Identifying the Factors Influencing the Cost of Mechanized Harvesting Equipment

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ABSTRACT: Developing an economical harvest plan requires a correct decision in choosing between alternative harvesting systems. In order to determine the least cost alternative, the variable factors influencing the cost of individual harvesting machines should be carefully determined. Modern mechanized harvesting systems have been developed and applied widely in North America and Europe, largely as an economic response to increased labor costs, rising demands for timber, and changes in timber management. These systems are not very common in current forest operations in Turkey because they are very expensive and highly correlated with the price of the fuel. They are also not favorable due to reduction in labor. However, mechanized harvesting systems would be more favorable if labor costs increase relative to fuel costs. In this study, variable factors influencing the cost of harvesting machines are identified and their mathematical formulations are presented. Besides, the unit costs of specific harvesting machines are computed.
Key Words: Mechanized forest harvesting, Harvesting equipment, Cost analysis

Makineli Üretimde Kullanılan Ekipmanların Maliyetini Etkileyen Faktörlerin Tanımlanması

ÖZET: Ekonomik bir orman istihsal planı geliştirmek alternatif istihsal sistemleri arasında doğru bir seçim yapmayı gerektirir. En düşük maliyetli alternatifi tespit etmek için, makineli üretimde kullanılan herbir ekipmanın maliyetini etkileyen değişken faktörler dikkatle tespit edilmelidir. Modern makineli orman istihsal sistemleri, pahalı işgücüne karşı ekonomik bir reaksiyon olarak, yükselen tomruk talebi ve tomruk üretimindeki değişikliklere bağlı olarak Kuzey Amerika ve Avrupa'da geliştirilmekte ve yaygın olarak kullanılmaktadır. Bu sistemler çok pahalı olmaları ve petrol fiyatları ile yüksek korelasyon göstermeleri nedeniyle Türkiye'de güncel orman operasyonları arasında çok yaygın değildir. Aynı zamanda, istihdamı azaltmaları nedeniyle de tercih edilmezler. Ancak, işgücü maliyetinin petrol fiyatlarına oranla yükselmesi halinde, mekanik istihsal sistemleri daha çok tercih edilebilir. Bu çalışmada, istihsal araçlarının maliyetini etkileyen faktörler tanımlanarak bu faktörlerin matematik ifadeleri sunulmuştur. Ayrıca, spesifik istihsal araçlarının birim maliyetleri hesaplanmıştır.
Anahtar Kelimeler: Mekanik orman istihsali, İstihsal araçları, Maliyet analizi

INTRODUCTION

There has been increasing interest in ground-based mechanized harvesting systems in North America and Europe due to some capabilities of the mechanized harvesting operations: (1) leaving the limbs and tops in the stand as an organic material, (2) conducting partial cutting, (3) working on smaller landings, and (4) labor efficiency. In Turkey, the application of mechanized harvesting is currently low (Erdas, 1987). The estimated rates of using manpower, animals, mechanized equipment, and skylines in the current timber production are 75%, 15%, 7%, and 3%, respectively (Erdas, 2000). However, changing economic conditions might increase interest in mechanized harvesting systems in Turkey.

Mechanized harvesting is defined as operations with at least one single-function or multifunction machine for felling, delimbing, bucking, or chipping where trees or logs are located in bunches prior to prehauling (Kellogg et al., 1993). Typical mechanized harvesting systems generally include ground-based machines, which operate on gentle terrain with slopes of less than 35 %, and in timber stands where the average tree diameter is 50 cm or less (Bettinger et al., 1993). Mechanized harvesting requires less labor to conduct the operation; more highly skilled labor, and may reduce the need for manual in-wood labor. Equipment downtime, seasonal restrictions on harvesting operations, the loss of production in steep terrain, and environmental impact may be critical problems with mechanized harvesting systems.

In order to select the most profitable harvesting equipment under given operating conditions, the harvesting manager must know how to determine logging costs to evaluate alternative systems effectively. This requires knowledge of the variable factors influencing cost elements.

The purpose of this paper is, essentially, to identify the variable factors influencing the cost of mechanized harvesting equipment; secondly, to present their mathematical calculations; and finally, to compute the unit cost of specific harvesting machines including skidder, feller-buncher, harvester, loader, and forwarder. The files of output and data were listed on the spreadsheet tables; so, updated machine costs can be computed and displayed in the appropriate formula blocks simply by entering updated values. These spreadsheet tables provide managers and researchers with a simple method of identifying the variable factors influencing logging cost for various harvesting alternatives.

