical specifications of Tajfun MOZ 500GR

Specifications	Value
Yarding distance	500 m
Tensile strength	60 kN
Required tractor power	105 HP
Yarding speed	4 m/second
Weight	3800 kg
Maximum working height	8 m
Max. carrying height/capacity	2.8 m/1900 kg
Skyline diameter/length	18 mm/500 m
Mainline diameter/length	9 mm/500 m
Guyline diameter/length	16 mm/45 m
Swing angle	180^{o}
Tire sizes	400/60R15.5
Control system	Remote
Fuel consumption	3 L/H
Carriage weight	240 kg

During the skyline operation, the first stage of the timber extraction begins with the movement of the carriage by gravity on the skyline from the upper station (landing) where the crane and tower are located, in the direction of the support tree used as the lower station. It ends with the wagon reaching the loading point. The second stage involves lowering the mainline from the carriage to the ground at the loading point. The third stage begins with pulling the mainline down to the ground laterally to where the timber products are and ends with choking the products to the mainline. The fourth stage involves pulling the mainline that connects products from the ground to the carriage. The fifth stage refers to the time spent pulling the loaded carriage uphill to the upper station on the skyline. The sixth stage involves lowering the mainline with the timber products to the ground on the landing, and the seventh stage involves untying the products from the mainline. The last stage refers to pulling the mainline onto the carriage.

2.3. Productivity Analysis

The video images were recorded using the "DJI Mavic Pro" model UAV for time measurement of the cable yarder (Figure 3). DJI Mavic Pro, which has the features of providing high-resolution images (12 MP for photos, 4K for videos) and preventing the vibration effect caused by windy weather with its three-axis "gimbal" apparatus, is one of the widely used UAV with its easy portability and durable structure. The flights were carried out at an altitude range of 40 m - 60 m, which would provide the best view of the operation and ensure safe flight. The maximum flight time for UAV flights was recorded as approximately 20 minutes. The images obtained in the field were recorded on the UAV's 128 GB memory cards and transferred to the computer. Then, the images were analyzed in the office, and the time values of the work stages were calculated with high accuracy.

Figure 3. A photo of the Tajfun MOZ 500 GR yarder taken with a UAV

In order to ensure normal distribution, a total of 30 turns were captured during the cable yarding operation. For each turn, the following work stages (WSs) were considered:

WS 1: Carriage reaches the loading point

WS 2: Lowering mainline to the loading point

WS 3: Pulling mainline to the product and choker setting

WS 4: Pulling the timer product onto the carriage

WS 5: Loaded carriage reaching the landing

WS 6: Lowering the product to the ground

WS 7: Unloading the product from mainline

WS 8: Pulling the mainline into the carriage

During cable yarding operation, the total lost time due to personnel (i.e., rest, food) or machinery (i.e., repair and maintenance) was not included in the total cycle time because productivity was computed based on productive working time and product volume per turn (Gülci, 2014). The Mid-Surface (Huber) Formula was used to calculate product volumes (Carus, 2002). The volume of each timber product was calculated using the median diameter (cm) and product lengths (m). Then, total load volume per turn was calculated by summing up the volume of each product.

2.4. Statistical Analysis

In the statistical analysis, the descriptive statistical values (minimum, maximum, average, standard deviation) for the time values of the work stages, independent variables, total productive working time, and hourly productivity were determined. Independent variables in the study were average product length, product diameter (medium diameter), lateral yarding distance, number of pieces, and total product volume. For normality tests, skewness and kurtosis values were examined. While skewness measures the degree to which a distribution is non-normal, kurtosis is an index that indicates the degree to which there are too many or too few samples in the middle of the distribution (Tabachnick and Fidell, 2013). Then, a correlation test was applied to investigate the relationships between the independent variables considered in the study and the hourly productivity of the cable yarder. In the final stage, regression analysis was applied to determine mathematical models for the independent variables that were determined to have a statistically significant relationship with hourly productivity. Statistical analysis was performed using the SPSS 20.0 program.

