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Cost Analysis of Skyline-assisted Felling Technique in Private Forests in Probolinggo, Indonesia

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ABSTRACT

Tree felling is an important component of the forest harvesting system. A skyline-assisted felling technique (locally known as the '*sandat'* felling technique) is used in private forest harvesting in Probolinggo, East Java, Indonesia, as an alternative to the conventional felling technique. This felling technique is used in private forests planted with an agroforestry pattern. Private forest farmers have recognized the technique as an effective way to protect multi-purpose tree species, especially coffee plants, but the technique's efficiency is not yet known. The study analyzed the costs and productivity of *sandat* felling techniques in private forests planted with agroforestry patterns in Probolinggo. Working time studies, branch-free height, and breast height diameter measurements were carried out to calculate felling costs and productivity. The present value cost function was developed to compare the costs of *sandat* felling techniques with conventional felling techniques. The study showed that the productivity of *sandat* felling techniques was lower than conventional felling techniques. In contrast, the operating costs of *sandat* felling techniques were higher than those of conventional felling techniques. The operating cost per m^3 rose by 20%. Additional operating costs for *sandat* felling techniques were incurred for procuring ropes and installing and uninstalling skyline. The felling costs will decrease with the felling team's increasing experience and skill.

1. Introduction

Log production in Indonesia comes from natural production forests, industrial plantation forests, and private forests. Natural production forests, originally the main supplier of logs in Indonesia, have declined in their potential and production. Meanwhile, the contribution of private forests as producers of logs shows rapid development (Kusuma et al. 2020; Purwawangsa et al. 2021). According to Susanti and Sarwoko (2023), the supply of logs in Indonesia is currently dominated by logs originating from industrial plantation forests (78%), while logs originating from private forests are 15%, and natural forests are 7%. Private forests are forests established on private-owned land. This forest has production, social, economic, and ecological functions. Private forests play an important role in Indonesia's forestry development and the economy of rural communities (Achmad et al. 2015; Sanudin and Fauziyah 2015) as a source of food and income for forest farmers (Apriyanto et al. 2016; Lestari et al. 2018), and conserve soil and water resource (Murtiono et al. 2019; Widarti 2015), as well as biodiversity (Oktaviyani et al. 2017). There are three typologies of private forests in Indonesia: monoculture forests, mixed forests, and agroforestry (Aminah et al. 2013; Arinah et al. 2021; Diniyati and Achmad 2015).

Factors considered in selecting tree felling techniques are terrain, tree density, tree species, tree condition, stand composition, and tree volume (Conway 1982; Staaf and Wiksten 1984). Stand composition can be a major consideration in determining tree felling techniques in private forests planted using an agroforestry pattern (Budiaman et al. 2024a). It is because non-forestry plants, such as crops, plantation crops, and multi-purpose tree species (MPTS), contributed greater economic value than forestry plants and became a high economic contribution to the income of private forest farmers (Asmi et al. 2013; Maharani et al. 2022; Natalia et al. 2014; Tiurmasari et al. 2016). The plantation crops gave the greatest economic contribution to private forests planted with agroforestry patterns in Indonesia (Pammu et al. 2020), followed by MPTS plants (Diniyati and Achmad 2015; Idris et al. 2019; Larasati et al. 2019) and crops (Lestari et al. 2018).

In general, tree felling in private forests uses a need-cutting system. Forest farmers will cut down their forests if they require funds for emergency needs (Hamdani et al. 2015; Nugroho et al. 2017). Ttree-felling techniques used in private forests in Indonesia are conventional felling technique (Budiaman and Hardjanto 2023), rope-assisted conventional felling technique (Sukadaryati et al. 2018), and *sandat* felling technique (Budiaman et al. 2024b). The traditional technique of felling relies only on making felling notches. The rope-assisted conventional felling technique is carried out by making a felling notch, and the tree is pulled to the ground by a rope. The traditional felling technique uses the rope if the desired felling direction is different or opposite to the natural felling direction. Meanwhile, the *sandat* felling technique is carried out by making a notch, and the tree is pulled with a rope towards a skyline (a stretch of rope stretched between two spar trees at 10 m above the ground). In this tree-felling technique, the tree being cut does not fall directly to the ground but hangs on the skyline. Lowering the felled tree to the ground is done by slowly reducing the stretched rope. The popular tree-felling technique in private forests in Indonesia is the conventional felling technique (Budiaman and Hardjanto 2023; Sukadaryati et al. 2018).

