ESTIMATING MACHINE RATES AND PRODUCTION FOR SELECTED FOREST HARVESTING MACHINES OPERATING IN THE WESTERN UNITED STATES AND DETERMINING THE MOST ECONOMICAL MACHINE COMBINATIONS UNDER REPRESENTATIVE CONDITIONS IN TURKEY

by

ABDULLAH EMIN AKAY

A PAPER

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During the last decades, there has been increasing interest in ground-based mechanized harvesting systems in the western United States as harvest of second growth increased. A major reason for that interest is that labor productivity using conventional methods decreases with smaller tree size. In Turkey, the application of mechanization is currently low due to low labor costs and high fuel costs. However, changing economic conditions might increase interest in mechanized harvesting systems in Turkey.

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. Analytical methods were used in this project to estimate machine cost and productivity for different harvesting system combinations.

Animal logging was also considered because highly mechanized timber harvest systems are expensive, and energy consuming. Animals and farm tractors are the major energy sources for agricultural and forestry work and transportation in Turkey. A small amount of animal skidding also takes a place in forestry operations in the western United States to reduce environmental impact.

Forty-two machines were selected from six categories of ground-based forest harvesting machines, including skidder, forwarder, harvester, feller-buncher, loader, and crawler tractor. Machine rates were estimated for selected forest harvesting machines under representative conditions in both western United States and in Turkey. Cable harvesting systems are described but not analyzed. A microcomputer spreadsheet program was developed to calculate machine rates.

Harvesting operations from stump to truck were investigated to have a clear picture of harvesting operations including fellling and bucking, skidding, forwarding, yarding, and loading. Harvesting production and harvesting costs were determined depending on the types of equipment being operated. To estimate production rates for specific logging equipment, cycle time was obtained from the production equations as a dependent variable, and converted to production using log size, volume, or weight. Production equations are based on studies that have provided useful data to investigate productivity of the logging equipment under various harvesting conditions.

Finally, the most economical machine combination, which minimizes the unit cost of logging, was investigated for three different regions of Turkey. The data including topographic data, road data, tree and log data, soil data, and cost data was collected from selected sample plots of each region as representative conditions. In the sample plots selected from Black Sea and Aegean regions, the cut-to-length system using four sawyers and a forwarder produced wood on the truck at the lowest cost, \$11.18/m^3, and \$13.88/m^3, respectively. In the sample plots selected from Mediterranean region, the whole-tree system using four sawyers, a grapple skidder, and a loader produced wood at the lowest cost (\$9.20/m^3). This compared to an estimated logging cost of about \$7.00/m^3 to \$10.00/m^3 in Turkey using chain saw felling, oxen skidding and manual loading.

APPROVED:

J. Sessions

Professor of Forest Engineering in charge of major

Head of the Department of Forest Engineering

Date paper is presented: January 2, 1998

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DEDICATION

This paper is dedicated to my dear

respected parents, Ahmet and Safiye AKAY

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I would have never finished this paper on time without the help and wishes of Allah (C.C.), the Merciful, the Compassionate. I would like to express my gratitude to my country, Turkey, and her people for providing me this rare opportunity to pursue my higher education in the United States of America.

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INTRODUCTION

In order to achieve the most economical logging plan requires a correct decision in choosing between alternative harvesting systems. This requires knowledge of the variable factors influencing cost elements. Harvesting systems chosen must be carefully balanced for the characteristics of the forest (number of species, age, stand density, timber size), site condition (slope, soil, obstacles), machine types (skidder, yarder, harvester, forwarder, helicopter, loader), intensity of the harvest operation (thinning or clearcut), and products (sawlogs, pulpwood, full tree, fuelwood) to reflect variable factors that affect cycle time, productivity, and unit cost (Aedo-Ortiz et al., 1997).

During the last decades, there has been increasing interest in mechanized harvesting systems in the western United States because tree size is decreasing as harvest of second growth increases, and labor productivity using conventional methods decreases with smaller tree size (Bettinger et al., 1993, and Miyata E.S., 1980). Besides, some capabilities of the mechanized harvesting operations, such as leaving the limbs and tops in the stand as an organic material, conducting partial cutting as well as clearcutting, and working on smaller landings, meet with the public demand which emphasizes the importance of multiple resources (Kellogg et al., 1992a).

The average tree size harvested in western Oregon over the next 8 decades and in eastern Oregon in the next 2 decades are estimated as 19 in. dbh and 18 in. dbh, respectively (Bettinger et al., 1993). Figure 1 indicates projected western Oregon harvest between 1991-2000 by dbh classes. It suggests that about 44 % of the total westside harvest will come from the trees between 16 in. and 23 in dbh. In eastern Oregon, on the other hand, only 13 % of the harvest will come from trees larger than 24 in. dbh (Figure 2). The amount of land on 0 to 35 % slopes in all timber classes in western Oregon and eastern Oregon is about 60 % and 85 %, respectively (Bettinger et al., 1993).

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 or operations where prehauling is able to handle multiple loads (Kellogg et al., 1992). 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 20 in. or less (Bettinger et al., 1993).

Mechanized felling machines are more effective than manual felling and delimbing in second growth, which has a higher amount of branchiness. They increase the efficiency of the skidding or yarding operation in thinnings, having ability to bunch smaller stems and to better control the felling direction, which reduces stand damage in skidding or yarding operations in thinnings.

Mechanized harvesting requires less labor to conduct the operation, it may cause more unemployment of in-wood labor. Equipment downtime, seasonal restrictions on harvesting operations, the loss of production in steep terrain, and unstable raw materials markets may be critical problems with mechanized harvesting systems (Schuhet et al., 1988). Since today highly mechanized systems are very expensive, energy consuming, and highly correlated with the price of fuel, animals are the energy sources for agricultural and forestry work and transportation in many developing countries (Rodriguez, 1986). Animal skidding sometimes replaces conventional harvesting systems in the western United States to reduce environmental impact.

A complete understanding of harvesting requires studies of harvesting systems since studies of individual machines can not provide a complete picture of harvesting (Kellogg et al., 1992b). The purpose of this project is, essentially, to have a better understanding of harvesting production and harvesting costs from stump to truck of methods used in the western United States; secondly, to identify the variable factors influencing the machine rate, production rate, and the unit cost of specific logging equipment in the western United States, and finally, after the unit cost computations of all the logging equipment considered in the project, to investigate the cost efficiency of selected harvesting systems in the sample plots representing regional conditions in Turkey. It was not possible in this project to list every machine and machine combination available, so, representative machines and machine combinations were analyzed.

Harvesting machines selected from six categories include skidder, forwarder, harvester, feller-buncher, loader, and crawler tractor. To compute machine rates for the specified machines, a microcomputer spreadsheet program (Microsoft EXCEL) was used, and the files of output and data were listed on the spreadsheet tables. 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.

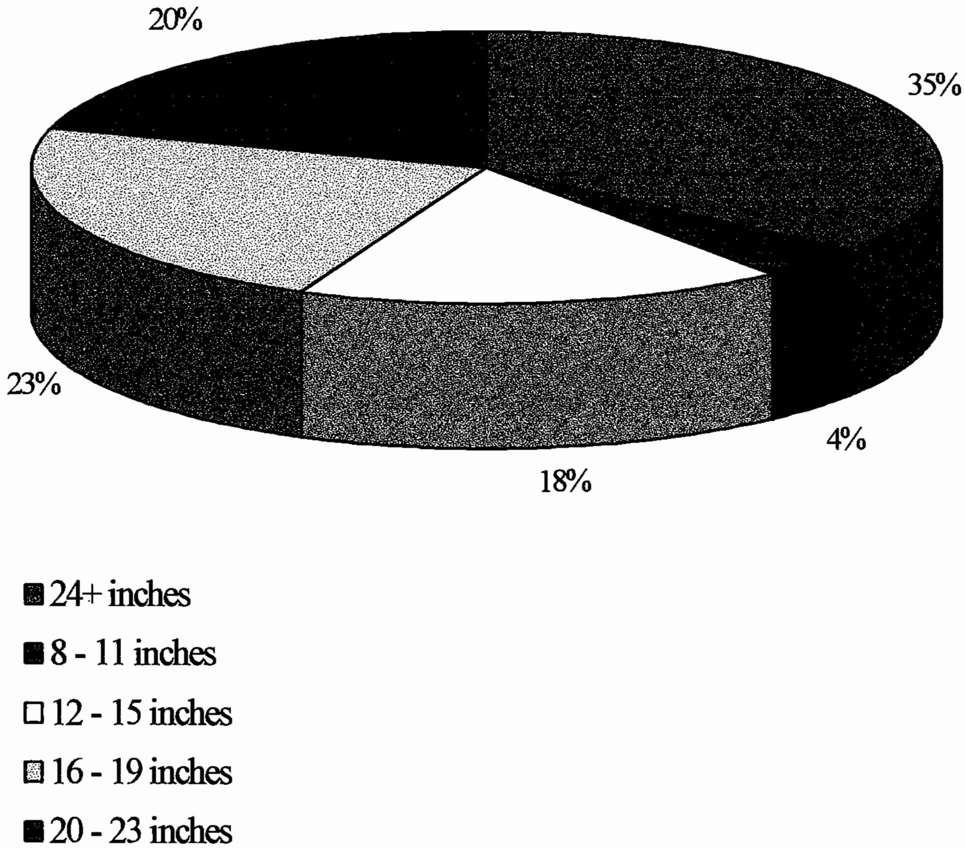


FIGURE 1. Projected Western Oregon Harvest, 1991-2000, by dbh Class (Adapted from Bettinger et al. 1993).

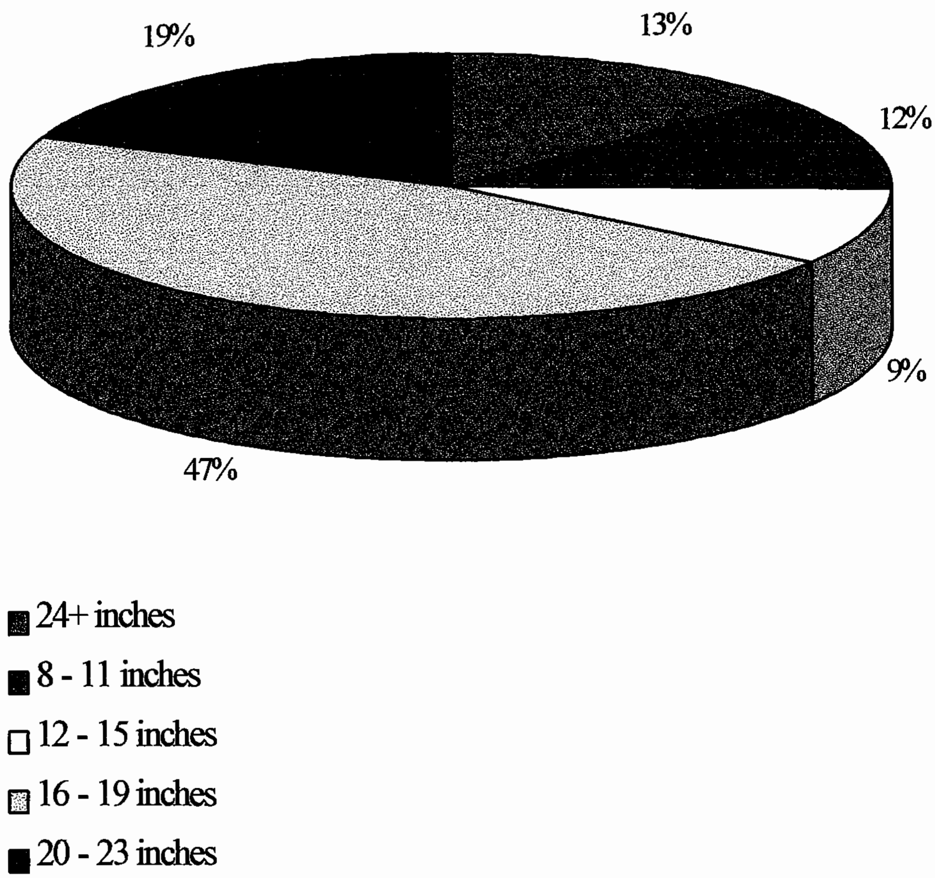


FIGURE 2. Projected Eastern Oregon Harvest, 1991-2000, by dbh Class (Adapted from Bettinger et al. 1993).

OBJECTIVES

Identify the machine rate for the logging equipment, and animal rate for skidding operations

a. Determine the components of ownership (fixed) cost
b. Determine the components of operating cost
c. Determine the components of labor cost
d. Estimate the machine rate for the specific harvesting equipment

Identify the cost per unit volume for the logging operations

a. Determine the operation and types of the equipment being operated
b. Determine work cycle time for the equipment
c. Determine the production rate for the equipment
d. Estimate the unit cost for specific harvesting equipment

Investigate the anticipated logging cost per unit volume for different harvesting systems

a. Determine the machine combinations for various harvesting systems
b. Determine the unit cost of logging for the selected machine combinations

1. MACHINE RATE CALCULATIONS

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 then added separately. In this study, labor costs are included in the machine rate.

The ownership cost includes actual equipment purchase cost (new or used), salvage value, depreciation costs, the cost of interest or opportunity cost, insurance premium, property tax, and license and storage fees of the equipment. Operating costs include the cost of fuel, lube and oil, equipment maintenance and repair, track or tire replacement, and wire rope replacement. Labor cost components include Wages, Draws, and Salaries, Social Security, Federal Unemployment Insurance, State Unemployment Insurance, Workmen's Compensation, Health Insurance, and Labor Burden Factor.