MATERIAL and METHOD

The unit cost of logging is basically estimated by dividing machine rate by the production. The hourly cost of the equipment with operator is called the machine rate.

When the equipment and production elements are not rented, the machine rate is usually divided into ownership costs, operating costs, and labor costs (Sessions, 1992). In some cases where the labor associated with the equipment works in a different number of hours from the equipment, labor costs are not included in the machine rate, but added separately.

Ownership Costs

Ownership costs, also known as fixed costs or overhead costs, do not vary with hours of operations. They are not affected by the amount of equipment activity or output.

Ownership costs occur on yearly scheduled machine hours basis and can be calculated by using average-cost method. In this method, the ownership cost components include depreciation cost, the cost of interest or opportunity cost, insurance premium, property tax, and license and storage fees of the equipment.

Depreciation Cost

Depreciation is the reduction in value of the machine over time. Depreciation occurs due to wear that gradually reduces the capacity of the equipment to perform its function due more downtime and repair costs or technological advances.

Depreciation cost is often computed by straight-line method, which is a simple, straightforward method to calculate equipment cost per unit of time. It assumes that the value of the over its economic life. The yearly depreciation charge, D, is computed as follows (Miyata, 1980):

$$D = \frac{P - S}{N} \tag{1}$$

where

P = initial purchase price
S = salvage value
N = economic life

Initial purchase price is the actual equipment purchase price, less the cost of tires, tracks, or other parts, which are subject to high wear rate. The actual equipment purchase price includes standard and optional attachment costs, sales taxes, and delivery costs (Sessions, 1992).

Salvage value is the price that used equipment can be sold for at the time of its disposal. The actual salvage value of equipment is affected by age, current market demand for used equipment, the number of hours on the machine at the time of resale, the types of jobs and operating condition, and the conditions of the equipment at the time of disposal (Miyata, 1980). It is also important to note that salvage values decrease sharply in the first years (Burgess et al., 1991). Brinker et al. (1989) published a summary table indicating the economic life and the salvage value for harvesting equipment (Table 1).

Cubbage (1981) recorded the original sales price and resale price data to calculate the salvage value for a total of 451 machines from five different categories (Figure 1). The categories are rubber-tired feller-buncher, cable skidders, grapple skidders, knuckle-boom loaders, and all equipment combined. Correlation and regression analyses were used to examine the effect of variable factors; equipment age, general condition of equipment, and geographic region.

Economic life is the period of time over which the equipment can operate at a feasible productivity and operating cost. It is generally measured in terms of year, hours, or kilometers (truck and trailers). Economic life depends on various factors including physical deterioration and functional destruction.

Table 1. Machine life and salvage value estimates (Brinker et al., 1989)

Machine category/description	Life (year)	Salvage value (%)
Feller-buncher, small, rubber-tired	3	20
Feller-buncher, medium, rubber-tired	4	20
Feller-buncher, large, tracked, boom	5	15
Cable skidder, medium, 80 to 100 Hp.	4	20
Cable skidder, medium, 101 to 120 Hp.	5	15
Cable skidder, more than 120 Hp	5	10
Grapple skidder, 70 to 90 Hp.	4	20
Grapple skidder, more than 91 Hp.	5	25
Grapple skidder, large, tracked, bunk	5	15
Forwarder, shortwood	4	21
Harvester, combine	4	20
Loader, bigstick	5	10
Loader, small to medium, hydraulic	5	30
Crawler tractor, less than 100 Hp.	5	20
Crawler tractor, 101 to 200 Hp.	5	20
Crawler tractor, more than 201 Hp.	5	20

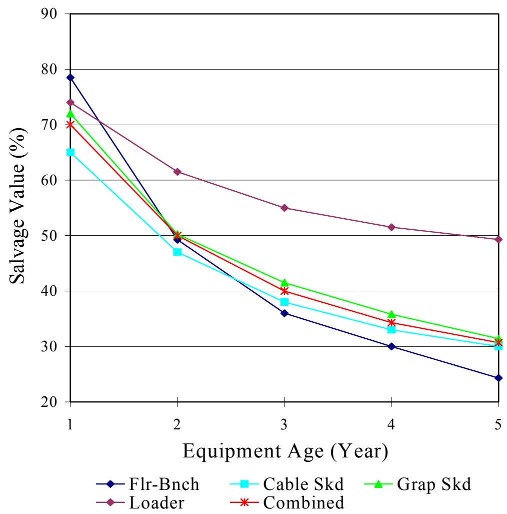

Figure 1. Predicted equipment salvage rates by machines (Cubbage, 1981).

