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Determining the Appropriate Tool for In-Stand Debarking with Analytical Hierarchy Process

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Abstract

The bark of logs from coniferous trees is mostly debarked in the stand or roadside. At the terminal points, storages, and mills industrial debarking machines have been operated for debarking of timber, as well. In recent time chainsaw mounted debarking apparatus (C-Debarker), axe, and a new tool that is brushcutter mounted debarking apparatus (B-Debarker) have been used for peeling barks in-stand. Debarking process is very time-consuming work phase within the total time for unit of wood procurement. In order to save operation time and to minimize unit costs for the operation, the logging operators have to make a difficult decision on suitable tools for debarking. The purpose of this study is to determine a procedure that helps to select the appropriate tool in-stand debarking of timber logs. In addition to the axe and C-Debarker, traditionally used in debarking, the recently developed peeling tool B-Debarker has been evaluated in terms of various criteria and compared with other methods. In multi-criteria analysis, Analytic Hierarchy Process (AHP) has been used to describe the appropriate tool. The criteria set are based on technically appropriate, economically viable, environmentally friendly, and socially acceptable debarking tool and operation. While the application potential of C-Debarker is high in terms of operational efficiency, the B-Debarker offers high potential in terms of ergonomics. On the other hand, it has been determined that the axe is a preferable tool for ease of use and accessibility.

Keywords: In-stand debarking, Debarkers, Log debarkers, Axe, Brush cutter, Technology selection, AHP

1. Introduction

In the wood supply chain, the harvesting of wood consists of operations that involve long periods of time and often require labor-intensive work. In particular, the debarking of the industrial logs obtained from coniferous trees in the stand causes both the prolongation of the production period and the increase in costs. These works, which are based on manual or motor-manual technology in Türkiye, bring dangers and risks in terms of work safety and health. Due to ecological and biological requirements and some technical reasons, it is necessary to facilitate the debarking process in-stand in terms of economic, ergonomics, and working comfort of the employee. In the last few decades, debarking (head) apparatus that can be mounted on the chainsaw (log debarker) has been used (Eker, 2004) and manual techniques, such as axe and spud, have been switched to motor-manual techniques (Eker and Özer, 2015). These debarking heads are also mounted on the motorized brushcutter, thus a new type of debarking technology has been developed (Piegai, 1996; Şefik, 2019). The change in debarking technologies has brought with it the difficulty of choosing the appropriate tool for debarking operators.

In Turkish forestry, mostly in the harvest of coniferous trees, cut-to-length harvesting method has been applied in site conditions. Although it depends on the sales method and the demands of the customers, in this method, the bark of the tree logs is mostly debarked in the stand using various techniques and tools. The interconnected sequential structure of the cut-to-length method and the delaying due to different requirements cause the harvesting process to spread over a long period of time (1-2 months). The low daily work efficiency also causes an increase in the unit price of the round wood obtained. Each work step in the harvesting process needs to be improved in terms of reducing the total supply chain costs. It can be said that the most critical step of the entire work (because it has the highest portion in standard working unit time) is the debarking stage (Gürtan, 1969; Eker, 2004; Eker et al., 2011). One of the most important problems encountered during the improvement of the peeling process is to decide what is the most appropriate debarking tool.

Debarking can be defined as the process of separating and removing bark from the wood surface using various tools (Gürtan, 1969; Chahal et al., 2021). Debarking can be done at the stump site in stand, on the forest or tertiary road side in stand, on the landing, at the terminal points in the forest, in the warehouse or factories (Erdaş et al. 2014). Debarking has many advantages, such as increasing wood quality and quantity, reducing log

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weight, minimizing the coefficient of friction on the ground, and facilitating transport along skidding and hauling distances. Also, it prevents insects damage and protects forest health, reduces the fumigation cost for the phytosanitary standard of wood and fertilizer costs by leaving bark residual in the stand, improves solid wood volume storage, reduces storage defects and destruction of bark debris by way of facilitating wood manipulation. (Grammel, 1988; Baroth, 2005; Yan et al., 2017; Heppelmann et al., 2019; Murphy, 2020). Debarking is more than a step in the processing of roundwood to an industrial log, and the bark itself is a highly valued and a necessary biological material for source of soil nutrient (Nemestothy and Grabner, 2021).