1.1. OWNERSHIP COST

The ownership costs components described in this section are purchase price, salvage value, economic life, scheduled operating time, productive time, depreciation, interest, insurance and taxes, opportunity cost, and storage and license fees, average annual investment (AAI), and effect of inflation. 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. They don't stop when the work stops and should be spread over the annual utilization hours per year (Sessions, 1992).

Ownership costs occur on a dollar per yearly scheduled machine hours basis and can be calculated by two different ways that are average-cost method and marginal-cost method (Bushman et al., 1988). Average-cost method is based on the average annual investment in one logging machine during its economic life (Appendix AI.). The marginal-cost method, on the other hand, is based current market value, and preferable for used equipment. In this study, ownership costs calculations are based on average-cost method (Appendix A.II.).

1.1.1. Initial Purchase Price

Initial purchase price is defined as the actual equipment purchase price, less the cost of tires, tracks, wire rope, or other parts which are subjected the greatest rate of wear and can be easily replaced without effect on the general mechanical condition of the machine (Miyata, 1980, and Sessions, 1992). The actual equipment purchase price includes standard and optional attachment costs, sales taxes (state or local), and delivery costs.

Delivery costs (freight costs) are based on F.O.B. free-on-board price. There are two common F.O.B. pricing policies (Ballau, 1973):

- F.O.B. factory price: the buyer takes the title of the equipment at the factory and is responsible for shipment.
- F.O.B. delivered price: the buyer takes the title to the equipment after it is delivered at a specific point. The delivered price includes freight, packing, and insurance.

Delivery costs include interstate permit and overweight fees (only for Washington State), license (only for Oregon State), and escort cars (McGonagill, 1975).
Other costs such as installation or adaptation of the equipment to the logging system should be included in the initial purchase price. Special attachments may have separate equipment cost if their economic lives are different than the main equipment (Sessions, 1992).

Purchases price of the harvesting machines including skidder, crawler tractor, feller-buncher, forwarder, processor, and loader were listed in the Appendix B.2. They were gathered from dealers and manufacturers during the winter of 1997.

In 1988, Cubbage et al. summarized historical data on timber harvesting equipment costs, and compared the trends in equipment purchase price with the general inflation rate and the rate of PPI-Industrial (Producer Price Index for Industrial Commodities). The results from their study showed that forest harvesting equipment had greater purchase price increases (1.1 % to 1.6 % per year) than the general rate of inflation from 1974 to 1987. The rate of PPI-Industrial, on the other hand, was slightly greater (0 % to 0.5 %) than equipment inflation.

1.1.2. Salvage Value

Equipment salvage value is the price that used equipment can be sold for at the time of its disposal (Sessions, 1992). 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).

Estimating the future salvage value of the equipment is very difficult since it is based on the unknown factors such as condition of the equipment and the future market value at the time of its resale (Miyata, 1980). It is also important to note that salvage values decrease sharply in the first years (Burgess et al., 1991).

Estimations of salvage value have relied on rules-of-thumb developed by early harvesting analysts. These estimates range from 10 to 25 percent of the initial purchase price. Miyata (1980) recommended that 20 percent of the initial price should be used as an estimation of salvage value in his equipment cost study.

Brinker (1989) published a summary table indicating the economic life and the salvage value for harvesting equipment (Table 1), which also relies on an average salvage value rate of 20 percent. Werblow (1986) and Cubbage (1981), on the other hand, recommended that salvage value should be 25 percent of the initial price.

None of these studies provided any experimental data for their salvage value estimates. Cubbage et al. (1991), however, recorded the original sales price and resale price data, and then salvage value was calculated for a total of 451 machines individually in five equipment categories. These machine categories are rubber-tired feller-buncher, cable skidders, grapple skidders, knuckle-boom loaders, and all equipment combined.

They used correlation and regression analyses to examine the effect of three variable factors, which are equipment age, general condition of equipment at the time of sale, and geographic region. As a result of their study, age and physical condition were useful to estimate salvage values, but geographic region was not.

They also found the old rules-of-thumb unrealistic for equipment resale values since their regression equation and the old rules-of-thumb indicated significant differences

TABLE 1. Machine life and salvage value estimates.

Machine category/description	Life (year)	Salvage value (%)
Chain saw	1	20
Tree shear, without carrier	5	50
Feller-buncher, small, rubber-tired	3	20
Feller-buncher, medium to large, rubber-tired	4	20
Feller-buncher, large, tracked, boom	5	15
Cable skidder, less than 80 Hp.	4	20
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
Slasher/loader, multistem	4	20
Delimber, iron gate	5	0
Harvester, combine	4	20
Loader, bigstick	5	10
Loader, small, hydraulic	5	30
Loader, medium, hydraulic	5	30
Chipper, small to medium, 12 to 18 inches	5	20
Chipper, large, over 22 inches	5	20
Crawler tractor, less than 100 Hp.	5	20
Crawler tractor, 101 to 200 Hp.	5	20
Crawler tractor, more than 201 Hp.	5	20

Adapted from Brinker (1989).

on resale values (based on the original price; grapple skidder value was 30 percent versus 25 percent; cable skidder was 35 percent versus 20 percent; and knuckle-boom loader was 49 percent versus 30 percent, respectively, in Figure 3).

1.1.3. Economic Life

This is the period of time over which the equipment can operate at an acceptable operating cost and productivity (Sessions, 1992). It is generally measured in terms of year, hours, mileage (truck and trailers) or in the case of wire-rope line in terms of million-board-foot. Economic life depends on various factors, including physical deterioration and functional impairment (Miyata, 1980).

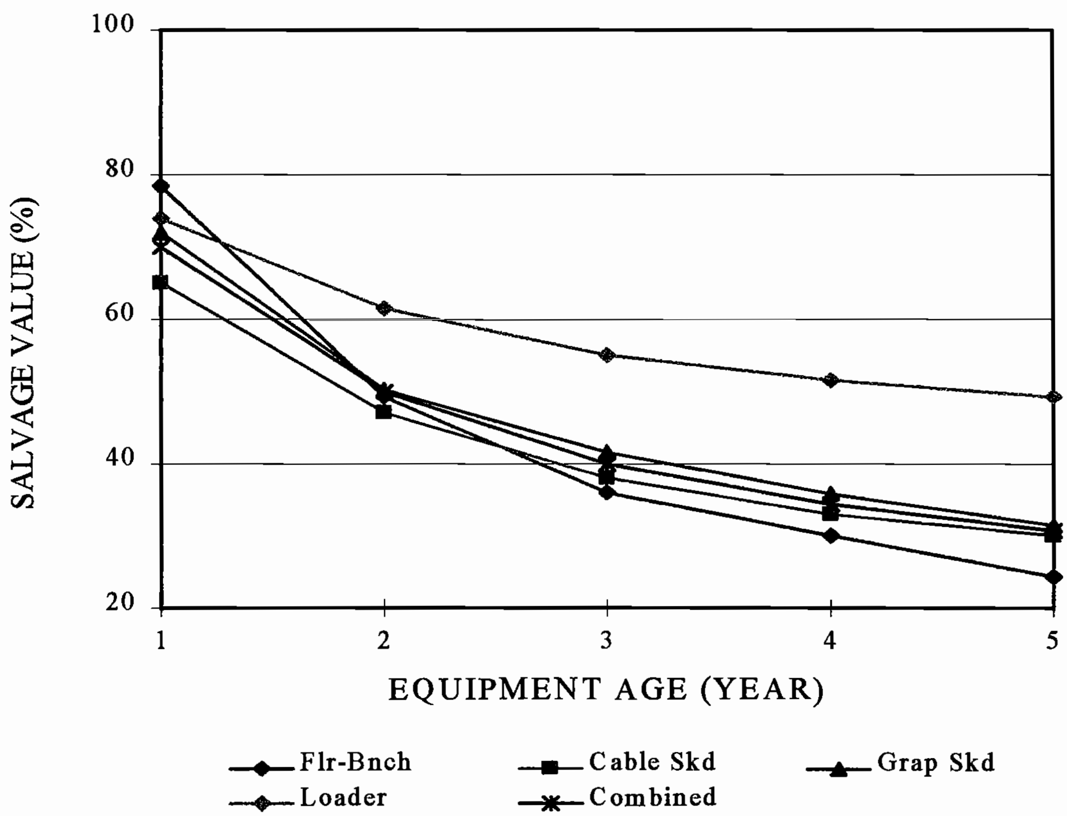


FIGURE 3. Predicted Equipment Salvage Rate by Machine Class (ages 1-5 years) (Adapted from Cubbage et al., 1991).

Physical deterioration can arise due to such factors as corrosion, chemical decomposition, or by wear and tear due to abrasion, shock, and impact. Routine and correct usage, abusive and incorrect usage, age, lack of maintenance, or hard environmental conditions may cause these factors (Miyata, 1980).

Functional impairment is when the equipment cannot meet the demand for expansion of operation and change of harvesting system or becomes economically or technologically obsolete (Miyata, 1980). Economic life of equipment can also be affected by economic conditions such as fuel prices, tax investment incentives, and interest rate.

Equipment owners generally trade the equipment when the down time of this piece of equipment causes the entire logging system to lose time, or when the cost of lost production exceeds the cost of owning a new piece of equipment (Miyata, 1980). The estimated economic life of certain types of harvesting equipment is listed in Table 1.

1.1.4. Scheduled Operating Time (SMH)

Scheduled operating time can be described as the time during which equipment is scheduled to do productive work (Rolston, 1968). The days during which a machine is out of duty is not considered as scheduled operating time. These days may include weekends, holidays, bad weather days, etc. (Miyata, 1980).

If logging equipment is scheduled for 8 hours usage per shift and the estimated number of shifts are 200, then;

$$SMH = 8 \text{ hr./day} \times 200 \text{ days/yr.} = 1{,}600 \text{ hr./yr.}$$

1.1.5. Productive Time

Operating time of logging equipment must be adjusted since machines are scheduled yearly for more hours than they are operated (Bushman et al., 1988). This adjustment called productive time is part of scheduled operating time during actual machine hours. Actual machine hours are the time during which the equipment actually operates per shift. Productive time is obtained in this way: scheduled machine hours per year × (actual machine hours per day ÷ scheduled machine hours per day).

Scheduled operating time and productive time would rarely be equal for logging equipment because of delays such as mechanical breakdowns, personnel, weather, etc. (Miyata, 1980). If equipment works very few hours per day, effects of local conditions should be checked to make more reasonable estimate because the derived equipment life may be unrealistically long. Examples of total ownership hours for some types of logging equipment, based on application and operating conditions, are shown in Table 2. Ownership hours of logging equipment are based on actual machine hours operated.

For example, suppose that a small track-type tractor is operating under medium-impact conditions. The total machine life in hours given in Table 2 is 10,000 hours. Assume that the machine is scheduled for 1,600 operating hours per year (200 shifts averaging 8 hours), but it actually operates 6 hours of each 8-hour shift. Then estimated productive time per year is:

Productive time = 1,600 hr./yr. × (6 hr. ÷ 8 hr.) = 1,200 hr./yr.

Total life in year = total machine life in hour ÷ actual machine hours per year

$$= 10{,}000 \text{ hr.} \div 1{,}200 \text{ hr./yr.} = 8.33 \cong 8.5 \text{ yr.}$$

TABLE 2. Guide for economic life based on application and operating conditions.