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Interest, Insurance, and Taxes

Interest is defined as the cost of using funds over a period of time (Sessions, 1992). Investment funds may be borrowed from the lending institutions or taken from savings. If borrowed, the lending institution establishes the interest rate, which varies with the locality. If the fund comes from personal savings, then opportunity cost should be used as the interest rate.

Private equipment owners often have one or more insurance policies to cover the cost of any loss due to fire, theft, or other damages (Sessions, 1992). Large private owners and public owners may be self-insured. The cost of insurance also varies with locality, the type of equipment, and size of a woods operation. Equipment owners often must pay property taxes or usage taxes on their equipment. The charges for interest, insurance, and taxes can be calculated by applying the average annual investment (Miyata, 1980):

$$Cost = AAI(r + i + t) \qquad (2)$$

where

AAI = average annual investment

r = rate of interest

i = rate of insurance

t = rate of taxes

Solving for AAI (Miyata, 1980),

$$AAI = \frac{(P - S)(N + 1)}{2N} + S \qquad (3)$$

Storage and License Fees

If there is a change for storage and off-duty protection of a piece of logging equipment, this change must be spread over the total hours of equipment use (Sessions, 1992). Logging equipment often does not have a license fee except trucks used for highway travel (Bushman et al., 1988).

Scheduled Operating Time

Ownership cost must be divided by the yearly scheduled operating time (in hours) to determine the hourly cost of equipment. Scheduled operating time (smh) can be described as the time during which equipment is scheduled to do productive work. Since machines are scheduled yearly for more hours than they are operated, operating time of logging equipment must be multiplied by an adjustment factor. This factor is called the rate of machine utilization, which is the ratio of the productive time to the scheduled time for a machine (Brinker et al., 1989). Productive time is the actual machine time during which the equipment actually operates per shift.

Operating Costs

Operating cost includes maintenance and repair costs, fuel and lubricant costs, and tire and track replacement costs. They are also known as variable costs and change in proportion to hours of operation or use (Miyata, 1980). Operating cost is divided by the adjusted scheduled operating time to determine the hourly cost of equipment.

Maintenance and Repair Cost

These may include everything from simple maintenance items to the periodic overhaul of engine, transmission, clutch, brakes, and other major equipment components (Bushman et al., 1988). Lube and oil changes are usually calculated under the lube and oil costs. Operator misuse of equipment, the difficulty of working conditions, maintenance and repair policies, and the basic equipment design affects maintenance and repair costs (Miyata, 1980).

The major components of the cost may be estimated from the owner's manual and the local cost of parts and labor, another owner's experience under the same working conditions, or having advice from the manufacturer (Sessions, 1992). The maintenance and repair cost can be estimated as a percent of depreciation. The percent of depreciation for some of harvesting equipment is listed in Table 2.

Fuel and Lubricant Cost

The fuel consumption rate of a piece of equipment is affected by the engine size, load factor, the condition of the equipment, operator's driving skill, environmental conditions, and the design of equipment (Miyata, 1980).

In order to determine the hourly fuel cost, the total fuel cost is divided by the productive time of the equipment, if total fuel cost is available. Otherwise, following formula can be used to estimate hourly fuel cost (Sessions, 1992):

$$LMPH = \frac{K \times GHP \times LF}{KPL} \quad (4)$$

where

LMPH = liter used per machine hour
K = kg of fuel used per Hp/Hr.
GHP = gross horsepower at governed engine rpm
LF = load factor (the portion of full-rated flywheel horsepower used during normal operation).
KPL = weight of fuel in kg/liter

Table 2. Maintenance and Repair Rates for Selected Equipment (Warren, 1977)

Machine Types	Rate (%)
Crawler tractor	100
Agricultural wheel tractor	100
Rubber-tired skidder with cable	50
Rubber-tired skidder with grapple	60
Loader with cable grapple	30
Loader with hydraulic grapple	50
Rubber-tired front-end loader	90
Forwarder	100
Cable yarder	65
Feller-buncher	50

Typical values for these variables are given in Table 3. Hourly fuel cost for diesel and gasoline engine is computed as follow (Sessions, 1992):

For diesel engine:

$$Fuel\ cost = \frac{0.17 \times 0.54 \times GHP}{0.84} \times \cos t / liter \quad (5)$$