Debarking is operated with various methods and techniques such that: (1) Manuel methods with hand tools (axe, debarking spade, debarking knife, and debarking spud), (2) Mechanical methods with debarking machines, (3) Chemical matters, and (4) Water pressure and friction techniques. Additionally, motor-manual tools has been developed to increase work efficiency in in-stand debarking. A chainsaw mounted log debarker (called as C-Debarker in the study) has been used in debarking of coniferous trees (Eker, 2004, Eker et al., 2011; Gülci, 2017). Some modified small-scale technology is also developed such as pneumatic debarking spade with manual orientated used in peeling of broad-leaved tree species (Enez and Nalbantoğlu, 2019). In addition, log debarkers obtained by mounting the debarking apparatus to the chainsaw and brushcutter are also used (Eker and Şefik, 2019; Öztürk, 2022).

The place, date, and technology of debarking depends on many variables, such as the time of cutting trees (wood-bark adhesion), local technology potential, operation costs, length of the working period, and amount of work. Choosing an effective debarking technology in terms of many criteria is an important problem for the roundwood harvesting operations. Due to the low growing capacity of forest soil, the need to leave the nutrient elements within the bark in the stand causes the bark of the logs to be debarked in the stand. However, annual wood production is approximately 30 million cubic meters in Türkiye, % 25 of which is only supplied by brutian pine (*Pinus brutia* Ten.) trees with cut-to-length harvesting method and in-stand debarking operations. This ratio means that at least 10 million timber logs of brutian pine are handled and debarked by a few debarking techniques at the stump site (in-stand) every year. Therefore, in-stand debarking is presumably the most considerable activity, and it is a technical necessity, especially for coniferous tree species operated with cut-to-length harvesting, in Türkiye (Eker and Özer, 2015).

Depending on the selected technique, debarking activity time usually covers 50-80 % of the total harvesting time for one unit of timber logs. In terms of time-saving and cost reduction of the harvesting process, the loggers and managers can be faced with the issue of which one is the most appropriate technology for in-stand debarking of the logs. The study focused on the determination of appropriate tool for the debarking of felled trees to ensure the future compatibility of the harvesting process in supporting sustainable development. Limited research has been conducted on effective decision-making for the appropriate debarking tools and there is a need for additional work to further improve the efficiency of debarking activity. The hypothesis of the study is based on the multi-criteria analysis of in-stand debarking for the cut-to-length harvesting method. It may suggest that overall supply chain efficiency can be provided by selecting an appropriate debarking tool.

The study intends to specify useful and systematic assessment method for selecting appropriate log debarking tools considering technical, economic, social, and environmental aspects. In this study, chainsaw-mounted log debarker (C-Debarker), brushcutter mounted log debarker (B-Debarker), and axe were compared. The study aims to use a criteria and indicators set for appropriate analysis of debarking technology for pine logs at the stump site, and then to compare and assess three debarking tools primarily along the criteria and indicators, and to highlight important parts of multi criteria decision-making (MCDM) process with Analytic Hierarchy Process (AHP) (Saaty, 1980) when selecting debarking methods and equipment.

2. Material and Methods

2.1. Study Area

Three tools were used in the debarking work step, which is a component of the wood harvesting process and forms the object of this study. The study focused on comparing the three debarking tools in terms of quantitative and qualitative characteristics and describing the most suitable one subject to many criteria and indicators, especially for debarking coniferous (*Pinus brutia* Ten.) logs in the stand. The peeled material was the logs that had just been cut, felled, and divided into lengths (cross-cut into sections) within the working day during the normal production process. However, thick-barked butt logs obtained from the bottom of the stem and very thin-barked logs obtained from the top of stem were not included in comparing the peeling tools. Differences in characteristics such as operator competences, power source (chainsaws of different power, axes of different sizes), stand characteristics, and tree characteristics were ignored to compare similar conditions.

The data and information for the study were based on the technical properties of debarking tools, working techniques and conditions, terms of use, productivity values, costs, and advantage-disadvantage of the debarking techniques. Data required for the comparison of debarking technique was obtained from field surveys (generally in forest land of Isparta Regional Directorate), indirect observations, previous studies, literature, guidebooks, application reports, and unstructured interviews done with forest workers at different times.