3. Results and Discussion

3.1. Time Study and Productivity

The statistical summary of the independent variables for cable yarding operation is given in Table 3. It was found that the average product length, product diameter, and total product volume were determined as 11.68 m, 20.30 cm, and 1.93 m^3, respectively. During the yarding operation, the average yarding distance, lateral yarding distance, and number of pieces were 185.00 m, 18.77 m, and 5.00, respectively. The values of the skewness and kurtosis coefficients obtained as a result of the normality tests of the data are also shown in Table 3. It was observed that the skewness and kurtosis values for the independent variables were between ±3 limit values. Since the skewness and kurtosis were not excessive, it does not pose a problem in terms of compliance with normal distribution. (Ross and Willson, 2018).

Descriptive statistical values of time measurements of the work stages (WS) and productivity of the cable yarder are given in Table 4. The total productive working time and productivity were 9.82 minutes and 11.76 m^3/hour, respectively. A study by Spinelli et al. (2015) examined the productivity of a mid-size cable yarder (product volume: 1.9 m^3, lateral yarding distance: 24 m) and determined the productivity as 12.1 m^3/hour.

Table 3. Statistical summary of independent variables for cable yarding operation

Variables	Unit	Minimum	Maximum	Average	Standard Deviation	Skewness coefficient	Kurtosis coefficient
Product length	cm	7.40	17.50	11.68	3.15	0,520	-0,877
Product diameter	cm	12	27	20.30	3.51	-0,175	-0,220
Number of pieces	#	3.00	10.00	5.00	1.68	1,539	2,255
Total product volume	m^3	1.008	3.94	1.93	0.76	0,936	0,435
Yarding distance	m	150	200	185.00	23.31	-0,920	-1,242
Lateral yarding distance	m	5	30	18.77	7.66	-0,045	-0,929

Table 4. Statistical findings regarding time measurements of work stages and productivity

Variables	Unit	Minimum	Maximum	Average	Standard Deviation
WS 1	min	1.14	2.01	1.38	0.176
WS 2	min	0.17	0.56	0.29	0.090
WS 3	min	2.18	4.69	2.99	0.585
WS 4	min	0.40	1.40	0.73	0.254
WS 5	min	1.47	3.39	2.43	0.537
WS 6	min	0.08	0.47	0.26	0.085
WS 7	min	0.68	3.08	1.43	0.484
WS 8	min	0.12	0.99	0.31	0.230
Productivity	m^3/hour	6.638	26.35	11.76	4.383

When the work stages in a total of 30 turns recorded during time measurements were evaluated, the most time-consuming stage was pulling mainline to the product and choker setting (WS 3) (2.98 minutes), followed by the time loaded carriage reaching the landing (WS 5) (2.43 minutes). In a similar study conducted by Yılmaz et al. (2022), the most time consuming work stage during a cable yarding operation was the choker setting of the timber products, followed by traveling loaded carriage to the landing.

3.2. Regression Models

The results of the correlation test indicated that there was a positive relationship ($p<0.001$) between product length, product diameter, total volume, and productivity of the cable yarder at the 99% confidence level (Table 5). According to similar studies where the productivity model was developed for a cable yarding operation, it was found that there was a positive relationship between productivity and product sizes and volumes (Spinelli et al., 2015; Akay et al., 2023).

The results indicated that yarding larger size (i.e., length and diameter) timber products, leading to high volume per turn, increased productivity (Yılmaz et al., 2022). Figure 4 and Figure 5 show that the productivity of the cable yarder increases as the length and diameter of the yarded product increase. The relationship between the productivity of the cable yarder and total volume per turn is indicated in Figure 6. This figure indicated that there is a meaningful positive relationship (R^2 = 0.90) between productivity and total product volume per turn. Previous studies, it was also stated that the increase in the product volume, in turn, increased the productivity of the yarding operations (Cho et al., 2018). This result may suggest that maximizing the total volume of the timber products per turn according to the payload capacity would play important role to improve the productivity of the cable yarder.