Machine Types	ZONE A Moderate	ZONE B Average	ZONE C Severe
Track-Type TRACTORS	Pulling scrapers, most agricultural drawbar., stockpile coalpile. No intermittent full throttle operation.	Production dozing in clay, sands, gravels. Pushloading scrapers, borrow pit ripping, most landclearing applications. Medium impact conditions. Production landfill work.	Heavy rock ripping Tandem ripping. Work on rock surface. Push-loading and dozing in hard rock. Continuous high impact condition.
Small	12,000 Hr	10,000 Hr	8,000 Hr
Large	22,000 Hr	18,000 Hr	15,000 Hr
FRONT SHOVELS	Continuous loading in loose banks or stockpile. Good underfoot conditions.	Continuous loading in poorly-shot rock or fairly tight bank. Good underfoot conditions; dry floor, little impact or sliding on undercarriage.	Continuous loading in poorly-shot rock, virgin lightlyblasted tight bank e.g., shales, cemented, Adverse underfoot conditions: rough floor; high impact skiding on undercarriage.
Small	20,000 Hr	18,000 Hr	15,000 Hr
Medium	40,000 Hr	33,000 Hr	25,000 Hr
Large	60,000 Hr	50,000 Hr	40,000 Hr
FELLER BUNCHERS	Continuous felling and stacking in good under-foot conditions. Flat ground uniform trees below 305 mm.	Continuous cycling in good underfoot conditions. Rolling terrain, some trees up to 508 mm. or some hardwoods.	Continuous cycling in steep terrain over stumps and fallen trees. Most trees 508 mm. or larger hardwoods.
	18,000 Hr	15,000 Hr	10,000 Hr

SKIDDER	Intermittent skidding for short distances, no decking.Good under-foot conditions: level terrain, dry floor, few if any stumps.	Continuous turning, steady skidding for medium distances with moderate decking. Good underfooting: dry floor with few stumps and gradual rolling terrain.	Continuous turning, steady skidding for long distances with frequent decking. Poor underfoot conditions: wet floor, steep slopes and numer-ous stump.
Whell	10,000 Hr	8,000 Hr	7,200 Hr
Track	12,000 Hr	10,000 Hr	8,000 Hr
WHEEL LOADERS	Intermittent truck loading from stockpile. Free flow-ing, low density materials. Load and carry on good surface for short distances with no grades.	Continuous truck loading from stockpile. Low to medium density materials in properly sized bucked. Loading from bank in good digging. Load and carry on poor surface and slight adverse grades.	Loading shot rock. handling high density materials with counter-weighted machine. Steady loading from very tight bank. Rough or very soft surface, continuous work
Small	12,000 Hr	10,000 Hr	8,000 Hr
Large	15,000 Hr	12,000 Hr	10,000 Hr
TRACK LODERS	Intermittent truck loading from stockpile. Minimum traveling, turning. Free flowing, low density mat-erials with standard buc-ket. No impact.	Bank excavation, intermittent ripping, basement digging of natural clays, sands, silts, gravels. Some traveling.Steady full throttle operation.	Continuous work on rock surfaces.Large amount of ripping of tight, rocky materials. High impact conditions.
	12,000 Hr	10,000 Hr	8,000 Hr

Adapted from the Caterpillar Performance Handbook (27th Edition, October 1996)

The ratio of the productive time to the scheduled time for a machine is known as the percent machine utilization (Brinker et al., 1989). Machine utilization percents for some types of harvesting equipment are as follow:

Equipment	*Utilization (%)*
Chain saw-straight blade	50
Chain saw-bow blade	50
Tree shear, without carrier	60
Feller-buncher, small, rubber-tired	65
Feller-buncher, medium to large, rubber-tired	65
Feller-buncher, large, tracked, boom	60
Cable skidder, less than 80 Hp.	65
Cable skidder, medium, 80 to 100 Hp.	65
Cable skidder, medium, 101 to 120 Hp.	60
Cable skidder, more than 120 Hp.	60
Grapple skidder, 70 to 90 Hp.	65
Grapple skidder, more than 91 Hp.	60
Grapple skidder, large, tracked, bunk	65
Forwarder, shortwood	65
Delimber, iron gate	90
Harvester, combine	65
Bigstick loader	90
Shortwood hydraulic loader	65

Equipment	*Utilization (%)*
Longwood hydraulic loader	64
Uniloader	60
Front end loader	60
Chipper, small to medium, 12 to 18 inches	75
Chipper, large, over 22 inches	75
Crawler tractor, less than 100 Hp.	25
Crawler tractor, 101 to 200 Hp.	60
Crawler tractor, more than 201 Hp.	60

Table 3 adapted from Brown (1995) shows the changes in the production rates calculated for a single grip harvester in terms of scheduled machine hour and productive time under 80.4 % of the estimated utilization rate.

TABLE 3. Harvester Production Rate.

TIME	Logs / hr.	ft^3 / hr.	bf / hr.	Tons / hr.	m^3 / hr.
Scheduled	151.5	589.4	2917.8	13.5	19.7
Productive	188.5	733.3	3630.5	16.8	20.8

1.1.6. Depreciation

Depreciation is defined as the reduction in value of the machine over time as it is working at a specific task (Sessions, 1992). Depreciation occurs due to wear that gradually declines the capacity of the piece of equipment to perform its function. Logging equipment may also depreciate since technological advances make it absolete (Bushman et al., 1988). The objective of the depreciation schedule is to recover the initial investment cost of equipment each year over its economic life (Miyata, 1980). Depreciation cost is computed by the three common methods: (1) Straight line, (2) decline balance, and (3) sum-of-the-year's-digits.

Straight Line Method:

Straight-line method assumes that the value of the equipment reduces at a constant rate for each year over its economic life. The straight-line method is the simplest way for estimating depreciation costs and may be most preferable method to calculate equipment cost per unit of time (Miyata, 1980). The mathematical formula for the yearly depreciation charge using the straight-line method is:

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

Where:

P = Initial purchase price (actual price less tire replacement)

S = Salvage value (percent of initial price; P)

N = Economic life (in year or scheduled machine hours)

For example, suppose that a track type feller-buncher costs $95,000 (actual purchase price). The track replacement cost, salvage rate (*S*), and economic life (*N*) are estimated as $10,000, 15 percent, and 5 years, respectively. Then:

$$\text{Initial purchase price } (P) = \$95{,}000 - \$10{,}000 = \$85{,}000$$

$$\text{Salvage value } (S) = \$85{,}000 \times 0.15 = \$12{,}750$$

$$\text{Depreciation charge } (D) = \frac{\$85{,}000 - \$12{,}750}{5\,yr.} = \$14{,}450 \quad \text{per year.}$$

If the estimated scheduled machine hours are 1,600 (200 8-hours shifts per year), depreciation cost per SMH is:

Depreciation charge (D) = \$14,450/yr. ÷ 1,600 hr./yr. = \$9.03 per hour.

The depreciation costs per year, and the undepreciated value at the end of each year is listed as follow:

Years	Depreciation costs (\$)	Undepreciated values (\$)
0	------	$85{,}000 = P$
1	14,450	70,550
2	14,450	56,100
3	14,450	41,650
4	14.450	27,200
5	14,450	$12{,}750 = S$

Declining balance method:

This method assumes that the value of equipment decreases at a higher rate during the early years, and lesser rate in the later years. The depreciation rate is 2, $1^1/_2$, and $1^1/_4$ times greater than the rate of the straight-line method (Miyata, 1980).

In the previous example, straight-line depreciation rate per year is; $\frac{1}{5yr.} = 20\,\%$, then suppose that depreciation rate is two times greater than that of straight line method, which means 40 percent is used. The depreciation charge and undepreciated values for first two years are:

Years	Depreciation costs (\$)	Undepreciated values (\$)
1	\$85,000 × .40 = \$34,000	\$85,000 – \$34,000 = \$51,000
2	\$51,000 × .40 = \$20,400	\$51,000 – \$20.400 = \$30,600

The declining balance method is preferable, in terms of income tax purpose, for someone who desires high written-off rates in the first years of ownership and lesser rate in the later years (Miyata, 1980).

Sum-of-the-year's-digits method:

This method assumes that a piece of equipment depreciates at a decreasing fraction each year. The denominators of all the fractions are the some of the numbers of years of economic life. The numerator of the fractions is the number of years of economic life used in sequence.

In the track type feller-buncher example, estimated economic life was 5 years and initial purchase price was $85,000. Denominator of the fraction is: 15 (1 + 2 + 3 + 4 + 5).

Depreciation value over its economic life is: $85,000 – $12,750 = $72,250

The depreciation charge and undepreciated values for first two years are:

Years	Depreciation costs ($)	Undepreciated values ($)
1	$72,250 $\times$ $^5/_{15}$ = $24,083	$85,000 – $24,083 = $60,917
2	$72,250 $\times$ $^4/_{15}$ = $19,267	$60,917 – $19,267 = $41,650

The three methods described above may be compared in terms of changes on the depreciation values during the economic life of the equipment. The declining balance method and the sum-of-the-year's-digits method have higher depreciation values during the early years (Miyata, 1980). The straight-line method, however, has a constant depreciation value for each year.

Another method for estimating depreciation costs of logging equipment has been developed by Butler and LeDoux in 1980. For computing depreciation cost in each period of year, they came up with an assumption that is:

$D(n) = D_1 (1 - D_3) D_3^{n-1}$ if $n \leq D_4$

$D(n) = 0$ if $n > D_4$

Where:

$D(n)$ = depreciation in n^{th} period,

D_1 = purchase price of the machine,

D_2 = salvage value of the machine,

D_3 = fraction of the current worth of machine,

remaining at the start of the next period, and

D_4 = number of periods until value of the machine declines to salvage value.

Butler and Ledoux assumed in their study that D_1, D_2, and D_4 should had been estimated by the logging manager directly, then D_3 could be computed from the formula

$$D_3 = (D_2 / D_1)^{(1/D_4)}$$

For example, suppose a new FMC 220CA Skidder costs $125,000 ($D_1$). The salvage value, and economic life are $18,750 ($D_2$), and 4 years, respectively. If there are two periods per year ($D_4 = 4 \times 2 = 8$), $D_3 = .8272$. Depreciation charges for period 1,2, and 3: D (1) = $26,389, D (2) = $20,818, D (3) = $16,423

The advantage of this method is that its parameters are easily estimated by a logging manager. However, any mistakes on the estimation of these parameters may cause extra charges, which is the weaknesses of each method used for estimating depreciation value.

1.1.7. 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 interest rate establishes by the lender and varies with the locality and lending institution (Miyata, 1980). If the fund comes from personal savings, then opportunity cost, or the rate this same money would earn if invested, should be used as the interest rate. Miyata (1980) recommended that twelve or 13 percent of the AAI might be used as a rule of thumb for 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 (Miyata, 1980). As a rule of thumb, 2 or 3 percent or the AAI may be used for insurance.

Every equipment owners must pay property taxes or usage taxes on his equipment (Sessions, 1992). Property tax is not charged against licensed and registered pickup trucks or crew vehicles (Bushman et al., 1988). Taxes, like interest, can be calculated by multiplying the tax rate by the average annual investment. Tax rate ranges from 2-3 percent and vary with locality and the type of equipment.

1.1.8. 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 does not have a license fee except trucks used for highway travel (Bushman et al., 1988). The annual license fee must be divided by the yearly scheduled machine hours to determine the cost of dollar per hour.

1.1.9. Average Annual Investment (AAI)

The charges for interest, insurance, and taxes can be calculated by applying the average annual investment. Two methods are usually used to compute the average annual investment. The first method provides the average annual investment over its economic life and requires straight-line method (Miyata, 1980).

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

Where:

AAI = Average annual investment over the economic life

P = Initial purchase price

S = Salvage value

N = Economic life in years

For example, using the same equipment example, the change for interest, insurance, and taxes may be calculated as follows:

Initial Purchase Price (P) = \$95,000 - \$10,000 = \$85,000

Economic Life (N) = 5 years

Salvage Value (S= 15 % of P) = \$12,750

Interest rate = 12 %

Insurance rate = 3 %

Tax rate = 3 %

$$AAI = \frac{(\$85{,}000 - \$12{,}500)(5+1)}{2 \times 5} + \$12{,}750 = \$56{,}100$$

The charge for interest, insurance, and taxes is:

$ 56,100 (0.12 + 0.03 + 0.03) = $10,098 per year.

The method is used for comparison with other equipment, or with the production cost of alternative equipment. The advantage of this method is simplicity.

The second method provides the average annual investment for each year (Church, 1978). The average annual investment equals initial purchase price at the beginning of the year plus undepreciated value at the end of the year divided by two.

Use the preceding equipment example and the data from the sum-of-the-year's-digits method of depreciation as follows:

Initial Purchase Price (P) for first year = $85,000

Depreciation Charges for the first year = $24,083

Undepreciated value for the end of year = $60,917

Then,

AAI = ($85,000 + $60,917) ÷ 2 = $72,958 for the first year.

The charge for interest, insurance, and taxes is:

$ 72,958 (0.12 + 0.03 + 0.03) = $13,132 for the first year.

The advantage of this method is that interest, insurance, and taxes can be calculated for each year. A factor of 0.6 times the initial purchase price is sometimes used as an estimation of the average annual investment (Sessions, 1992).

1.1.10. Inflation

The effect of inflation should be taken into account since the costs calculated by the AAI method are depending upon year. In order to make an adjustment for the effect of inflation; the current ownership cost is multiplied by the annual rate of inflation (Bushman et al., 1988). For example, suppose that ownership cost is \$ 25.00 /hr. at the year of 1990, and the inflation rate for 1991 is estimated to be 6 %. It is assumed that all components of the ownership cost are inflating at the same rate. The ownership cost for 1991 might be:

$ 25 /hr. × 1.06 = $ 26.5/hr.

1.2. OPERATING COST

Operating cost include maintenance and repair costs, fuel and lubricant costs, tire, track, and wire-rope replacement costs, and inflation. They are also known as variable

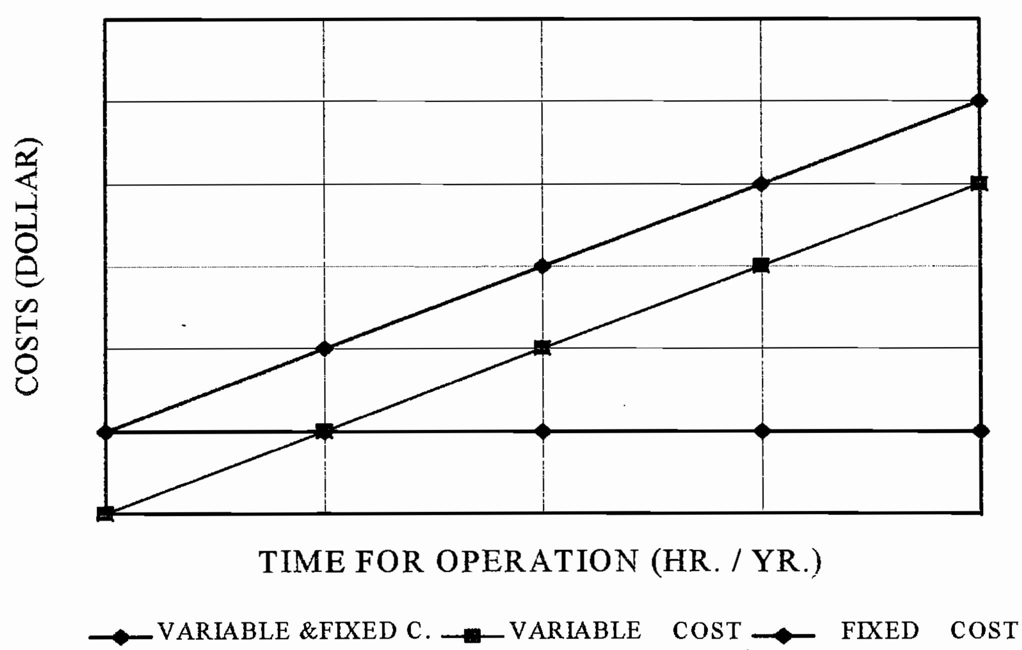


FIGURE 4. Operation and Fixed Cost as a Function of Operation and Use.

costs and change in proportion to hours of operation or use (Miyata, 1980). Figure 4 shows operation costs and fixed cost (ownership costs) as a function of hours of operation.