The study methodology followed using this material, respectively: 1) Debarking operations were observed and examined, and criteria and indicators sets were derived on the scale of assessments. 2) Three peeling tools were evaluated by taking these criteria and indicators into account with direct and indirect observations. Then a database was created in which their advantages and disadvantages were listed. 3) Afterwards, the criteria and indicators were prioritized by applying the ranking and AHP method (Saaty, 1980). 4) Then, the 3 tools were compared with each other and evaluated through their weighted importance scores. All tabulation, ranking, and AHP analysis were successfully achieved on MS Excel spreadsheets.

Tools of the debarking techniques were C-Debarker (Figure 1), bruchcutter mounted log debarker (B-Debarker) (Figure 2), and traditional Turkish axe (Figure 3). In terms of system components, all three tools were used by one operator. The debarking head that could be mounted on both the chainsaw and the brushcutter had been produced by Baseh. It was mounted directly on the body of the chainsaw with the belt system and thus gained power. It is an attachment that weighs 2.9 kg, requires at least 1.2 kW (1.61 hp) engine power, and has 4 double-sided steel blades, each with a 3 cm blade width (Figure 4) (Baseh, 2022; Eker and Şefik, 2019).


Figure 1. Chainsaw mounted log debarker (C-Debarker)


Figure 2. Brushcutter mounted log debarker (B-Debarker)

The chainsaws, where the debarking apparatus has been mounted and operated, can be of various brands and models. Husqvarna 268, the most common brand model in field studies, has a 66.7 cc cylinder volume, 4.4 hp engine power, and 6.2 kg weight for C-Debarker (Figure 1). B-Debarker, used in this research to collect data, was developed by Şefik (2019) in the Transport and Geomatics laboratory of Isparta University of Applied Sciences, Faculty of Forestry. The power source of this system was Orac BG 520 brand and model brushcutter. This machine has a displacement of 51.7 cc, an engine power of 1.9 hp and a weight of 8.2 kg (Figure 2). Baseh brand debarking head was also mounted on this brushcutter (Şefik, 2019; Eker and Şefik, 2019). On the other hand, axe, is a tool produced in the local industry, with an average weight of 1.5 kg and a wooden handle length of 80-100 cm.


Figure 3. Axe for log debarking


Figure 4. Debarking head by Baseh

The conceptual framework of the study method was established for technology selection (Eker; 2004). The evaluation of the appropriate technology for debarking was based on the definition that were the most appropriate debarking technique should be; technically possible, economically feasible, environmentally sound (ecologically balanced), institutionally acceptable, societal agreeable, biodiversity respectful, silviculturally acceptable, locally controlled, cost effective, labor intensive, reasonably flexible and reliable as well. These criteria were technical, ecological/environmental, economic, and social criterion, each of which had indicators represented the main criterion (Table 1). In addition to these requirements, sustainable forest management principles were also used in the determination of the criterion and indicator set. These main criteria had the capacity of quantifiable, comparable, and ratable to facilitate decision making process. The methods developed and used by Engür (1996), Eker (2004), Eker and Özer (2015) were used to create indicators that could represent each criterion (Table 1).

To avoid mistakes and fortify the consistency of the decision making process, a multi-stage sequential methodology was developed and applied in multi criteria analysis to choose the appropriate debarking tool. This process is summarized sequentially below. Although AHP (Saaty, 1980; Saaty, 2000; Eker, 2004) was the mainstay of this study, the theory of AHP was not given in this article because the method had a well-known structure.