For gasoline engine:

$$Fuel\ cost = \frac{0.21 \times 0.54 \times GHP}{0.72} \times \cos t / liter \quad (6)$$

The consumption rate of lubricants depends on the type of equipment, environmental working condition (temperature), and the basic design of the equipment. Lubricants include engine oil, transmission oil, final drive oil, hydraulic oil, grease, and filters. If a piece of equipment is having normal oil changes and no leaks, the lubricant consumption liters per hour for skidder, tractors, and front-end loaders might be estimated by using lubricant consumption rate, Q in liter/hr (Sessions, 1992):

Q = .0006 × GHP (crankcase oil)
Q = .0003 × GHP (transmission oil)
Q = .0002 × GHP (final drives)
Q = .0001 × GHP (hydraulic controls)

When the machines are operating in heavy dust, deep mud, or water, the estimates are increased 25 percent. Besides, in machines with complex and high-pressure hydraulic systems such as forwarder, processor, and harvester, the consumption of hydraulic fluids might be much greater.

Tire and Track Replacement Cost

The estimates of tire and track costs vary with the operator's driving skills, environmental and terrain conditions, harvest conditions, weather, and local price (Miyata, 1980). In standard equipment cost computations, replacement costs of these items are often based on the assumption that new parts are used to replace the ones worn out (Bushman et al., 1988). However, used tracks or tires can also be purchased for replacement. Also, partial replacement of the tracks and retread of tires are not uncommon.

Tire costs are an important part of the hourly cost of any wheel equipment. In order to make a best estimate of tire costs, tire life should be available for different application zones and based on local experiences. If local experience is not available, estimates of tire life based on tire failure under various application conditions are given in Table 4 for off-highway equipment. These values are estimates of actual machine hours and must be converted to scheduled machine hours by using the utilization rate.

If there is no known reference for estimating the life of tracks, previous studies, local experiences, or equipment dealers may be able to give an estimate of track life. The hourly tire or track cost is obtained by dividing the total tire cost (including tire and labor) and maintenance by the total life of tire. If data are not available for the tire, the hourly tire cost may be estimated as follows (Jarck, 1965):

$$Hourly\ tire\ cost = \frac{1.15 \times (tire \cos t)}{tirelife} \quad (7)$$

where 1.15 = 1.00 + .15 (for labor). If there is any available company record about track replacement, a cumulative hourly cost can be obtained by determining total replacement cost and divided by the scheduled machine hours during the same period of operation (Bushman et al., 1988).

Labor Costs

The cost to keep an operator on the job may be on an hourly basis, per unit of output basis, or a combination of both (Miyata, 1980). Since the labor associated with the equipment works often a different number of hours from the equipment, labor costs should be carefully considered. Labor cost is generally considered as an operator cost, however, operators do minor repairs when the machines are down.

Labor cost components include wages, draw, and salaries, social security, health insurance, unemployment insurance, workers' compensation insurance, and labor burden factor. Other possible employer contributions, which might be paid vacation, retirement plans, travel pay, and administrative cost, do not include labor cost unless they are paid by the employer (Bushman, 1987).

Table 3. Fuel weights, consumption, and load factors engines (Sessions, 1992)

ENGINE TYPES	Weight (KPL) (kg / liter)	Fuel Consumpt. (K) (kg / brake hp-hour)	Load Factor (LF) Low	Med	High
Gasoline Engine	0.72	0.21	0.38	0.54	0.70
Diesel Engine	0.84	0.17	0.38	0.54	0.70

Table 4. Guideline for tire life for off-highway equipment* (Anonim, 1996)

EQUIPMENT TYPES	Tire Life (Machine Hours) ZONE A	ZONE B	ZONE C
Skidder	5000	3000	1500
Truck (Off-Highway)	5000	3000	1500
Wheel Loaders	4500	2250	750
Wheel Tractors	4500	2250	750

*Application Conditions:
Zone A: All tires wear through the tread from abrasion.
Zone B: Most tires wear out normally while some fail prematurely due to rock cuts, impacts, and non-repairable punctures.
Zone C: Few tires wear through the tread due to non-repairable damages from rock cuts.

Wages, Draws, and Salaries

Wages are defined as hourly payment, and divided into regular wages and overtime wages. Regular wages are paid for the regular time portion of work, overtime wages are paid for the overtime portion of work (over 40 hours per week) (Bushman et al, 1988). Draws and salaries are predetermined amount of payments given to employees on a regular basis.