1.2.1. 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 use or misuse of equipment, the hardness of working conditions, maintenance and repair policies, and the basic equipment design and quality 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 Caterpillar Performance Handbook (1996) provides an estimate of the dollar-per-hour cost for maintenance and repair under varying operation conditions for different classes of equipment. An extended-life multiplier is given for the case, where a machine is to be used beyond its economic life, to adjust the cost for total estimated hours of machine use.

Another method, which is commonly used, is to estimate maintenance and repair cost as a percent of depreciation. Table 4 shows the percent of depreciation for some types of harvesting equipment. Hourly maintenance and repair cost is estimated by multiplying the percent rate by the depreciation cost.

TABLE 4. Maintenance and Repair Rates for Selected Equipment (Adapted from McGonagill 1975, Warren 1977, and Sessions 1992).

MACHINE TYPES	PERCENTAGE RATE
Crawler tractor (including winch)	100
Chain saw	100
Agricultural wheel tractor (including winch)	100
Rubber-tired skidder (cable chokers)	50
Rubber-tired skidder (hydraulic 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

For example, using the data from the preceding equipment example, depreciation charge for feller-buncher is $9.03 per scheduled machine hour, and maintenance and repair rate is 50 % from table 4, then,

$9.03 /SMH × .50 = $4.52 /SMH

If utilization for feller-buncher is 65 %, maintenance and repair cost per actual machine hour is:

Depreciation charge = $14,450 per year

Maintenance and repair cost (SMH) = $14,450 × .50 = $7,225 per year

Scheduled machine hour per year	= 200 days/yr. × 8 hr./day = 1600 hr.
Actual machine hour per year	= 1600 × 0.65 = 1040 hr./yr.
Maintenance and repair cost	= \$7,225 ÷ 1040 hr. = \$6.95/hr.

1.2.2. 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),

$$LMPH = \frac{K \times GHP \times LF}{KPL}$$

Where:

LMPH = Liter used per machine hour

K = kg of fuel used per Hp/Hr.

GHP = Gross engine 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

Typical values for these variables are given in Table 5, which is adapted from Sessions (1992).

TABLE 5. Fuel weights, consumption rates, and load factors for diesel and gasoline engines.

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

For diesel engine;

$$\text{Hourly fuel cost} = \frac{0.17 \times 0.54 \times GHP}{0.84} \times \cos t / liter$$

$$= 0.109 \ \times GHP \times \cos t \ / \ liter \text{ (local price)}$$

For gasoline engine;

$$\text{Hourly fuel cost} = \frac{0.21 \times 0.54 \times GHP}{0.72} \times \cos t / liter$$

$$= 0.158 \times GHP \times \cos t \ / \ liter \text{ (local price)}$$

It is important to convert fuel used based on machine hours to fuel used based on scheduled machine hours. For example, suppose that a cable skidder (gasoline engine) has 90 Hp and the local price of fuel is \$0.38 per liter under medium load conditions.

Then,

Fuel amount per hour = 0.158 × 90 = 14.22 liters

Fuel cost per hour = 0.158 × 90 × 0.38 = \$5.4 /Hr.

If the skidder works only 6 machine hours out of a scheduled eight hours shift, then fuel consumption per SMH becomes:

$$14.22 \text{ liters} \times \frac{6hr / SMH}{8SMH} = 10.67 \text{ liters}$$

Fuel cost per hour = 10.67 liter/SMH × \$0.35/liter =\$3.74 /SMH

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 (Sessions, 1992). 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 formula as follows (Sessions, 1992):

$Q = .0006 \times GHP$ (crakcase oil)

$Q = .0003 \times GHP$ (transmission oil)

$Q = .0002 \times GHP$ (final drives)

$Q = .0001 \times GHP$ (hydraulic controls)

Q = Lubricant consumption rate (liter/hr)

When the machines are operating in heavy dust, deep mud, or water the estimates should be increased 25 percent (Sessions, 1992). 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.

Another way that relies on rule of thumb is that the cost of lubricants and grease is 36.8 percent of the cost of fuel (Brinker et al., 1989). For example, suppose that fuel consumption is 10 liters per SMH, fuel cost is $.38 per liter, and lubricant cost is 36.8 percent of the fuel cost, then, cost for fuel would be:

10 liter/SMH × $0.38 /liter = $3.80 /SMH,

For lubrication:

$3.80 /SMH × .368 = $1.40 /SMH

The Caterpillar Performance Handbook (1996) also provides several tables, which show hourly fuel and lubricant consumption for different classifications and uses of equipment.

1.2.3 Tire, Track, and Wire-Rope Replacement Cost

Tires, tracks, and wire-rope costs should be estimated separately from the piece of equipment and considered an operating cost due to their shorter lives. Labor costs for these replacements are included in this cost. The estimates of tires, tracks, and wire-rope 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, 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. There are a few sources available that show tire, track, or wire-rope life. Tire and track life is expressed in hours while wire-rope life is in total production achieved before replacement is required.

If local experience is not available, estimates of tire life based on tire failure under various application conditions are given in Table 6 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.

TABLE 6. Guideline for tire life for off-highway equipment (Adapted from Caterpillar Performance Handbook 1996).

EQUIPMENT	TIRE LIFE (MACHINE HOUR)		
TYPES	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.

Since 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):

$$\text{Hourly tire cost} = \frac{1.15 \times (tire - \cos t)}{tire - life}$$

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, 1988). For example, assume that total cost of track replacement is $15,000 for a 3-years period of operation. If annual production time for this operation is

$$1{,}200 \text{ SMH } (1{,}600 \times \frac{6hr./SMH}{8SMH} = 1{,}200 \text{ SMH})$$

The total scheduled machine hours are: 1,200 × 3 =4,800 hr. for a 3-years period, then,

$$\text{Hourly track replacement} = \frac{\$15{,}000}{4{,}800hr.} = \$3.13 \text{ /SMH}$$

Wire-rope life can be converted from MBF to scheduled machine hours if gross MMBF produced before replacement, and estimated average production per actual machine hour are known (Bushman, 1988). For example, suppose that gross MBF produced before replacement is 10,000 and estimated average production per hour is 6 MBF, then estimate of wire-rope life in scheduled machine hours is:

10,000 MBF ÷ 6 MBF/hr. = 1666 SMH

In order to determine the cost of wire-rope replacement, the following parameters must be known: the length of the wire-rope to be replaced and replacement cost per unit length. For example, if wire-rope length is 900 meters (about 3000 ft), and the price per meter of wire-rope replacement is $4.4, then replacement cost per SMH is:

(900 m. × $4.4/m.) ÷ 1666 SMH = $2.38/hr.

Table 7 has been developed by the US Forest Service as a guide for wire-rope life for cable logging systems in the Pacific Northwest.

TABLE 7. Wire-Rope Life in MMBF (Adapted from Cable Logging Sysytems 1974).

Logging System	Line Use	Line Size (in)	Line Classification	Line Life (MMBF)
Standing Skyline	Skyline	1 3/4	6 × 21	20 to 25
		1 1/2	6 × 21	15 to 25
		1 3/8	6 × 21	8 to 15
	Mainline	1	6 × 26	10 to 15
	Haulback	3/4	6 × 26	8 to 12
		7/8	6 × 26	8 to 12
Live Skyline	Skyline	1 1/2	6 × 21	10 to 20
		1 3/8	6 × 21	8 to 15
		1	6 × 26	6 to 10
	Maine Line	1	6 × 26	10 to 15
		3/4	6 × 26	8 to 12
		5/8	6 × 26	8 to 12
	Haulback	7/8	6 × 26	8 to 12
		3/4	6 × 26	8 to 12
		1/2	6 × 26	6 to 10
	Slackpulling	7/16	6 × 26	5 to 8
Running Skyline	Mainline	1	6 × 26	8 to 12
	Haulback	3/4	6 × 26	4 to 8
High Lead	Mainline	1 3/8	6 × 26	8 to 15
		1 1/8	6 × 26	6 to 12
	Haulback	3/4	6 × 26	6 to 12
Carriage	Skidding	1/2	6 × 26	0.5
		7/8	6 × 26	3 to 5
Strawline		3/8 to 7/16	6 × 19	5 to 8
Skyline Chokers		1/2 to 3/4	6 × 25	0.2 to 0.3
Guylines			6 × 25	4 years

1.2.4. Inflation

Adjustment for inflation in operating costs are relatively easy to take into account since the current cost of fuel and lubricants, and tire, track, or wire-rope replacement can be used (Bushman, 1988). Maintenance and repair cost should be inflated by the current inflation rate if this cost was estimated by using a percent of depreciation.

1.3. LABOR COST

The cost to keep an operator on the job maybe 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 (Sessions, 1992). Labor cost is generally considered an operator cost, however, most operators do minor repairs when the machines are down. In this paper, labor cost, in scheduled machine hour, is calculated separately from other components.

Labor cost components include wages, draw, and salaries, Social Security, Federal Unemployment Tax, State Unemployment Tax, Workers' Compensation Insurance, Health Insurance, and Labor Burden Factor. Other possible employer contributions, which might be paid vacation, retirement plans, travel pay, and administrative cost, are not include to labor cost unless they are paid by the employer (Bushman, 1987).

1.3.1. Wages, Draws, and Salaries

Wages are defined as a dollar per hour 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). Calculation of total wage payment is; total hours worked per hour plus the hours worked over 40 in week are multiplied by the overtime wages that are one and a half of the regular wages per hour.

Draws are a predetermined amount of payment given to employee on a scheduled basis like twice a month and contribute about 20 % to the total labor cost in Oregon (Bushman, 1987). Salaries are also a predetermined amount of payment given to permanent employees on a regular basis.

1.3.2. Social Security

Social security provides retirement benefits, survivors' benefits to wife and children in the event of the father's death, disability insurance, and health insurance for those over 65 (Bromley, 1968). The employer and the employees, including partners and salaried employees, make 50-50 payments for Social Security tax (Bushman et al., 1988). The social security rates are determined by Congress and take effect on January 1 of each year.

The ratio of Social Security payment to the total wages can be determined by dividing the total social security tax paid for the year by total company wages for the same year (Bushman, 1987). After that it is easier to compute the total cost of Social Security for the logging crew by multiplying total crew wages by the non-adjusted rate of Social Security tax.

1.3.3. Federal Unemployment Insurance

Every employer who employs a person for any part of a day during each of 20 different calendar weeks or pays wages of $1,500 or more in any calendar quarter is subject to federal unemployment insurance (Miyata, 1980). This is used by the federal government to supplement unemployment benefits for workers. The insurance rate is determined by Congress and remains in effect for the whole year (Bushman, 1987). Payments to registered partners are not subject to federal unemployment insurance.

1.3.4. State Unemployment Insurance

It is essential to remember that these rates differ from state to state. Each state requires specific records, and the rates of taxation is from 1.4 percent (Mississippi) to 2.8 percent (Maine) (APA, 1977). In many states, the rate paid by the employer varies depending on the amount of unemployment insurance money paid to his ex-employees (Bromley, 1968). More information can be obtained from the Sate Employment Security Agency and State Insurance Commission.

1.3.5. 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 (Bromley, 1968). The rate of workmen's compensation also varies from state to state. In Oregon, any person who furnishes services for payment is subject for this insurance (Bushman et al., 1988). According to Hensel (1977) this rates range from $10.20 (North Carolina) to $55.52 (Kentucky) per hundred dollars of payroll in logging or lumbering operations. The straight-time portion of pay and monetary incentive pay are subject to workmen's compensation. However, partners and corporate officers are not subject workers under the law.

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. Table 8 indicates the major logging industry classifications and their associations. In order to compute the workmen's compensation premium factor, a simplified formula can be used as follows (Bushman et al., 1988);

(Logging classification rate ÷ 100 (from Table 8)

× (experience modification)

× (1 – premium discount)

× (1 + tax rate for Workmen's Compensation)

+ 0.0012 for Workday Tax

= Workmen's Compensation factor

1.3.6. Health Insurance

The portion of health insurance premiums paid by the employer is considered as part of the total labor cost (Bushman, 1987). To compute health or life insurance cost, the amount of insurance premiums paid for each dollar of total wages must be computed (Bushman et al., 1988). Cost of insurance premiums paid for whole year is determined by total wages for the same time period. Other employer contributions may include paid vacation, paid holidays, paid sick leave, uniforms, safety equipment, etc. (Miyata, 1980). These items vary with locality and employers.

TABLE 8. Workmen's Compensation Rates (Oregon Logging Classification 1986).