Table 1. Criteria and indicators for decision matrices

Criteria/C	Economical/C_1	Environmental/C_2	Social/C_3	Technical/C_4
Indicators/*I*	Operational costs (I_1C_1) Fixed costs(I_2C_1) Capital investment(I_3C_1) Productivity(I_4C_1) Profitability(I_5C_1) Energy requirement(I_6C_1)	Soil compaction(I_1C_2) Erosion(I_2C_2) Nutrient losses(I_3C_2) Hydrological cycle(I_4C_2) Water quality(I_5C_2) Waste matter(I_6C_2) Emission and Noise(I_7C_2) Biological diversity(I_8C_2) Forest health(I_9C_2)	Employment capacity(I_1C_3) Opportunities(I_2C_3) Dependency to rules(I_3C_3) Hygiene(I_4C_3) Health and safety(I_5C_3) Training requirement(I_6C_3) Regional development(I_7C_3) Work load (I_8C_3)	Reliability(I_1C_4) Access to resource(I_2C_4) Availability(I_3C_4) Locally controllable(I_4C_4) Reasonably flexible(I_5C_4) Cleanliness(I_6C_4) Work and product quality(I_7C_4) Precision requirement(I_8C_4) Planning requirement(I_9C_4) Dependency to conditions($I_{10}C_4$)

Step 1: Prior to the pairwise comparison of the criterion and indicators in the usual AHP method, a preliminary scoring – prioritization study was carried out. In the first stage, the importance (priorities) of the criteria were scored by 6 experts who worked on debarking technologies using the simple ranking method (Eker, 2004; Roszkowska, 2013) (Table 2). By taking the arithmetic average of the rank values given by the experts, the singular importance of the criteria (reference value given independently from each other) was determined (Table 3). Likewise, for all indicators, the average value of the significance was determined by the expert group according to the individual evaluation. Thus, unique to this study, a reference value vector was created that the researcher can benefit from while making pairwise comparisons of both criteria and indicators in the AHP procedure. These ranking results helped the researcher to make consistent decisions in pairwise comparisons of criteria and indicators. Then, well-known AHP methodology was used in rating, scaling and prioritizing of the indicators and criteria.

Table 2. Scale values and definition to be used for ranking

Definition	Degree	Leveling Scale	
Near unimportant	1	Low	L
Less important	3	Medium to Low	ML
Important	5	Medium	M
Very important	7	Moderate to High	MH
Most important	9	High	H

Table 3. Example of reference values based on singular scoring for criteria set

Criteria	Leveling Scale	Degree	Proportion
Technical	High	9	0.3103
Economic	Moderate to High	8	0.2759
Environmental	Medium	5	0.1724
Social	Moderate to High	7	0.2414

Step 2: The priority value of the main criteria was determined by pairwise comparison method through AHP procedure. For the pairwise comparison matrix, the modified relative appropriateness value (for eigenvector) was generated by converting classic relative importance values (Table 4). To solve the comparison matrices, "the best method" (Saaty, 1980) was used in processes. The result of the Step 1 made it easier for criteria to be compared with each other and rated. Thus, the priority, that is, the importance of each criterion, was determined. This step was repeated for indicator set in each criterion.

Table 4. Converted gradation scale for quantitative comparison of alternatives

Intensity of importance in AHP		Appropriateness grading scale	
Rating	Definition	Definition	Rating
1	Equal	Equally appropriate	1
3	Somewhat more	Somewhat more appropriate	3
5	Much more	Much more appropriate	5
7	Very much more	Very much more appropriate	7
9	Absolutely more	The most appropriate	9
2, 4, 6, 8	Intermediate	Intermediate appropriateness	2, 4, 6, 8

Step 3: Each alternative debarking tool was symbolized by "leveling strategy" with respect to indicators, as in Step 1. The leveling strategy was based on a leveling scale represented by letter from low to high. With the support of the first and second step, a gradation value was appointed to each alternative respect to each indicator. The grading scale consisted of numerical ranking values from 1 (the worst) to 9 (the best) (Table 5).

Table 5. Significance level of the indicators belonging to the economic criterion

Criteria	Indicators	C-Debarker	B-Debarker	Axe
Economic	Operational costs	H	M	M
	Fixed costs	H	L	L
	Capital investment	H	L	LM
	Productivity	H	L	M
	Profitability	M	H	H
	Energy requirement/dependency	H	LM	L

Comparison of each debarking tool with each indicator scale within each criterion was performed based on data and information about these tools. Most of the previous studies were able to provide results that would allow the evaluation of economic indicators and their indicators (Eker, 2004; Eker et al., 2011; Önal, 2012; Eker and Özer, 2015; Gülci et.al., 2017; Şefik, 2019; Çağlar, 2021; Öztürk, 2022). However, in order to compare the tools on the scale of ecological and social criteria and their indicators, it was possible to use field observations for the study, indirect observations (monitoring the debarking operations in the video recordings), literature information, and machine catalogs. The collected quantitative and qualitative data were listed as positive and negative aspects of each tool (Table 6) and were scored relatively first with a single evaluation as in Step 3 and then with a pairwise comparison as in next steps.