The basic principle of the *sandat* felling technique is to hold the felled tree not directly touching the ground but attached to a skyline in a hang-up position so that the felled tree does not crush the residual plants around the felled tree. Then, the felled trees that are hung up are debranched. Debranching starts from the base towards the top of the tree. After debranching, the felled tree is bucked. A single tree management is applied in this felling technique. The next tree will be felled when the bucking of the first felled tree has been completed. *Sandat* felling technique is applied using a manual system. Felling, debranching, and bucking the felled tree is done with a chainsaw. The logs are then extracted to the landing point using human power or motorbikes, depending on the length of the skidding distance and topography (Budiaman et al. 2024c). Manual forest harvesting is suitable for the conditions of private forests, most of which are located in rural and remote areas, with small and scattered harvest areas and limited investment capacity (Hardjanto 2017).

Cost analysis of *sandat* felling techniques is needed to estimate the production, equipment, and labor costs required to operate *sandat* felling techniques in private forests and develop an efficient operational plan for *sandat* felling techniques. To date, there has been no study that comprehensively calculates the operational cost of felling in private forests. Therefore, the study aimed to estimate the operating costs and productivity of *sandat* felling techniques in private forests planted using agroforestry patterns.

2. Materials and Methods

2.1. Study Site and Time

The study was conducted from January to March 2023 in a private forest planted with an agroforestry pattern owned by forest farmers in Roto Village, Krucil District, Probolinggo Regency, East Java. The study site is located at a coordinate of 7° 53' 27" S and 113° 36' 41" E. The private forest farmers are members of the Alas Mandiri Probolinggo Private Forest Cooperative, which partners with PT Kutai Timber Indonesia. Forest topography varies from flat to undulating. The study area is at an altitude of approximately 600 masl. The study area is 0.59 ha, and the silviculture system used is a selective cutting system, followed by replanting.

2.2. Sandat Felling Technique

The tree-felling technique used at the study site was a tree-felling technique with the assistance of a skyline. This technique is locally known as the '*sandat*' felling technique, a safety rope technique. The stages of *sandat* felling techniques include installing skyline, tree felling operation, and uninstalling skyline. In this felling technique, the rope is used to pull the fallen tree and support it so that it does not fall directly to the ground but hangs up in the stretched rope. The rope is installed between two supporting trees approximately 10 m from the ground surface (or at the height of the first branch). One end of the rope is tied tightly to one of the trees, while the other is tied loosely to another. Loosely tying the rope is intended to help the felled tree slowly lower to the ground. The length of the skyline varied from 5–12 m (**Fig. 1**).

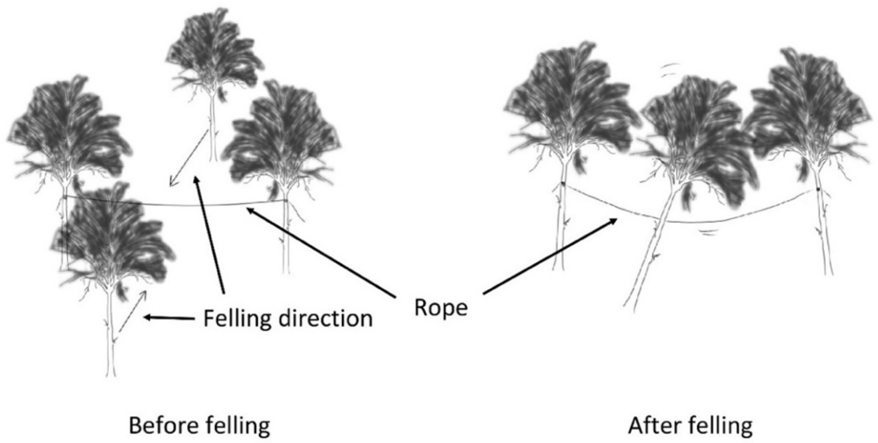

Fig. 1. Rope installations in *sandat* felling techniques at the study site.

All trees that will be cut are directed to fall into the stretched rope. Before making the felling notch, a first worker climbs the felled tree to install the rope at a height on the first branch. Afterward, two workers held the rope, and the chainsaw operator began to make a felling notch. The felled trees were lowered to touch the ground by slowly loosening the stretched rope. The rope used has a diameter of 4.76 cm and a length of 20 m for the tree-pulling rope and 40 m for constructing the skyline (**Fig. 2**).

2.3. Data Collections

Data collected in the field included the diameter and height of the free branches of the felled tree, the working time, and data related to the cost of *sandat* felling techniques. The number of settings in this study was 4 settings. Settings generally refer to the area where felled trees are extracted to a landing. The tree species to be cut was sengon, 5 years old. The number of sample trees was 31, determined by the farmer who owns the forest. The trees to be felled were marked by the forest owner together with the wood buyer. Before felling, the diameter at breast height and the height of the first branch of the tree were measured.