CLASSIFICATIONS	JOBS COVERED	RATE ($/$100 of payroll)
2702	All logging positions Falling - Bucking (Hand and Mechanical) Mechanics (on logging site) Road, Landing, and Skidtrail Construction During Logging Operation	27.50
2703	Mechanics (repair shop)	6.40
5511	Road, Landing, and Skidtrail Construction Before Logging Operation	12.15
0124	Brush Piling (Hand and Mechanical) Slash Burning, Stremcourse cleanout	27.98
9310	Log-truck Drivers	15.60
9309	Fire Watch	8.75
8810	Clerical (Separate Office Area)	0.56

Adapted from Bushman (1988).

1.3.7. 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.

If partner draws are considered into total labor cost, they must be handled with a separate labor burden factor because unemployment tax and workers' compensation insurance don't include labor cost (Bushman, 1987). The following example shows the use of the labor burden factor for a felling and bucking operation where 4 employees and 2 owners are involved the job. Owners usually are paid more compared with the other employees since they have more responsibilities and they may organize the operations.

HOURLY EMPLOYEES

WAGES

Straight-time Portion (\$20/hr. × 4 workers)	\$ 80 /hr.
Overtime Portion	\$ 8 /hr.
Total Hourly Wages	\$ 88 /hr.

LABOR BURDEN

Workmen's Compensation (Table 8)	27.5 %
Social Security	7 %
State Unemployment Insurance	4 %
Federal Unemployment Insurance	1 %
Health Insurance	2 %
Burden Factor for Workemen's Compensation:	27.5 %
Burden Factor for Other Items:	14 %

Hourly employees =	\$ 88 /hr.	= \$ 88 /hr.
	+ \$ 80 /hr. × .275	= \$ 22 /hr.
	+ \$ 88 /hr. × .14	= \$ 12 /hr.
	Hourly Labor Cost	= \$ 122/hr.

PARTNER DRAWS

DRAWS

Straight-time Portion (\$25/hr × 2 owners)	\$ 50 /hr.
Overtime Portion	\$ 0 /hr.

LABOR BURDEN

Social Security	7 %
Health Insurance	10 %
Total Burden Factor:	17 %

Partner draws =	\$ 50 /hr.	= \$ 50 /hr.
	+ \$ 50 /hr. × .17	= \$ 8 /hr.
	Partner Draws	= \$ 58 /hr.

Total Labor Cost = Hourly labor cost + Partner draw

= \$ 122 /hr. + \$ 58/hr. = \$ 180 /hr.

During the last few decades, the Workmen's compensation rate has become a serious limiting factor in terms of the number of labor employed for logging operations. In some cases where this rate approaches to 100 percent, workmen's compensation burden becomes equal to straight time portion of hourly wages.

1.3.8. Direct Labor Cost and Supervisions

Labor cost can be computed by following approach which is more simple than the way described above, however, less sensitive since fringe benefits rates are assumed as the same for all employees worked during the operation (Bushman, 1987). On the other hand, this method is commonly used for labor cost calculations because of its simplicity.

In this method, total labor cost is divided into two sections; Direct Labor Cost and Supervision and Overhead.

Direct labor cost portion is computed as following equation:

$$\text{Direct L.C.} = TW \times \left(\frac{100+F}{100} + \frac{T}{OP}\right)$$

Where:

TW = Total crew wages ($/hr.)

OP = Operation time per per day (hr./dy)

T = Travel time per day (hr./dy)

F = Fringe benefits rate (%)

Supervision and overhead portion of the total labor cost is defined as the percentage of the direct labor cost.

Supervision = Direct L.C. × SV

SV refers to percent of Direct L.C. for supervision. Therefore, total labor cost is equal Direct L.C. plus Supervision. Use the preceding labor cost example, total wage for a felling and bucking crew including two owners is $133 per hour. Percent of fringe benefits, travel time per day, and operating hours per day are estimated as 30 %, 0.5

hours, 8 hours, respectively. Suppose that one of the owners is supervising the operation, which means direct labor cost is equal to total labor cost.

Then,

$$\text{Total L.C.} = \$133/\text{hr.} \times \left(\frac{100+30}{100} + \frac{0.5hr.}{8hr.}\right) = \$181/\text{hr.}$$

1.4. CONCLUSIONS

Machine rate results for the various forest harvesting equipment selected for analysis are listed in the tables in the appendices part of the project. In these tables, machines were first organized by category and manufacturer, then other information including mobility type, attachment type, and engine horsepower are shown in Appendix B.1. Parameters such as purchase prices, economic life in year, utilization rate, salvage rates, maintenance and repair rate, interest, insurance and tax rate, kg of fuel used for HP/hr., load factor, weight of fuel, fuel consumption, fuel price per liter, and percent of fuel cost for lubricant were listed in Appendix B.2 and Appendix A.3.

Appendix B.4 contains annual cost data including Depreciation cost, Average Annual Investment, Interest cost, Insurance, and Tax cost, and Maintenance and Repair cost. Labor cost parameters including hourly wages, labor burden factors, and labor cost were listed in Appendix B.5. Appendix B.6 indicates total ownership cost, total operating cost, and total machine rate based on both SMH and PMH for specific harvesting machines. Tire and truck replacement cost and labor were computed under repair and maintenance cost. Labor costs for equipment operators and other logging positions were updated from Associated Oregon Loggers 1996 Annual Wage Survey. In order to estimate labor rates for the year of 1997, a 3 % average annual percentage rate of increase was used in the following formula:

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

Where:

V_n = Average labor cost in 1997

V_o = Average labor cost in 1996

n = Number of years

i = Inflation rate for labor cost

Appendix B.7 indicates the data, hourly wages for various logging positions, machine operations, annual inflation rate (3 %), labor burden rates, and estimated labor costs. The format of the machine rate worksheet used to calculate actual machine rate was shown in Appendix A.1. Machine rates were also estimated for selected forest harvesting machines under representative conditions in Turkey (Appendix D.5). The data including interest rate (20%), insurance (5%), tax (9%), fuel price ($0.87/liter), average hourly wages ($4.25/hr), labor burden rate (28%) are collected from Turkey and listed in Appendix D.

As a result, machine life, and purchase price are the most important factors influencing machine rate. Even a 1-year change in machine life estimation results in a dramatic change in the average annual investment and annual depreciation. That changes all the costs defined by these values. Purchase price, on the other hand, changes the value of the average annual investment, annual depreciation, and maintenance and repair costs. Machine rate estimates may be used to compare machines or machine combinations to determine the most economical combinations for different harvesting systems.

2. ANIMAL RATE

Today highly mechanized systems have been used for forest harvesting in many countries. Machines have replaced the traditional sources of energy, which are human power and animal power. They are very expensive, energy consuming, and highly correlated with the price at the fuel that is limiting factor in developing countries (Rodriguez, 1986). In some cases where machines have very low cost efficiency, draught animals provide a solution to the need for power and make a useful contribution in energy saving.

In many regions of the world, animals are the energy sources for agricultural and forestry work and transportation. Various species of animal have been used such as oxen, donkeys, horses, elephants, lamas, yaks, and mules (Rodriguez, 1986). In this paper, skidding with ox is studied due to its versatility (Rodriguez E.O. 1986). It can be used in agricultural and forestry activities. The ox is slow but very strong and easy to drive, and at the end of its active life, it provides a good yield in beef, so the investment in it may be recovered.

Animal rate calculation is similar to the machine rate, however, some types of cost vary. The animal rate is usually divided into fixed cost, operating cost, and labor cost.

2.1. FIXED COST

Fixed cost components include the investment cost of the animal or team, double head yoke, logging chains, and any other investments with a life more than a year. The salvage cost of animal is similar to the machine rate, but in the animal case, the salvage value is often determined by its selling value for meat (Sessions, 1992). Average annual investment, interest, taxes, and insurance are computed the same as for equipment. Since the animal yokes and miscellaneous investments usually have different life times, the fixed costs for them must be calculated separately.

Animal support costs, which include pasture rental, food supplements, medicine, veterinarian services, and any after hours care-feeding, washing or guarding, do not vary with working hours. The money investment in medical attention, medicine and vaccination can be considered to be five percent of the purchase value of a team of oxen (Rodriguez, 1986). Medical costs per hour are estimated by the purchase value of a team of oxen divided by annual work in hours. Pasture area (ha/animal) is estimated by dividing the animal consumption rate (kg/animal/month) by the forage production rate (kg/ha/month) (Sessions 1992). Food supplements, medicine, vaccinations, and veterinarian schedules can be obtained from Agricultural Extension Agents.

2.2. OPERATING COST

Operating cost components include maintenance and repair costs for yokes, chains, and miscellaneous equipment (Sessions, 1992). Additional or special feed given to oxen during skidding may also include operating costs.

2.3. LABOR COST

This is made to the driver (and any other helpers) for driving the animal during skidding (Sessions, 1992). It covers only the wage of one workman and doesn't include expenditure for people engaged in stacking, since this is a different job. For full year operation, it is calculated as the labor cost per year including social costs divided by the average number of working days or hours for the driver (Sessions, 1992).

3. FELLING AND BUCKING

Felling is the first job of the harvesting system, and probably the most difficult and dangerous part of the logging operation, which requires skill and good judgment (Simmons, 1979). Bucking, the second job of the harvesting systems, may or may not follow the felling, which depends on the specified harvesting systems as follow (Burrows, O.J. 1983):

Whole-Tree: Trees are felled and the full tree with limbs and top is yarded.

Tree-Length: Trees are felled, topped, and limbed at the stump, and yarded as a tree length piece.

Log-Length: Trees are felled, limbed, and bucked in the stump area.

Bucking a tree into logs to maximize value is an important factor in optimizing log value. Loggers must be able to buck trees into logs that will maximize their profit. Optimal bucking is defined as cutting a tree into parts that maximize total tree value according to the view point of the decision-maker (Sessions, 1988). Computers are now used in some harvesters to control bucking decisions. Bucking a tree into the log-length is very difficult in the woods due to the natural obstacles such as brush, rocks, stumps, piled trees, snow or mud (Simmons, 1979).

3.1. FELLING AND BUCKING OPERATION

The efficiency of felling and bucking is affected by two factors including productivity and preparation for handling after felling. Productivity is the amount of production laid down on the ground ready for skidding or prehauling and is measured in cords or other units per working hour. Preparation for handling after felling is related to how well the fallen trees are arranged for the following operation.

Direction of fall is one of the factors influencing production. Especially in bigger timber, directional felling is highly desirable to make the skidding job faster and to reduce stand and log damage. Proper location of skid trails is very important since it makes the job more productive and economically feasible (Simmons, 1979).

The herringbone pattern is the most desirable method to fell trees so that they can be easily transported out butt first onto a skid trail (Figure 5). When delimbing has to be

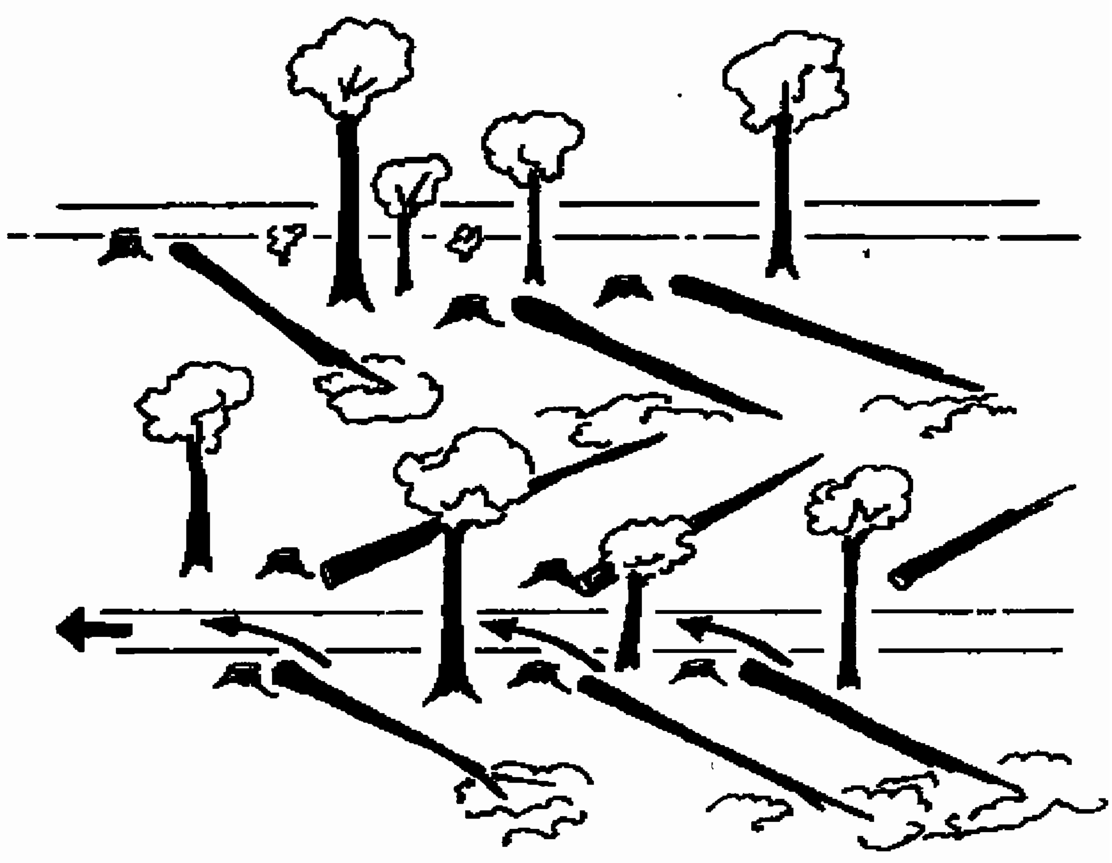


FIGURE 5. Felling in a Herringbone Pattern Away From a Skid Road (Adapted from Aulerich 1975).

done in the woods, the majority of the limbs and tops are left away from the skid trail (Simmons, 1979). Therefore, there is no rehandling required to remove them out of the way and skidding equipment will not have to spend extra effort to plow through them. If whole-tree logging is practiced, this method of pulling trees out butt first is the only possible one (Simmons, 1979).