Table 6. Example of a qualitative comparison table of two tools based on reliability indicator

Reliability	
B-Debarker	**C-Debarker**
Since the dust, sawdust, chips and shell particles broken off by the blades during peeling are not likely to come into contact with the motor part of the scythe, it is possible for the motor to operate for a longer period of time without contamination and failure. The power transmission belt (by design) is short. There are stretching problems. Since cracking, breaking and melting may occur in the belt, it requires replacement after 40-50 logs are peeled.	Since the peeling equipment is connected to the chainsaw with a short (35-40 cm) arm, dust and particles from the shell penetrate directly into the engine and cause premature wear of the engine, frequent filter cleaning and damage to the operator. The belt on C-Debarker can also wear out over time. The blades in the debarker head require sharpening at regular intervals for both tools. However, because the chainsaw works more powerfully and at a faster speed, the blades may wear out more and faster.

Step 4: A pairwise comparison matrix was created for each indicator. Three alternative tools were compared in pairs with itself and the other tool. To generate pairwise comparison matrix, the modified relative appropriateness value (for eigenvector) was produced by converting classic relative importance values within AHP methodology.

Step 5: The priority vector of each indicator was multiplied by relative appropriateness value and acquired the total weighted eigenvector for each alternative respect to indicators.

Step 6: Step 5 was repeated for each criterion, thus; the weighted eigenvector was obtained for rating alternatives and selection of the best alternative among debarking tools. This was solution of the decision matrix.

The next step was to look for any data inconsistencies. The aim was to capture enough information to determine whether the decision-makers had been consistent in their choices. The consistency of the matrix of order n (number of criteria) was evaluated. Comparisons made by this method were subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If this consistency index fails to reach a required level, then answers to comparisons might be re-examined. The consistency index, CI, was calculated using the methodology of Saaty (2000). At the end of calculation, if the consistency ratio, CR; is less than 0.1, the results are considered consistent. If inconsistent results were obtained, the pairwise comparisons matrix was re-evaluated.

3. Results and Discussion

The priority vector achieved by comparing of technical, economic, environmental, and social criteria for the selection of the best debarking tool, in the scale of pine tree logs, was summarized in Table 7. The technical criterion had the high level priority as the usual manner, as shown in the table. The priorities vector of each indicator was calculated, as well. Table 8 gives all the priority vectors for the indicators in each criterion.

Table 7. Pairwise comparison matrix of the criteria with priority vector

Criteria	**Technical**	**Economic**	**Environmental**	**Social**	**Priorities**
Technical	1.00	2.00	3.00	3.00	0.447
Economic	0.50	1.00	3.00	2.00	0.288
Environmental	0.33	0.33	1.00	1.00	0.127
Social	0.33	0.50	1.00	1.00	0.138
Lmax=4.045	*CI=0.01531*	*CR=0.01547*			

Table 8. Priority vector for the indicators of all criteria

Indicators	Priority	Indicators	Priority	Indicators	Priority	Indicators	Priority
I_1C_1	0.296	I_1C_2	0.155	I_1C_3	0.251	I_1C_4	0.151
I_2C_1	0.155	I_2C_2	0.277	I_2C_3	0.024	I_2C_4	0.214
I_3C_1	0.273	I_3C_2	0.261	I_3C_3	0.023	I_3C_4	0.248
I_4C_1	0.165	I_4C_2	0.029	I_4C_3	0.088	I_4C_4	0.052
I_5C_1	0.067	I_5C_2	0.077	I_5C_3	0.238	I_5C_4	0.074
I_6C_1	0.045	I_6C_2	0.038	I_6C_3	0.058	I_6C_4	0.076
		I_7C_2	0.043	I_7C_3	0.049	I_7C_4	0.102
		I_8C_2	0.051	I_8C_3	0.259	I_8C_4	0.041
		I_9C_2	0.068			I_9C_4	0.021
						$I_{10}C_4$	0.035
Lmax=6.207 *CI=0.041* *CR=0.031*		*Lmax=9.926* *CI=0.116* *CR=0.075*		*Lmax=8.916* *CI=0.131* *CR=0.088*		*Lmax=10.868* *CI=0.096* *CR=0.061*	