Table 5. Correlation test results of yarder productivity

		Productivity	Product diameter	Product length	Total volume	Lateral yarding distance	Number of pieces
Productivity	Pearson	1	.650**	.659**	.944**	-.204	-,063
	Sig. (2-tailed)		.000	.000	.000	.280	,739
Product diameter	Pearson	.650**	1	.390*	.680**	-.153	-,608**
	Sig. (2-tailed)	.000		.033	.000	.420	,000
Product length	Pearson	.659**	.390*	1	.594**	-.175	-,318
	Sig. (2-tailed)	.000	.033		.001	.356	,087
Total volume	Pearson	.944**	.680**	.594**	1	-.142	,004
	Sig. (2-tailed)	.000	.000	.001		.453	,982
Lateral yarding distance	Pearson	-.204	-.153	-.175	-.142	1	,115
	Sig. (2-tailed)	.280	.420	.356	.453		,544
Number of pieces	Pearson	-.063	-.608**	-.318	.004	.115	1
	Sig. (2-tailed)	.739	.000	.087	.982	.544	

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

*. Correlation is significant at the 0.05 level (2-tailed)

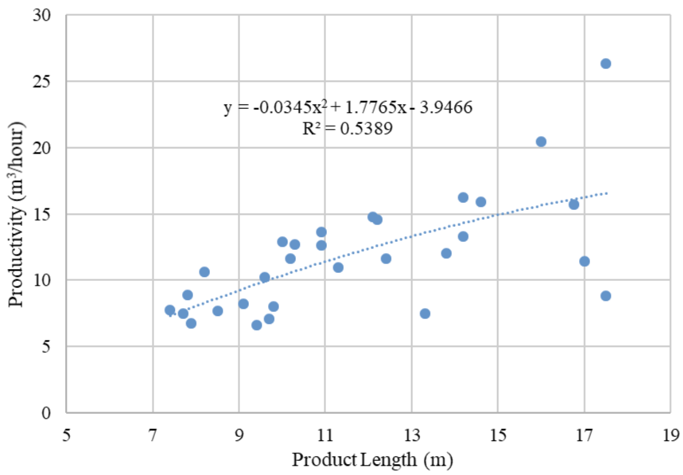

Figure 4. The relationship between productivity and product length

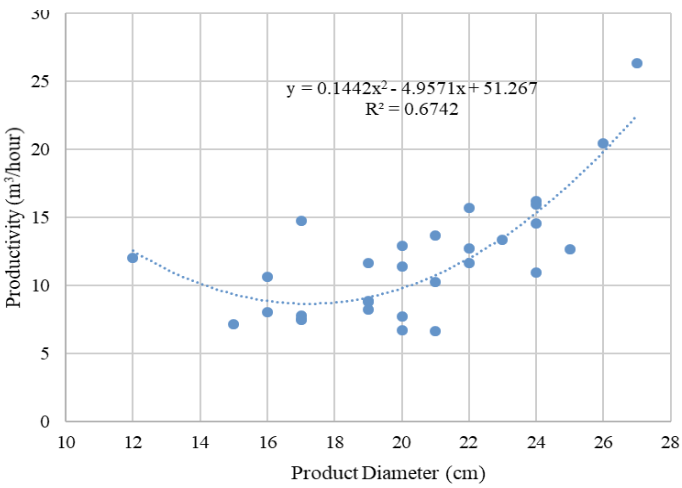

Figure 5. The relationship between productivity and product diameter

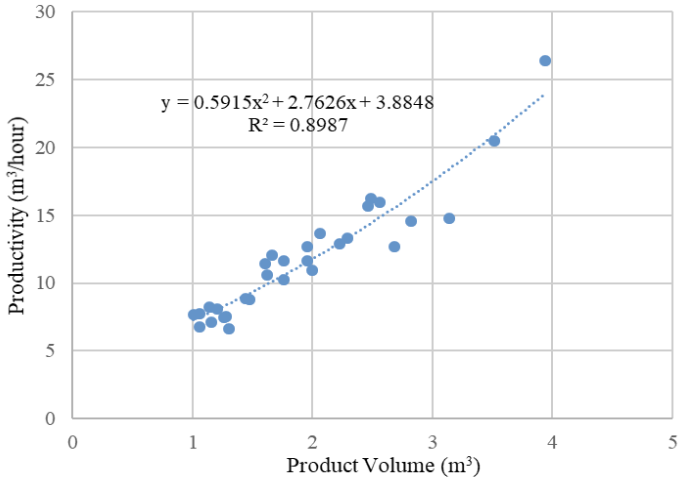

Figure 6. The relationship between productivity and product volume per turn

Spinelli et al. (2015) reported that lateral yarding distance, as well as product sizes and volume, are effective on the productivity of the cable yarder. Although this present study did not reveal a statistically significant relationship between lateral yarding distance and productivity, it was revealed that productivity decreased as the lateral yarding distance increased (Figure 7).