Aulerich (1975) studied felling and bucking to determine cutting production and cost for thinning operations over different conditions. Three random thinning operations including light thinning (37 % stem removal), medium thinning (51 % stem removal), and heavy thinning (62 % stem removal), and herringbone thinning (100% stem removal) were evaluated (Figure 6).

As a result of his study, average felling and bucking time per tree was divided into two activities and summarized in seven categories (Table 9). The following results were obtained from the study:

- "Buck tree" and "Other" are the most time-consuming activities (Table 9).
- The time required for felling and bucking decreases as thinning intensity increases, which means daily production increases as percent of stems per hectare increases.
- Loggers spend more time cutting trees and less time selecting trees in high intensity.
- Hangups occur more often as thinning intensity decreases, and requires additional work to land the tree on the ground.

Various other studies have shown that felling and bucking production increases and harvesting cost decreases with strip thinning than with selection thinning (Kramer 1974, Aulerich 1975, and Twaddle 1977). According to Hamilton (1980), the cost of unit layout is also lower with strip thinning than selection thinning since tree marking can be

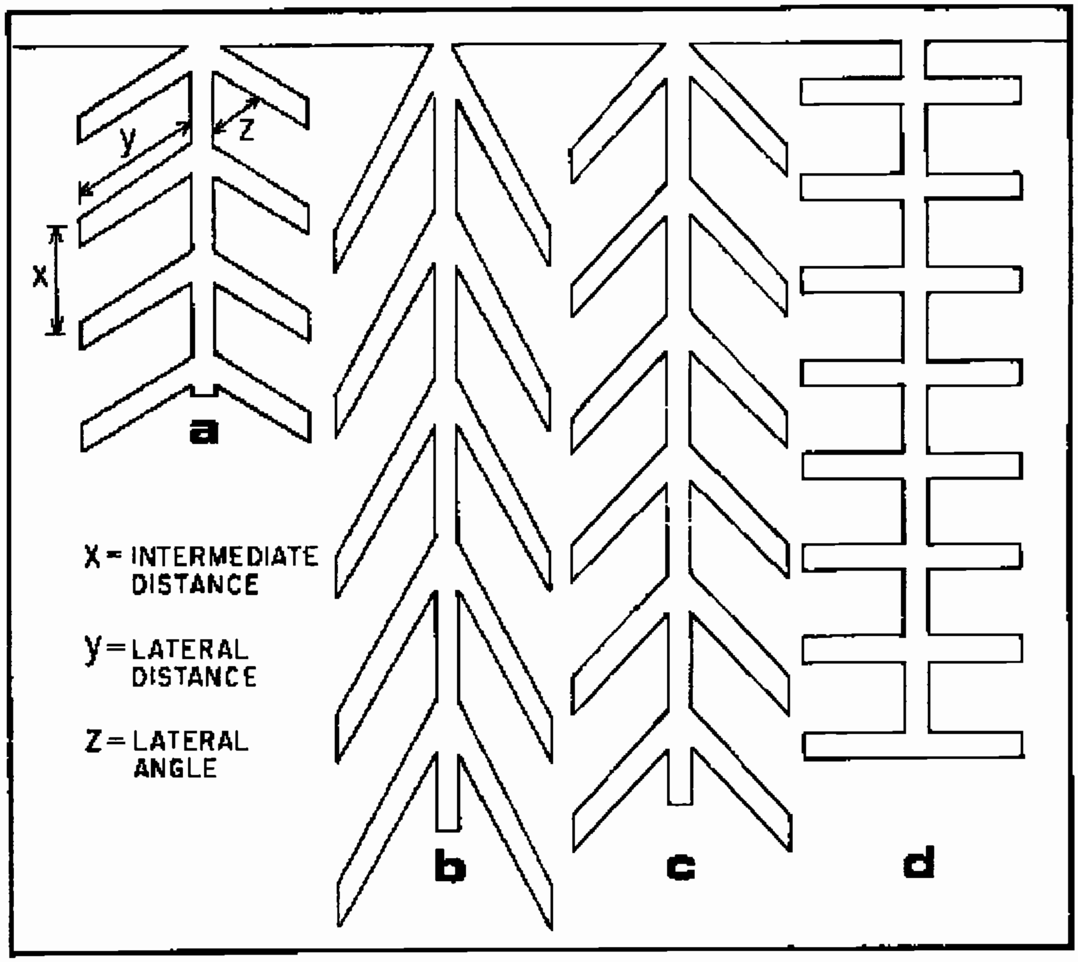


FIGURE 6. Herringbone Thinning Patterns adapted from Aulerich (1975).

(a) Lateral Distance = 35.7 m (117 ft)
Intermediate D. = 27.4 m (90 ft)
Lateral Angle = 60 ^{0}

(b) Lateral Distance = 61.0 m (200 ft)
Intermediate D. = 43.0 m (141 ft)
Lateral Angle = 30 ^{0}

(c) Lateral Distance = 43.4 m (142 ft)
Intermediate D. = 35.1 m (115 ft)
Lateral Angle = 45 ^{0}

(d) Lateral Distance = 30.5 m (100 ft)
Intermediate D. = 24.4 m (80 ft)
Lateral Angle = 90 ^{0}

TABLE 9. Average Felling and Bucking Time per Tree by Activity and Intensity of Stem Removal (Minutes per Tree/ Percent of Total Time per Tree).

Intensity	Select Tree	Fell Tree	Correct hangup	Buck Tree	Limb Tree	Delay	Otrher[1]	Total/ Tree
Light	0.79/11	0.97/14	0.56/8	1.00/20	0.24/3	1.31/18	1.79/25	6.66
Medium	0.89/12	1.24/16	0.54/7	1.75/23	0.82/11	0.79/11	1.49/20	7.52
Heavy	0.43/7	1.01/16	0.23/4	1.36/22	0.44/7	1.29/21	1.37/23	6.13
Herringbone	0.05/1	1.45/26	0.10/0	1.76/32	0.51/9	0.59/11	1.51/21	5.61

[1] Includes moving, site preparation, equipment collection, felling of non-merchantable material, and helping another worker.

eliminated. Kellogg, Olsen, and Hargrave (1986) compared felling and yarding production, and cost rates between thinning treatments including narrow spacing, wide spacing, and strip. Total cycle time was divided into two elements, one contributed directly to output during the cycle and one is minor, nonproductive. Delay time was recorded separately. Independent variables measured for developing a multiple linear regression model were move distance, number of bucking cuts, number of limbs, slope, species, and tree volume.

3.2. FELLING AND BUCKING EQUIPMENT (CUTTING HEADS)

Cutting heads are divided into two types: fellers that cut trees at the base, and harvesters that both fell and process (delimbs and crosscuts) trees into log lengths (Kellogg et al., 1992a). Most common types of fellers and harvesters are listed in Figure 7.

3.2.1. Fellers

They are of two types: shear felling heads and non-shear felling heads.

Shear Felling Heads: The major disadvantages of the shear head are butt damage and the associated loss of wood fiber. According to Greene and McNeel (1990), design improvements (McLauchlan et al., 1975) and better shear maintenance can not eliminate butt damage. However, shears have been used predominately for harvesting trees for pulpwood and, occasionally, saw timber (Kellogg et al., 1992a).

Non-Shear Felling Heads: Non-shear felling heads were developed to offset the drawbacks of shears in early 1980s (Kellogg et al., 1992a). The most popular non-shear head is the disk saw in North America. Disk-saws are of two types: continuous and intermittent. Continuous saws have a horizontal disk on which the cutting teeth are cone

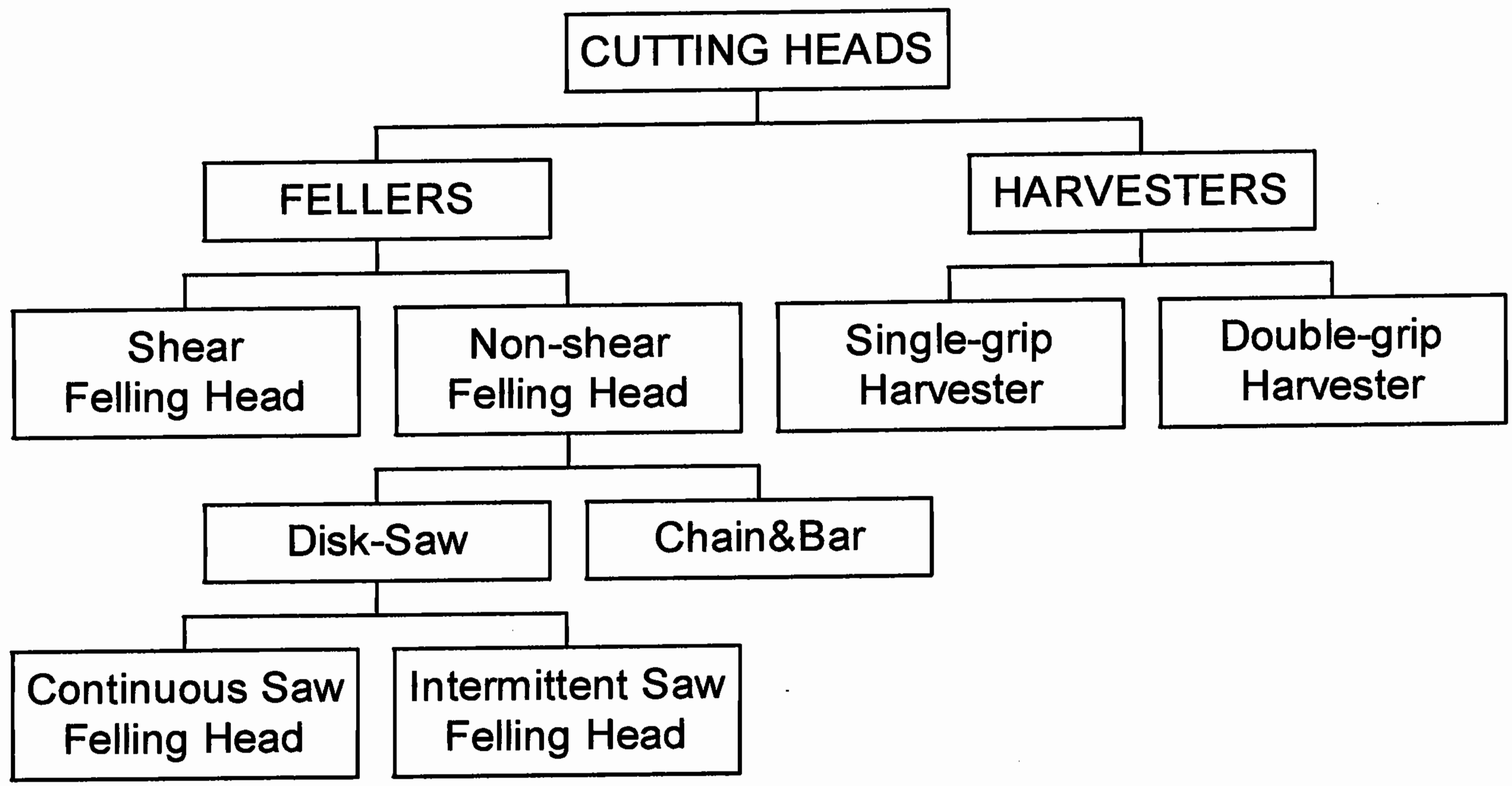


FIGURE 7. Categorization of the Most Common Types of Cutting Heads (Adapted from Kellogg et al., 1992a).

shaped and easily replaced. The head relies on inertial energy and large mass of the thick disk to sever the tree, and the tree is gripped by the head after felling is completed (Kellogg et al., 1993).

The continuous disk saw has the advantage of making a minimum butt damage due to gripping the tree after felling is done, and of having higher efficiency in dense stands of small-diameter trees (Kellogg et al., 1992a). However, the disadvantage of the saw is making a wide kerf and leaving high stumps.

Intermittent saws rely on high torque to sever the tree, and the thinner horizontal disk is activated after the arms of the felling head grasp the tree (Greene et al., 1989). Intermittent saws provide better control during felling since the tree is gripped during felling, which may reduce butt damage. They are used in larger timber than the continuous saws, and require less power to run. Besides, they can operate on steeper terrains with simple carriers (Kellogg et al., 1992a).

Chain-and-bar saw heads use conventional saw-chain and bars, which travel from one side of the head to the other to sever the tree. The chain and bar is very similar to a chain saw, but is operated from the machine cab. It makes a clean cut and causes narrow kerf, however, requires a more skilled operator because of need to prevent bar damage (Kellogg et al., 1992a).

Greene (1991) had a survey to identify factors relating to the use of saw heads, including chain-and bar saw heads, continuous saws, and intermittent saws for harvesting sawlogs. He listed important factors influencing purchase of these saw heads and compared their productivity and cost. According to this study, purchase price, fuel economy, production rate, and maximum tree size was the most important factors affecting chain-and-bar saw head's purchase. Purchase price is a major factor since operations with chain-and-bar saw heads are less capital intensive.