The relative value vector (eigenvector) for each alternative debarking tool was computed respect to each indicator. Then, the eigenvector of each indicator was multiplied by priority vector, and the weighted eigenvector was obtained (Table 9, 10, 11. 12).

Table 9. Combined comparison matrix of the alternatives with respect to indicators of economic criterion

Economic Criterion Indicators and Alternatives	Operational Cost	Fixed Cost	Capital Investment	Productivity	Profitability	Energy Requirement	*Total Eigenvector*	*Weighted Total Eigenvector*
C-Debarker	0.096	0.061	0.623	0.649	0.707	0.061	0.366	0.365*
B-Debarker	0.619	0.216	0.138	0.295	0.201	0.216	0.281	0.326
Axe	0.284	0.723	0.239	0.057	0.092	0.723	0.353	0.310
CR	*0.065*	*0.090*	*0.020*	*0.061*	*0.072*	*0.090*	*CR<0.10*	

* Example of the most appropriate debarking technique respect to economic consideration

Table 10. Combined comparison matrix of the alternatives with respect to indicators of environmental criterion

Environmental Criterion Indicators and Alternatives	Soil Compaction	Erosion	Nutrient Losses	Hydrological Cycle	Water Quality	Waste Matter	Emission	Biological Diversity	Forest Health	*Total Eigenvector*	*Weighted Total Eigenvector*
C-Debarker	0.278	0.090	0.343	0.366	0.354	0.068	0.068	0.092	0.083	0.193	0.278
B-Debarker	0.278	0.143	0.575	0.532	0.556	0.146	0.146	0.154	0.193	0.303	0.356
Axe	0.444	0.767	0.082	0.102	0.090	0.786	0.786	0.755	0.724	0.504	0.366*
CR	*0.025*	*0.041*	*0.022*	*0.071*	*0.040*	*0.084*	*0.084*	*0.024*	*0.049*	CR<0.10	

Table 11. Combined comparison matrix of the alternatives with respect to indicators of social criterion

Social Criterion Indicators and Alternatives	Employment Capacity	Opportunities	Dependency to Legislation	Hygiene	Occupational Health and Safety	Training Requirement	Regional Development	Workload	*Total Eigenvector*	*Weighted Total Eigenvector*
C-Debarker	0.214	0.731	0.110	0.057	0.069	0.193	0.633	0.061	0.258	0.154
B-Debarker	0.092	0.158	0.309	0.295	0.777	0.083	0.260	0.723	0.337	0.450*
Axe	0.694	0.111	0.581	0.649	0.155	0.724	0.106	0.216	0.404	0.387
CR	*0.066*	*0.092*	*0.002*	*0.061*	*0.062*	*0.049*	*0.029*	*0.090*	CR<0.10	

Table 12. Combined comparison matrix of the alternatives with respect to indicators of technical criterion

Technical Criterion Indicators and Alternatives	Reliability	Access to Resource	Availability	Locally Controllable	Reasonably Flexible	Cleanliness	Work and Product Quality	Precision Requirement	Planning Requirement	Dependency to Conditions	*Total Eigenvector*	*Weighted Total Eigenvector*
C-Debarker	0.162	0.180	0.155	0.252	0.260	0.122	0.309	0.260	0.193	0.094	0.199	0.193
B-Debarker	0.072	0.071	0.069	0.159	0.106	0.230	0.581	0.633	0.083	0.168	0.217	0.170
Axe	0.766	0.748	0.777	0.589	0.633	0.648	0.110	0.106	0.724	0.738	0.584	0.653*
CR	*0.067*	*0.022*	*0.062*	*0.041*	*0.029*	*0.020*	*0.020*	*0.029*	*0.049*	*0.011*	CR<0.10	

When the relative value vector of each alternative with respect to the main criteria was added, the final priority vector and decision support values could be achieved by a multi-criteria decision making procedure (Table 13). According to Table 13, it was determined that debarking with the axe (manual technology) was the most appropriate technique, as technically feasible, economically viable, environmentally sound, and socially acceptable, for debarking pine logs.