Social Security, Health Insurance, and Unemployment Insurance

Social security provides retirement and survivors' benefits to wife and children in the event of the father's death, disability insurance, and health insurance for those over the age of retirement (Bromley, 1968). The portion of health insurance premiums paid by the employer is considered as part of the total labor cost.

Table 5. Basic input data for specific harvesting machines; manufacturer, mobility type, attachment type, and engine horsepower

No:	Machine Make	Machine Type	Mobility	Attachment	HP
1	CAT 515	Skidder	Rubber-Tire	Cable	140
2	CAT 525	Skidder	Rubber-Tire	Grapple	160
3	TJ 240	Skidder	Rubber-Tire	Cable	116
4	TJ 360	Skidder	Rubber-Tire	Cable	148
5	TJ 1210-B	Forwarder	Rubber-Tire	Knuckle-Boom	172
6	TJ 1270-B	Harvester	Rubber-Tire	Single-Grip	204
7	PRENTICE 620	Feller-Buncher	Track	Shear	215
8	PRENTICE 720	Feller-Buncher	Track	Shear	260
9	TJ 2618	Feller-Buncher	Track	Shear	205
10	TJ 2628	Feller-Buncher	Track	Shear	230
11	PRENTICE T210	Loader	Rubber-Tire	Knuckle-Boom	145
12	PRENTICE T410	Loader	Rubber-Tire	Knuckle-Boom	169
13	CAT 320A	Loader	Track	Knuckle-Boom	128
14	CAT 322B	Loader	Track	Knuckle-Boom	153
15	CAT D5HCS	Crawler	Track	Cable	120
16	CAT D5HCS	Crawler	Track	Grapple	120

To compute health or life insurance cost, the amount of insurance premiums paid for total wages must be computed (Bushman et al., 1988). Unemployment insurance is used by the government to supplement unemployment benefits for workers.

Workmen's Compensation

Workmen's compensation insurance provides protection for an employee against occupational hazards and benefits for his family to offset diminishing income resulting from any accidental injury or death on the job and work related illness (Miyata, 1980).

These benefits or payments are paid according to a schedule of benefits regardless of anyone's fault concerning the injury. Premium rates for workers' compensation insurance differ by the logging industry classifications since employees working in different part of logging operations do not have to contend with the same dangers.

Labor Burden Factor

Labor burden is defined as the amount of additional cost paid above wages to operate a crew, and normally expressed as a percent of wages (Bushman, 1987). Salaried employees can be included along with the hourly wage employees to determine labor burden cost if the same labor burden factors applied to the salaried employees and hourly employees (Bushman et al., 1988). When the owners work with the crew, they are also subject to hourly payment named partner draws.

RESULTS

Machine rates, in US dollar, were estimated for selected forest harvesting machines based on the data representing average economic conditions in Turkey. The estimated data include interest rate (21%), insurance (5%), tax (9%), fuel price per liter ($1.26), average hourly operator costs ($5.5). Results are listed in the tables. In these tables, machines are first organized by category and manufacturer, then mobility type, attachment type, and engine horsepower are shown in Table 5.

Parameters such as purchase prices, economic life in year, salvage rates, utilization rate, and maintenance and repair rate are listed in Table 6. These parameters were obtained from previous studies (Miyata 1980, Cubbage 1981, Brinker et al. 1989, and Sessions 1992) and machine dealers and manufacturers. It was assumed that the machines were scheduled to work 2000 hours in a year. Total fuel and oil costs were estimated based on average value for weight of fuel (0.72kg/liter), load factor (0.54), weight of fuel used per hp/hr (0.21kg), and lubricant and oil rate (37%).

Table 6. Parameters for ownership and operating cost calculations; price, machine life, salvage rate, utility rate, and maintenance and repair rate

No:	Purchase Price ($)	Machine Life (year)	Salvage Rate (%)	Utility Rate (%)	Maintenance and Repair Rate (%)
1	160200	5	0.15	0.60	0.75
2	183600	5	0.10	0.60	0.75
3	113300	5	0.15	0.60	0.75
4	143400	5	0.10	0.60	0.75
5	424800	5	0.21	0.65	0.70
6	585600	5	0.20	0.65	0.70
7	356400	5	0.15	0.60	0.75
8	393600	5	0.15	0.60	0.75
9	439200	4	0.15	0.60	0.75
10	478800	4	0.15	0.60	0.75
11	91200	5	0.30	0.65	0.70
12	146400	5	0.30	0.65	0.70
13	477200	5	0.30	0.65	0.70
14	428500	5	0.30	0.65	0.70
15	246000	5	0.20	0.60	0.75
16	330000	5	0.20	0.60	0.75

The depreciation cost, interest, insurance and tax costs, maintenance and repair cost, fuel and oil costs are computed and shown in Table 7. Tire and truck replacement cost are computed under repair and maintenance cost.