The most critical purchase factors for continuous sawheads are the local dealer, production rate, and the manufacturer. They are highly productive in a range of tree sizes. They are 40 percent more productive than shears in 10 to 20 in. timber (Greene et al., 1989).

Intermittent operation, safety, easy to fix teeth, and local dealer were the important factors influencing intermittent sawhead purchase. It was found that fuel consumption of intermittent saw heads was more than for chain-and-bar heads, but less than for continuous saw heads.

Another study was conducted by Greene and McNeel (1991) to examine the productivity and costs of chain-and-bar saw heads, intermittent-disk saw heads, continuous-disk saw heads, a shear head, and a Bell Model T saw head feller-buncher. In timber of less than 22 in. dbh, intermittent-disk saw heads and chain-and-bar saw heads were as productive as shears. The saw heads were more productive than shears in timber of 12 in. dbh or greater. The continuous-disk saw head had a cost of felling-bucking, which was nearly equal to a 20 in. dbh shear in timber of 11 in. dbh or greater.

The Bell feller-buncher, on the other hand, felled and bunched trees at a lower cost than the 20 in. shear in timber of 8 in. dbh. Thus, with the exception of the Bell feller-buncher, saw head feller-bunchers are more expensive for harvesting trees than shear feller-bunchers.

3.2.2. Harvesters

Harvesters are commonly used in mechanized cut-to-length (log-length) systems in which the harvester fells and processes trees into log lengths (max. 20 ft), and a forwarder transports the logs to the roadside. The most important factors influencing the productivity of a harvester are log size, operator skill and motivation, branch size, number of merchantable trees per in unit area, slope, ground conditions, and undergrowth density (Makkonen, 1991, and Raymond, 1988). When stand density and tree size increase, there is an increase in production and a decrease in the harvesting cost per unit volume.

However, high initial investment, cutting less than a fixed diameter (max.20 in.) of the material, unsafe operation conditions on steep slopes, and high possibility of value lost for solid wood products such as lumber because of splitting above the cut, have become the most important disadvantages of the mechanized felling heads (Kellogg et al., 1992a). Harvesters are divided into two groups: single-grip (Figure 8) harvesters and double-grip harvesters (Figure 9). Single-grip harvester both fell and processes (delimbs and crosscuts) with a single boom-mounted unit (Kellogg et al., 1992b). The double-grip harvester severs the tree with a boom-mounted unit and places it, butt first, in the carrier-mounted processing unit for delimbing and bucking (Kellogg et al., 1992a and Kellogg et al., 1992b).

In timber of less than 22 in. diameter, the single-grip harvester is extremely productive at felling, delimbing, and bucking (Brown, 1995). According to a study conducted by Kellogg et al (1992a), single-grip harvesters have become more popular than double-grip harvesters.

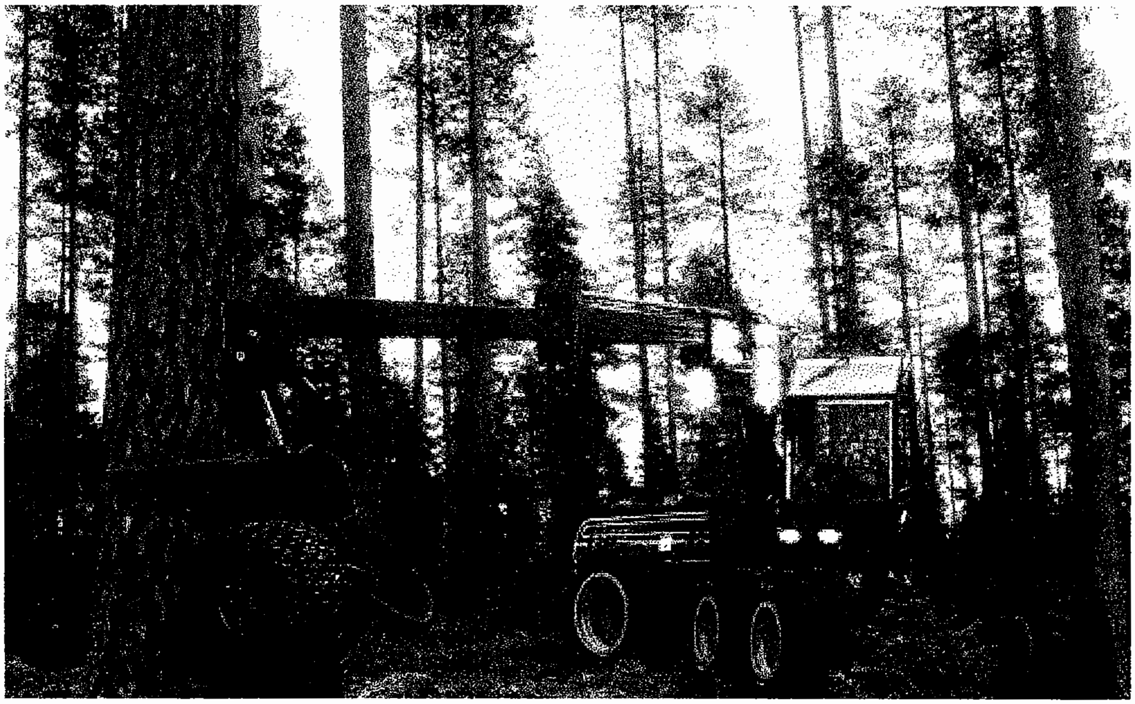


FIGURE 8. Single-grip Harvester Cutting the Trees in the Woods.

FIGURE 9. Double-grip Harvester Delimbing, and Bucking The Trees During Thinning Operation.

3.3. TIME ELEMENTS

The time elements of felling and bucking considered in the work cycle include move and select, cut and wedge, and buck and limb (Figure 10).

Move and select: This is the time spent moving from the completion of the previous activity, selecting the next tree to be cut, and preparing to fall the tree.

Cut and wedge: This is the time spent working to fall the tree.

Buck and limb: This is the time spent limbing, measuring, and bucking the tree.

In addition to the time elements, independent variables of felling and bucking are listed as follows (Kellogg et al., 1984):

Diameter: Butt diameter inside the bark of the felled tree.

Number of bucking cuts: Number of bucking cuts during the limbing and bucking process, including the top cut.

Move distance: Estimated total distance that the cutter travels from the work area to next tree to be cut.

Number of limbs: Number of limbs per tree removed during the limbing and bucking.

Tree volume: Total gross volume in cubic meter from stump to merchantable top.

Slope: Ground steepness (%) measured perpendicularly to the contour at a tree being cut.

Species: Types of tree cut: Douglas-fir, hemlock, or spruce.

Time elements for the harvester are (Kellogg et al., 1994):

Moving: The time begins when the harvester tracks start moving, and ends when it stops moving to perform some other task.

Position: The time begins when the boom starts to swing toward a tree, ends when felling head rests on a tree.

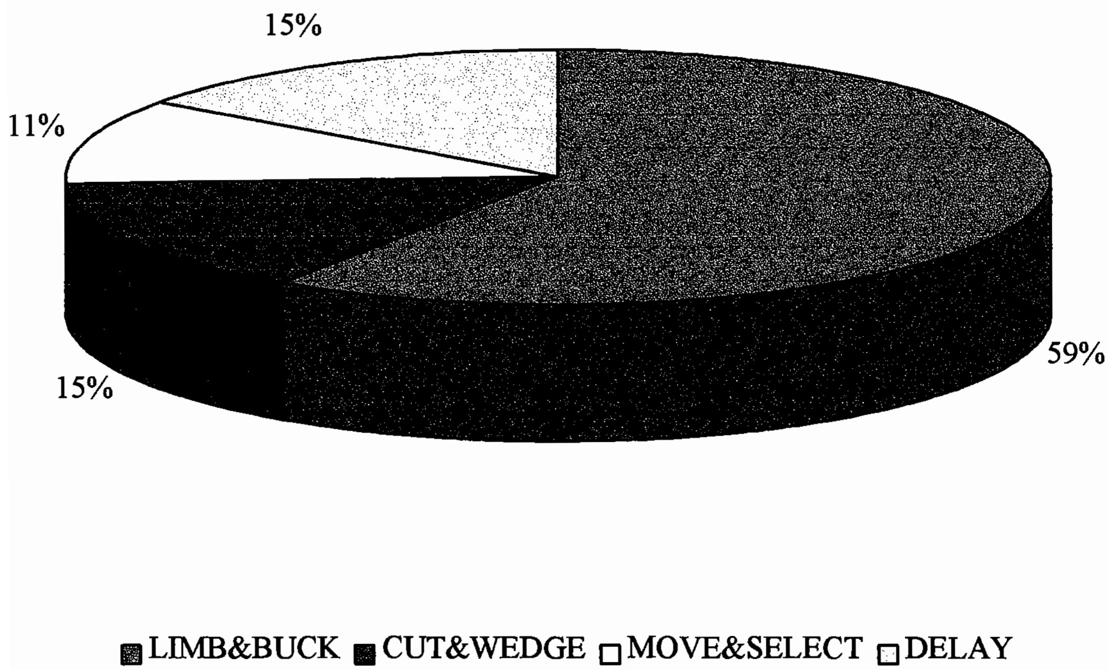


FIGURE 10. Felling Cycle Elements (Adapted from Kellogg, 1986).

Felling and Dropping: The time begins when the felling head is attached to a tree, ends when the tree hits the ground, or when processing begins.

Processing: The time begins when the tree hits the ground, or when the felling head begins to pull the tree through the delimbing knives, ends when processing is complete.

Brushing: The time spent on removing brush and felling of unmerchantable trees.

Piling: The time spent on piling or sorting logs in the woods.

Planning: Assessment by the harvester operator of area or tree to cut, while remaining in the stationary machine.

3.4. DETERMINING CYCLE TIME

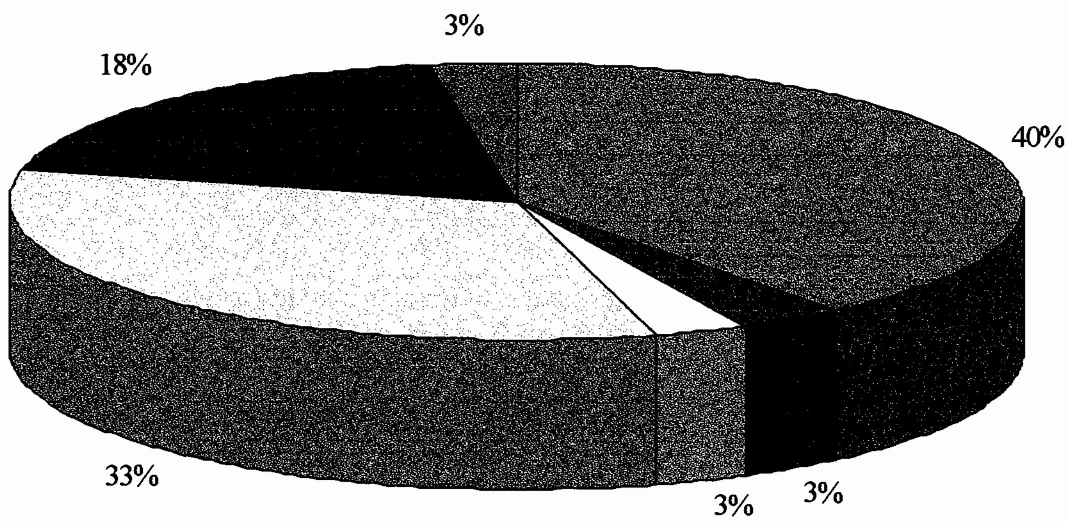
Cycle time is divided into two parts: delay time and delay-free cycle time.

3.4.1. Delay Time

Delay time components during felling and bucking operation are repair delays, maintenance delays, fuel and oil delays, personal delays, operating delays including walking in or out of the unit, and felling hangups and non-merchantable material, and other delays such as site preparation and helping another worker. Kellogg et al. (1986) categorized the delay time during the felling and bucking operation in their research bulletin as shown in Figure 11.

3.4.2.Delay-Free Cycle Time

The major variables influencing the cycle time in the felling-bucking operation are the tree diameter and number of bucking cuts after felling. An example of a formula to obtain the cycle time in felling and bucking is (Sessions, 1992):



OPERATING PERSONAL OTHER FUELING MAINTENANCE REPAIR

FIGURE 11. Felling Delays in Total Felling Cycle Time (Adapted from Kellogg, 1986)

$T = a + b \times D^2 + C \times B$

Where:

T = The cycle time (the time per tree in min.)

b = The minutes per unit diameter.

D = Diameter (cm.)

c = The time spent per bucking (min.)

B = The number of bucking cuts.

a = The coefficient of the time per tree spent on walking between trees or preparing to cut.

If the terrain conditions is hard and brush is taken into account, the following form of the equation is used:

$T^{I} = (1 + f) \times T$

Where: f = the adjustment factor for terrain or brush.

3.5. DETERMINING PRODUCTION

The production rate, defined in cubic meters per hour, is calculated by dividing the average volume of wood per cycle by the time per cycle including delays. In most harvesting time studies, the work cycle time has been modeled as a first step to determine production rates and costs (Aubuchon, 1982). The production rates were obtained as follow (Kellogg, 1986):

$$\text{Production } (m^3/hr.) = \frac{Volume(m3 / cycle)}{\frac{hours}{cycle} + delay \;\&\; others(hr / cycle)}$$

They also summarized felling and bucking production and cost values in a table, which showed that the wide-spacing and strip thinning were similarly more productive and less costly than (Table 10) narrow spacing.