Fig. 2. Type of rope used in *sandat* felling technique at the study site.

2.4. Working Time and Productivity

The working time of *sandat* felling techniques is determined by time-motion studies (Björheden and Thompson 1995; Szewczyk and Sowa 2017). The working time used is the working time at the workplace (WP). Working time at the workplace consists of time for work and not for work. Time not to work includes eating, drinking, resting, smoking, and other worker needs. Meanwhile, time for work consists of productive time and supporting time (Björheden and Thompson 1995). Working time measurements are carried out based on analysis of video images taken during felling operations in the field. Each work cycle is measured and recorded using the stopwatch installed on the camera. The stages of *sandat* felling techniques observed included installing and uninstalling skyline and tree felling operations. The diameter and free-branch height of the felled tree are used to calculate felling production. Furthermore, the productivity of *sandat* felling techniques is calculated based on working time (hour) and the volume of felled trees (m^3) (Abbasi et al. 2013; Silayo and Migunga 2014).

The number of work cycles observed is determined based on Sutalaksana (2006). If $N' \leq N$, the number of work cycles is sufficient for working time analysis. N' is the minimum number of work cycle measurements required. N is the number of measurements used in the preliminary study. The number of work cycles in the initial research was 31. Using an α of 10%, the number of work cycles required was 26. Thus, the number of work cycles of the preliminary study can be used for working time analysis.

2.5. Cost Analysis

The cost per equipment unit is calculated using the calculation method developed by FAO (1992). The cost of *sandat* felling techniques is calculated by summarizing machine and labor costs. Machine costs are based on fixed costs (including depreciation and interest on capital) and variable costs (costs for repair and maintenance, fuel, lubricants, and labor wages). Total fixed costs are the sum of interest, insurance, taxes, and depreciation.

Meanwhile, labor costs in this study are labor wages. Chainsaw maintenance and repair costs are determined at 100% of the machine’s depreciation costs. Fuel and oil input were determined by refilling the entire engine tank at the end of each work day and recording the fuel and oil used that day. This number is divided by the stopwatch hour and prorated to each setting based on the hour required to fell the trees. The equipment used in this study was a chainsaw and a rope made from hemp. Tree felling was carried out by an experienced felling operator using a chainsaw manufactured in China, Maestro Plus (**Table 1**). Basic data for calculating the costs of the *sandat* felling technique are presented in **Table 2**.

Table 1. Specifications of chainsaws used in felling activities at the study site

Specification	Description
Brand	Maestro Plus, 6500L
Engine (engine power)	2 strokes (2.2 kW)
Cylinder content	52 cc
Chain	Oregon 73LPX 0.325 × 0.050 38T
Bar length	22 inches (52 cm)
Oil tank capacity	0.26 L
Fuel tank capacity	0.52 L
Fuel	Gasoline mixed with 2-stroke oil
Weight	10 kg
Manufacturer	China

Table 2. Basic calculation of costs for *sandat* felling technique at the study site

Description	Unit	Value
Purchase price of rope (length= 60 m)	IDR	600,000
Life span of rope	Years	1
Purchase price of chainsaw	IDR	2,100,000
Salvage value of chainsaw	IDR	800,000
Life span of chainsaw	Years	2
Purchase price of the bar	IDR	300,000
Life span of bar	Months	6
Purchase price of chain	IDR	200,000
Life span of chain	Months	2
Purchase price of fuel	IDR/liter	12,000
Fuel consumption	Liter/day	7
Purchase price of lubricant	IDR/liter	35,000
Lubricant consumption	Liter /day	1
Bank interest	%	6.7
Wages for chainsaw operators	IDR/day	70,000
Wages for helpers	IDR/day	60,000
Working hours per year	hours	990

Note: IDR= Indonesia Rupiah.

2.6. Data Analysis

The data was analyzed descriptively. Descriptive data analysis is an analysis method that provides an overview or general description of study subjects based on variable data obtained from certain subject groups (Hastono 2006). The data of this study are presented in the form of tables, histograms, average values and percentages. Working time data is grouped based on work elements and working time structure. Data on operational costs of *sandat* felling techniques are grouped based on the type of costs and stages of *sandat* felling techniques. Considering the limited scientific publications related to the analysis of felling costs in private forests, a present value function was developed to analyze and compare the costs of *sandat* felling techniques with conventional felling techniques carried out in different years.