Finally, Table 8 indicates the results for total ownership cost, total operating cost, productive machine hours, and total machine rate based on both scheduled machine hours (smh) and productive machine hours (pmh).

Machine costs can be updated and displayed in the appropriate formula blocks simply by entering updated values. In order to update economic data for the following years, the effect of inflation should be taken into account based on the following formula:

$$V_n = V_o \times (1 + i)^n \quad (8)$$

where

V_n = Future value in year n

V_o = Present value in year 0

n = Number of years

i = Estimated inflation rate in percent

DISCUSSION and CONCLUSION

The variable factors effecting the cost of mechanized harvesting equipment were identified and their mathematical formulations were presented. The machine rates for selected harvesting equipment were calculated. The results indicated that purchase price and fuel cost were the most important factors influencing machine rate. Purchase price played important role on the value of the average annual investment, depreciation cost, and maintenance and repair costs. That changes all the costs defined by these values. Machine life also has a dramatic effect on the average annual investment and depreciation cost. Interest, insurance, and tax costs were the second highest cost component of the total equipment cost due to high interest rate and tax. Machine rate estimates can be used to compare machines or machine combinations to determine the most economical combinations for different harvesting systems.

Table 7. Ownership and operating cost components in scheduled machine hours

No:	Depreciation Cost ($/smh)	Interest, Insurance, and Tax Costs ($/smh)	Maintenance and Repair Cost ($/smh)	Fuel and Oil Costs ($/smh)
1	13.62	18.50	10.21	38.06
2	16.52	20.56	12.39	43.50
3	9.63	13.09	7.22	31.54
4	12.91	16.06	9.68	40.24
5	33.56	50.85	23.49	46.76
6	46.85	69.69	32.79	55.46
7	30.29	41.16	22.72	58.45
8	33.46	45.46	25.09	70.69
9	46.67	52.36	35.00	55.73
10	50.87	57.08	38.15	62.53
11	6.38	11.49	4.47	39.42
12	10.25	18.45	7.17	45.95
13	33.40	60.13	23.38	34.80
14	30.00	53.99	21.00	41.60
15	19.68	29.27	14.76	32.63
16	26.40	39.27	19.80	32.63

Table 8. Total equipment cost summary

No:	Ownership Cost ($/smh)	Operating Cost ($/smh)	Productive Machine Hour	Machine Rate ($/smh)	Machine Rate ($/pmh)
1	32.12	48.28	5.50	85.90	143.16
2	37.09	55.89	5.50	98.48	164.13
3	22.72	38.76	5.50	66.98	111.63
4	28.97	49.92	5.50	84.38	140.64
5	84.41	70.25	5.50	160.16	246.40
6	116.53	88.26	5.50	210.29	323.52
7	71.46	81.17	5.50	158.13	263.55
8	78.92	95.78	5.50	180.20	300.33
9	99.03	90.73	5.50	195.26	325.43
10	107.95	100.69	5.50	214.14	356.90
11	17.88	43.89	5.50	67.27	103.49
12	28.69	53.12	5.50	87.32	134.33
13	93.53	58.18	5.50	157.21	241.87
14	83.99	62.59	5.50	152.08	233.97
15	48.95	47.39	5.50	101.84	169.73
16	65.67	52.43	5.50	123.60	205.99

The mechanized harvesting equipment analyzed in this study are not common in current logging operations in Turkey because they are very expensive, energy consuming, and operating cost is highly correlated with the price of the fuel. They are also not favorable due to reduction in labor, which may cause significant unemployment. Approximately 99 % of the forest is publicly owned and managed by the Forest Services, which makes the labor issue one of the major concerns in forestry operations. However, mechanized harvesting systems would be more competitive if labor costs increase relative to fuel costs. Besides, they satisfying the public demand, which emphasizes the importance of multiple resources. The cost factors in this project have not included road costs, worker safety, and environmental costs. If these factors were considered in future studies, mechanized harvesting might also be more attractive in Turkey.

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