Table 13. Decision matrix and solution respect to multi-criteria by using of AHP

Criteria	Technical	Economic	Environmental	Social	Total Eigenvector	Final Priority
Priorities	0.447	0.288	0.127	0.138		
C-Debarker	0.193	0.365	0.278	0.154	0.247	0.248
B-Debarker	0.170	0.326	0.356	0.450	0.326	0.277
Axe	0.653	0.310	0.366	0.387	0.429	0.481*

Before applying the AHP, the weight of each indicator was determined according to the ranking method by making internal and external comparisons within the entire indicator universe, taking into account the effects of the indicators of all criteria on each other, as in the Analytic Network Process (ANP) procedure (Saaty, 2006). This weight ratio was used as the contribution ratio in pairwise comparisons of indicators. Thus, the indicators of each criterion could be evaluated on the scale of the indicators of other criteria. This approach is very close to that of the ANP method. However, the AHP procedure has been followed in terms of general operation. Usually, in evaluating all indicators among themselves, each indicator is considered to have equal weight. Alternatively, the indicators of each criterion can be weighted within itself. However, it is not possible for the evaluations within the criteria to affect or be affected by the other criteria. The ranking we made at the beginning allows all indicators to be compared against each other. Therefore, a unique assessment method was developed and applied to this study.

In this study, scenario-based weighting was not used for the criteria (Eker and Özer, 2015). However, considering only the economics of forestry operations, C-Debarker seems to be the most suitable debarking tool along with other criteria and indicators. Especially in terms of efficiency, C-Debarler has 3-5 times superiority over the axe (Eker and Acar, 2004; Gülci et al., 2017). On the other hand, B-Debarker's advantages include ergonomic principles such as work hygiene, workload, repetitive movements, and occupational health and safety (Şefik, 2019; Öztürk, 2022) can dictate the preference of B-Debarker from a social perspective.

The high priority value of the technical criterion and the high score of the axe on the technical indicators scale (eigenvector) characterized the axe as the most appropriate peeling tool according to the total weighted average. The advantages of the axe such as being only dependent on human resources energy, easy supply, use as desired, easy maintenance, low environmental waste and emission value (life cycle impact) (Önal, 2012; Eker and Çoban, 2019), are among the ergonomic and efficiency indicators. has prevailed.

4. Conclusions

Debarking operations within the cut-to-length harvesting process take a long operation time for wood. The unit cost per cubic meter calculation is based on standard working time and unit expenditure. Currently, the salary or the cost of debarking is not easily separated from the cutting process. Therefore, optimizing the debarking treatment with the use of right or best debarking tool is possible.

Results showed that in-stand debarking with the axe was the most appropriate tool for multi-criteria decision process. Although forestry operations in developed and developing countries evolve towards heavy mechanization (advanced technology), the emergence of the body-powered axe as a solution in this study depends on fuel prices, increasing labor abundance, purchasing costs of machinery, emissions, employment capacity and other reasons.

These results originated from general information of each alternative, but not site-specific or stand level. If the comparison between these alternative tools was performed with stand-level and state-based, it was possible to reach more concrete results. However, in the decision process of which debarking technique is more suitable, the recommendation can be taken into consideration below:

- If there is an inadequate labor force, intensive work, need for time, thin-barked trees, and an abundance of chainsaw, then C-Debarker can be suitable for the situation. Besides, B-Debarker can be operated in this condition with similar productivity. Furthermore, if any problem with payment or cost calculation processing accounted for, both C-Debarker (for thin-barked logs) and axe (for thick-barked logs) can be used together.
- If the harvesting time is in the spring and/or within the vegetation period, thinning or tending operations are to be performed, and there are thin barked logs, the axe can be available for the time savings and cost reduction, and product quality as well.
- Additionally, in the future works, ergonomic studies should be carried out on these tools on issues such as emissions, dust exposure, and motion analysis.

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