3. Results and Discussion

3.1. Results

The study showed that the average workplace time (WP) of *sandat* felling techniques was 1.12 hours/setting, which consists of 0.16 hours (14.06%) non-work time (NT), 0.76 hours (68.23%) productive work time (PW), and 0.20 hours (17.70%) supporting work time (SW), as shown in **Table 3**. The study showed that the *sandat* felling technique requires preparation, especially for installing and uninstalling the skyline. The working time of skyline installations and felling operations was 33.34% and 66.66%, respectively. Skyline installation required an average time of 22.42 minutes/setting, consisting of 13.45 minutes for skyline installation and 9.97 minutes for skyline uninstallation. The average time of skyline installation was longer than the uninstalling time. The longest working time for skyline installation was the rope lengthening (37.16%); meanwhile, the rope-releasing element had the longest for skyline uninstalling (32.04%). The tree felling operation took an average of 44.62 minutes/setting. As much as 31.71% of tree felling activities were used for making felling notches until the tree fell to the ground.

Table 3. Working time structure of the *sandat* felling technique in a private forest in Probolinggo, East Java, Indonesia

Setting	Number of trees	Working time (hours)			
		NT	PW	SW	WP
1	8	0.16	0.74	0.20	1.11
2	7	0.14	0.68	0.18	1.00
3	8	0.17	0.76	0.21	1.14
4	8	0.16	0.86	0.20	1.22
Average		0.16	0.76	0.20	1.12
Standard deviation		0.01	0.07	0.01	0.09

Notes: NT = non-work time; PW = productive work time; SW = supporting work time; WP = workplace time.

The average diameter of felled trees was 23.4 cm. The average total and commercial heights were 19.9 m and 9.23 m, respectively. The volume of felled trees ranged from 0.14 to 0.41 m^3/tree, with an average of 0.29 m^3/tree. The production volume of *sandat* operation ranged between 0.99 and 3.25 m^3, with an average of 2.30 m^3. The productivity of the *sandat* felling technique ranged from 0.99 to 2.66 m^3/hour, with an average of 2.02 m^3/hour (**Table 4**).

Table 4. Productivity of the *sandat* felling technique in private forest in the study site

Setting	Number of trees	Volume/tree (m^3)	Total volume (m^3)	Work time (hours)	Productivity (m^3/hour)
1	8	0.26	2.09	1.11	1.88
2	7	0.14	0.99	1.00	0.99
3	8	0.36	2.88	1.14	2.53
4	8	0.40	3.25	1.22	2.66
Average	7.75	0.29	2.30	1.12	2.02
Stdev	0.50	0.12	1.00	0.09	0.76

Note: Stdev = standard deviation.

The operating cost for the equipment used in the *sandat* felling technique was IDR 19,319.94/hour, which consists of fixed costs of IDR 1,198.73/hour and operating costs of IDR 18,121.21/hour. The expenses were IDR 18,660.2/hour for the chainsaw and IDR 659.78/hour for the rope (**Table 5**).

Table 5. Total equipment cost of *sandat* felling technique at the study site (IDR/hour)

Type of Cost	Chainsaw	Rope
Fixed Costs	538.95	659.78
• Depreciation	404.04	606.06
• Capital interest	103.09	36.36
• Tax	12.73	7.27
• Insurance	19.09	10.09
Variable costs	18,121.21	0
• Fuel	14,000.00	0
• Lubricant	2,000.00	0
• Maintenance and repair	404.04	0
• Bar	606.06	0
• Chain	1,111.11	0
Total cost	**18,660.2**	**659.78**

The operational cost of *sandat* felling techniques was IDR. 40,419.40/m^3, which consists of IDR 30,528.45/m^3 (78.3%) for labor costs and IDR 9,890.95/m^3 (21.7%) for equipment costs (**Table 6**). Of the total labor costs, 81% were labor costs, and 19% were costs of chainsaw operators. The cost of the tree felling operation was smaller than the skyline installation. The cost of tree-felling operations was IDR 19,964.17/m^3, while the cost of skyline installation was IDR 20,455.23/m^3.

Table 6. Operating costs of *sandat* felling techniques at the study site

Steps of *sandat* felling technique	Cost component	Costs (IDR/hour)	Productivity (m^3/hour)	Cost per unit (IDR/m^3)
Skyline installation	Labor	20,000.00	2.02	9,900.99
	Rope	659.78	2.02	326.62
	Total			10,227.61
Felling operation	Labor	10,000.00	2.02	4,950.49
	Operator	11,666.67	2.02	5,775.98
	Chainsaw	18,660.16	2.02	9,237.70
	Total			19,964.17
Skyline uninstallation	Labor	20,000.00	2.02	9,900.99
	Rope	659.78	2.02	326.62
	Total			10,227.61
Total costs				**40,419.40**