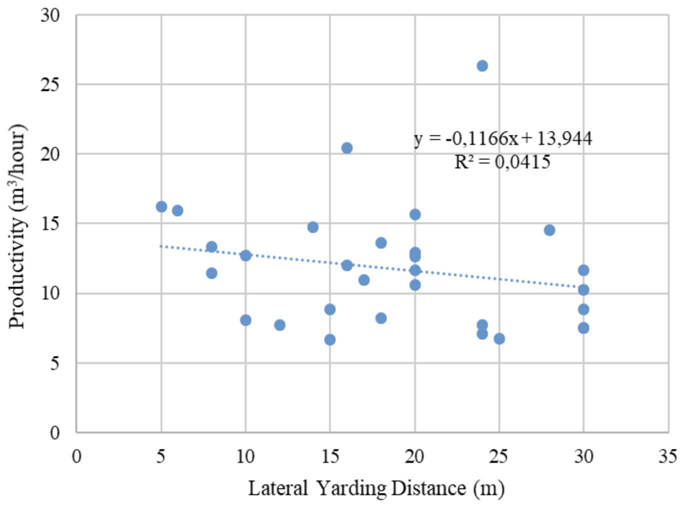

Figure 7. The relationship between productivity and lateral yarding distance

According to the correlation test results, Linear Regression Analysis was used to reveal the relationship between the productivity of cable yarder and the independent variables (product length, product diameter, total volume) that had a significant relationship with productivity. According to the One-Way ANOVA results, the regression model regarding the productivity of the cable yarder and the independent variables was found to be significant ($p<0.001$) at the 99% confidence level (Table 6). The obtained R^2 value (0.906) showed that the regression model explained the productivity at a high level.

Table 6. One-Way Variance Analysis results of the cable yarder for productivity

Model	Sum of	df	Mean	F	Sig.
Regression	504.39	3	168.13	83.090	0.000[b]
Residual	52.61	26	2.023		
Total	557.00	29			

a. Independent variables: Product length, product diameter, total
b. Dependent variable: Productivity

The regression model, which includes the dependent variable (y) representing the productivity of the cable yarder and the independent variables ($x1$ = product length; $x2$ = product diameter; $x3$ = total volume), is shown in the equation below:

$$y = -0,568 + (0,212)x1 + (0,025)x2 + (4,842)x3 \quad (1)$$

4. Conclusion

In Turkiye, the mid-size cable yarding method has been preferred, especially in the mountainous regions where intensive forestry is performed. In order to benefit from the opportunities offered by the mid-size cable yarders, the timber extraction method must be well planned considering hourly productivity of the yarder. The productivity of the mechanized logging equipment is determined based on the working time which is usually measured using the time study technique. Since timber extraction using cable yarders takes place in steep and rough terrain conditions, applying the time study analysis at the work site is difficult. In this study, high resolution digital video images of a mid-size cable yarder (Tajfun MOZ 500 GR) taken with a UAV were evaluated in productivity calculations based on time study data measurements obtained from these video images.

The results indicated that the productivity analysis of a cable yarder can be performed effectively by using high-resolution digital videos captured with a UAV. Statistical analysis also revealed that working time results and productivity estimations were compatible with the results obtained by the previous studies on cable yarding operations conducted by using traditional time study techniques. Important drawback of using UAVs is limited flight time due to short battery life, however, UAVs can be attached by a ground power station since the UAV does not have to move and it can hover in the same position while capturing digital video images. In the future studies with a sufficient budget for ground power stations and particular UAVs, UAVs can fly and capture video images during the whole operation using ground power stations. Besides, providing vide view angle at specific flight altitude, UAVs can be used to obtain digital video images of multiple forestry equipment working at the field simultaneously. Then, the working time and productivity of each equipment can be evaluated separately by using the same video images in the office.

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