3.2. Discussions

Regarding productivity and operation costs, the *sandat* felling technique was no more efficient than the rope-assisted felling technique. The study showed that the productivity of *sandat* felling techniques in private forests in Probolinggo was 2.02 m^3/hour. The productivity of the *sandat* felling technique was two times smaller than the conventional felling technique. Sukadaryati et al. (2018) reported that the productivity of conventional felling techniques in private forests in Ciamis varied from 3.39–4.48 m^3/hour. The *sandat* felling technique required additional time to install and uninstall the skyline, whereas the conventional felling technique does not have both working elements. The analysis of working time revealed that working time for installing and uninstalling skyline *sandat* contributed one-third of the total working time. The study showed that the productivity of felling was not only influenced by several factors that have been assumed to determine the level of felling productivity, such as forest location, the slope, condition of felled trees, tree species, and volume of trees harvested (Abbasi et al. 2013; Nikooy et al. 2013; Yuniawati and Tampubolon 2021), but was also influenced by the work methods used.

The cost of *sandat* felling techniques in Probolinggo was two times greater than conventional felling techniques. The study showed that the cost of *sandat* felling techniques was IDR 40,419.40/m^3 for the productivity of 2.02 m^3/hour or IDR 20,009.6/hour. The previous research in Ciamis showed that the cost of felling private forests using conventional felling techniques varied from IDR 27,049/m^3–38,915/m^3 for productivity of 3.39 – 4.48 m^3/ hour (Sukadaryati et al. 2018). If it is assumed that the interest rate used is 6.7% per year, then the present value of the cost of conventional felling private forests in Ciamis varies from IDR 36,787/m^3–52,924/m^3 (IDR 10,851.62/hour–11,813.39/hour). The causes of higher costs in *sandat* felling techniques are related to the additional work elements and materials used. The *sandat* felling technique required additional costs for ropes and additional working elements such as skyline installation and uninstallation.

The study showed that the largest cost element of *sandat* felling techniques was labor cost, which is 78.3% of the total cost. It indicated that felling operations in private forests in Indonesia were labor-intensive. This work system is considered appropriate to the social conditions of rural communities, where labor is available and cheap, and employment opportunities are limited. Using *sandat* felling techniques can create employment opportunities for communities around the private forest. Achmad et al. (2015) reported that the potential for employment in the agricultural sector, including forestry, in the Ciamis regency is relatively high, namely more than 75%. Concerning labor absorption, several villages in Ciamis Regency allocate labor absorption to manage private forests ranging from 104.77 to 216.93 MWH/ha/year (MWH: equivalent to men's working hours). The study of Fauziyah et al. (2014) showed that the private forest farmers spending time in Wanafarma private forests in several villages in Cilacap district varies from 2.7 to 4.4 working days. Income rate, age, experience, education, and land size influence working time.

The *sandat* felling technique's main asset is the skyline's effectiveness. The private forest farmers in the study site have recognized that installing the skyline is an effective way to protect non-forestry plants during felling operations. Initially, the conventional felling technique was applied in the study area. Still, it caused damage to the MPTS plants, especially the coffee plants that the farmers relied on as a source of income. Due to this condition, felling teams applied the *sandat* felling technique. Budiaman et al. (2024a) studied the effectiveness of the *sandat* felling technique in private forests planted with agroforestry patterns. Felling errors and hang-ups were used as indicators of effectiveness. The study showed that the *sandat* felling technique made all felled trees fall in the skyline, and 81% of the felled trees were hung up on the skyline. These results showed that the *sandat* felling technique can reduce the chance of felled trees directly falling on the residual stands.

4. Conclusions

The study examined only the costs of *sandat* tree felling techniques in private forests planted with an agroforestry pattern in Probolinggo, Indonesia. The felling technique consisted of three stages: installing the skyline, tree felling operation, and uninstalling the skyline. The cost of *sandat* felling techniques was higher than conventional felling techniques. The total cost of *sandat* felling techniques was IDR 40,419.40/m^3. Installing and uninstalling skyline was 51% of the total felling costs, and the remainder (49%) was the cost of tree felling operation. The *sandat* felling technique is an important innovation in private forest harvesting, but its efficiency is still low. Therefore, the operational costs of this technique need to be reduced with several efforts, including increasing the capabilities and skills of the felling team and proper planning. These efforts are expected to increase the productivity of the *sandat* felling technique. Increasing work productivity will reduce operational costs. Besides, this study has not presented the data and information on potential damage to residual stands. Therefore, it is useful to conduct further studies on the impacts of the *sandat* felling technique on residual stands and understorey plants in private forests.

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