TABLE 10. Production and Cost for Felling and Bucking (Adapted from Kellogg, 1986).

ITEMS	THINNING TREATMENTS		
(Time&Production&Cost)	Narrow	Wide	Strip
Felling cycle time (min)			
Delay free	4.97	4.19	4.31
Delay time / cycle	0.85	0.85	0.85
Total time / cycle	5.82	5.04	5.16
Hourly production			
Number of trees	10.31	11.90	11.63
Volume (m^3)	249.50	287.98	281.45
Cost			
$/unit	11.23	9.73	9.95
$/M bd ft[1]	33.03	28.62	29.26

[1] 3.4 bd ft per ft^3

3.6. UNIT COST OF FELLING AND BUCKING

In order to define the unit cost of felling and bucking per unit volume, the production rate and machine rate including ownership cost, operating cost, and labor cost must be known. Then, unit cost is estimated by dividing machine rate by the corresponding production (Lambert et al., 1990). For example, machine rate for a single-grip harvester (Link Belt Carrier and Waratah 22` head) can be computed as:

Delivered cost = $ 400,000 Life in hour = 12,000

Scheduled Machine Hour = 2,400

Utilization = 65 %

Depreciation = 70 %

Fuel consumption = 15.14 liters/hr.

Fuel cost = \$ 0.38 /liter

Percent of fuel cost for lubricant = 36.8 %

Salvage rate = 20 %

Labor cost = \$ 18.62/hr.

Social cost rate = 41.5 %

Interest, Ins&Tax = 13 %

Cost of tracks = \$10,000

Life of tracks = 5,000 hr.

$$\text{Depreciation Cost} = \frac{\$400{,}000 \times 0.80}{12{,}000 SMH} = \$\ 26.68/\text{SMH}$$

$$\text{A.A.I.} = \frac{(\$400{,}000 \times 0.80) \times (5yr + 1)}{2 \times 5yr} + \$400{,}000 \times 0.20 = \$272{,}000\ /\text{yr.}$$

$$\text{The charge for Interest and Ins\&Tax} = \frac{\$272{,}000 \times 0.13}{2{,}400 SMH} = \$14.73/\text{SMH}$$

Repair and Maintenance Cost = $\$26.68 \times 0.70 = \$18.68$/SMH

Fuel Cost = 15.14 liters/hr. $\times 0.65 \times \$0.38 / liter$ = \$3.74/SMH

Oil&Lubricant Cost = \$3.74/SMH × 0.368 = \$1.38/SMH

$$\text{Tire or Track Replacement Cost} = \frac{\$10{,}000}{5{,}000 hr.} \times 0.65 = \$1.30/\text{SMH}$$

Labor Cost = \$18.62/hr × (1.415) = \$26.35/SMH

Total Ownership Cost = \$ 41.41 /SMH

Total Operating Cost = \$ 25.10 /SMH

Machine Rate (Ownership + Operating + Labor) = **\$ 92.86 /SMH**

The unit cost of felling and bucking with a single-grip harvester is obtained by using the production and cost data as follows:

UC = C / P

Where:

UC = The unit cost of Felling-Bucking ($\$/m^3$)

C = Machine rate for the equipment ($/hr.)

P = Production rate (m^3/hr.)

4. SKIDDING AND FORWARDING WITH GROUND-BASED VEHICLES

Transporting logs from the stump to a haul-truck loading point may be done either by skidding or forwarding, or a combination of the two in ground-based harvesting systems. In the skidding operation, the material transported is dragged either completely in contact with the ground (ground lead) or partly in contact with the ground (partial suspension).

When material is transported on a equipment that carries it completely off the ground, the operation is called forwarding (Simmons, 1979). Skidding and forwarding production varies due to wide range of timber harvesting conditions, not only in the different forest regions, but also within the regions.

4.1. LAYOUTS FOR SKIDDING

In order to make ground based yarding more efficient, it is desirable to clearly mark skid trails before the felling crew goes into the woods (Simmons, 1979). The first step in layout is location of the landing where logs are collected and loaded onto trucks. The landing should have enough area to accommodate trucks, the loader, and log decks (Figure 12). This space depends on terrain conditions, timber stand conditions, and feasible skid distances. According to research, average skid distance of 800 feet or less

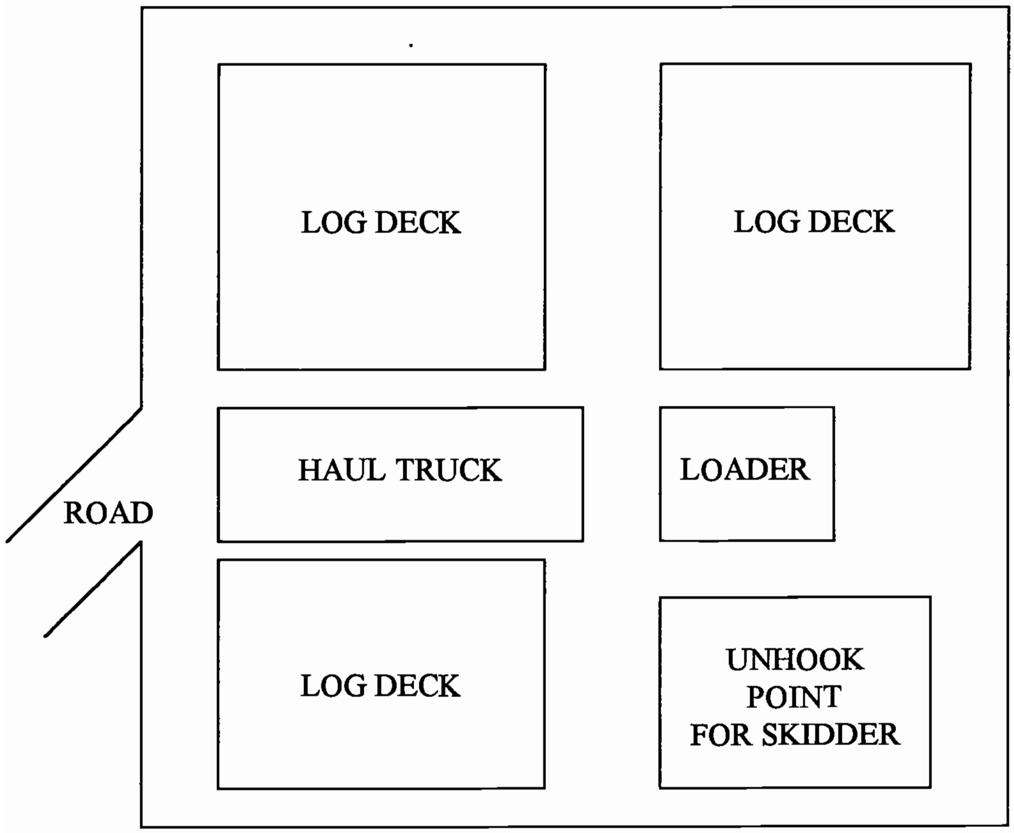


FIGURE 12. Landing Lay Out for Ground-Based Harvesting Systems.

reduces logging cost (Garland, 1983). Closer landing spacing will improve the efficiency of operation, if they are environmentally acceptable.

Skidding trail orientation is important especially when the whole-tree length system has been used. Skid trails should be kept as straight as possible to avoid damage to trees left along trail borders as well as hangups. Also, when skid trails are straight, skidding speed increases.

It is also important for skid trails to closely follow the contours of the land being traversed to avoid erosion, and stream siltation during storms (Simmons, 1979). To reduce soil compaction and disturbance, the amount of ground area covered by skid trails during harvesting operation must be minimized-less than 15 % of the area including landings (Garland, 1983).

Skid trail patterns vary with terrain conditions and ground slope. On moderately flat ground, the skid trail pattern is generally parallel. On gentle slope, one or more main trails has several branches of trails to provide access to the area; on steeper slopes, the parallel skid trails lay on the ground as parallel to contours and connect to the main trail (Garland, 1983).

The direction of the skid trail depends greatly on ground slope. For all ground-based harvesting systems, downhill skidding to the landing is called favorable; an uphill trail to the landing is termed unfavorable or adverse grade (Garland, 1983). Recommended grades for unfavorable and favorable skid trails are up to 10 percent and 20 percent, respectively. On the other hand, if the trail is straight, 20 percent unfavorable may be reasonable with skidding distance of 100 feet to 200 feet (Garland, 1983).

According to Garland (1983), harvesting systems with planned and designated skid trails may be only slightly more expensive, or even less expensive than harvesting systems with conventional skidding where the machine operator decides where to place the skid trails.

4.2. SKIDDING AND FORWARDING EQUIPMENT

Harvesting equipment used in skidding and forwarding operations are selected according to the timber size, ground slope, terrain conditions, and stand density (Simmons, 1979). In this study, three main types of skidding and forwarding equipment including skidders, farm tractor, and forwarders will be analyzed.

4.2.1. Skidders

The skidding operations are usually done with skidders and crawler tractors that transport logs by dragging them with a grapple or chokers. Kellogg et al. (1992b) defined three types of skidding equipment as follows:

Cable (Choker) Skidder: A skidder with an articulated rubber-tire or steel track (Figure 13). Equipped with single or double winches that contain wire rope and chokers to access and hold the load (Society of Automotive Engineers, 1991).

Grapple Skidder: A skidder with an articulated rubber-tire or steel track for transporting a load by lifting the log ends clear of the ground in a grapple (Figure 14).

Clam-Bunk Skidder: A skidder with an articulated rubber-tire or steel track to transport whole trees by supporting the butt end clear of the ground in a top-opening log bunk (inverted fixed grapple). The load is placed within this grapple.

FIGURE 13. Ground Skidding with Chokers Using a Crawler Tractor.

FIGURE 14. An example of the Rubber-tired grapple Skidder.

Rubber-tired skidders are lighter and less expensive than crawler tractors with similar horse-power. They have twice as much speed as tracked vehicles. Skidders are operated on slopes up to 45 % (Bromley, 1968). They are also easier and less expensive to maintain, especially rubber tires compared with crawler's steel tracks. Rubber tires give long service at low cost in sandy soil, however, they wear rapidly on rock while tracks stand up well (Bromley, 1968). Skidders can travel on highways with tires, but crawlers have to be transported.

The skidders provide better traction over rocks than crawlers of the same weight (Bromley, 1968). In swamps, they can be fitted with oversized tires to reduce ground pressure and to increase traction. Skidder traction can be improved by installing chains over the tires. Some attempts have been made to combine the utility of a rubber tired and tracked vehicle by putting steel tracks over rubber tires (bogie wheels) (Simmons, 1979).

The time spent to load logs and unload them at the landing is sometimes 40 percent of the cycle time from landing to landing for both machines (Simmons, 1979). Even though the time spent to hook on the first log is low, adding the next one takes more time and effort, therefore costing more. In order to reduce time spent on loading, a grapple skidder might be used instead of cable chokers.

Crawlers have a larger ground contact area, thus exert lighter ground pressure, nearly the same as the pressure of a man's foot (Bromley, 1968), and provides better traction in mud and on slippery soils (Simmons, 1979). Crawlers deliver a large percent of motor power to the drawbar due to greater ground contact (Figure 15). They are more maneuverable in heavy brush and in difficult terrain with closely located obstacles. Crawler tractors can pull more load than rubber-tired vehicles of the same horsepower due to the better traction and heavier machine weight.

Greene et al. (1987) examined six thinning systems to determine their performances. Two systems produced tree-length material and four systems were producing log-length material. Two feller-buncher and two grapple skidders were used in the grapple skidder systems. In the cable skidder system, six sawyers required three cable skidders, while one feller-buncher kept two forwarders busy in the forwarder system.

Grapple skidder and cable skidder systems were examined for producing tree-length and log-length material. The grapple skidder systems combined with a feller-

FIGURE 15. Crawler Tractor equipped with Grapple for Skidding and Blade for Light Road Construction.

buncher provided the lowest cost for tree-length logging as well as log-length logging. Cable skidder systems were the most expensive systems. The tree-length grapple skidder system produced the cheapest wood and was the most efficient in labor and capital investment. They also found that increasing bunch size significantly reduced the cost of logging with grapple skidder.

4.2.2. Farm Tractor

A farm tractor may be beneficial to use to produce long-length logs if the operation is planned properly, and uses directional felling (Cadorette, 1995). The skidding operation with farm tractors is often limited by the type of soil, terrain conditions, and the size of trees and their accessibility. They skid logs downhill, up to 25 % ground slope (Heinrich, 1987). A farm tractor equipped with appropriate forestry attachments can be used for forestry purposes without any other major investment and gives the farmer an additional use of the tractor.

A tractor assisted by a cable and pulley may be used for bringing tree lengths or logs to the trailside, if a logging winch is not available (Cadorette, 1995). The pulley has to be installed on the tree best placed to angle the load, so that load can be brought to the trail by the tractor, pulling the load in a straight line (Figure 16).

Tractor-attached winches are used for uphill extraction of logs for distance of 30 to 50 m. (Heinrich, 1987). The winch may bring several trees per turn from the stump to the closest extraction trail or skid road where the tractor always stays. The tractor-mounted winch is used alone or assisted by a pulley. Using a pulley, the pulling

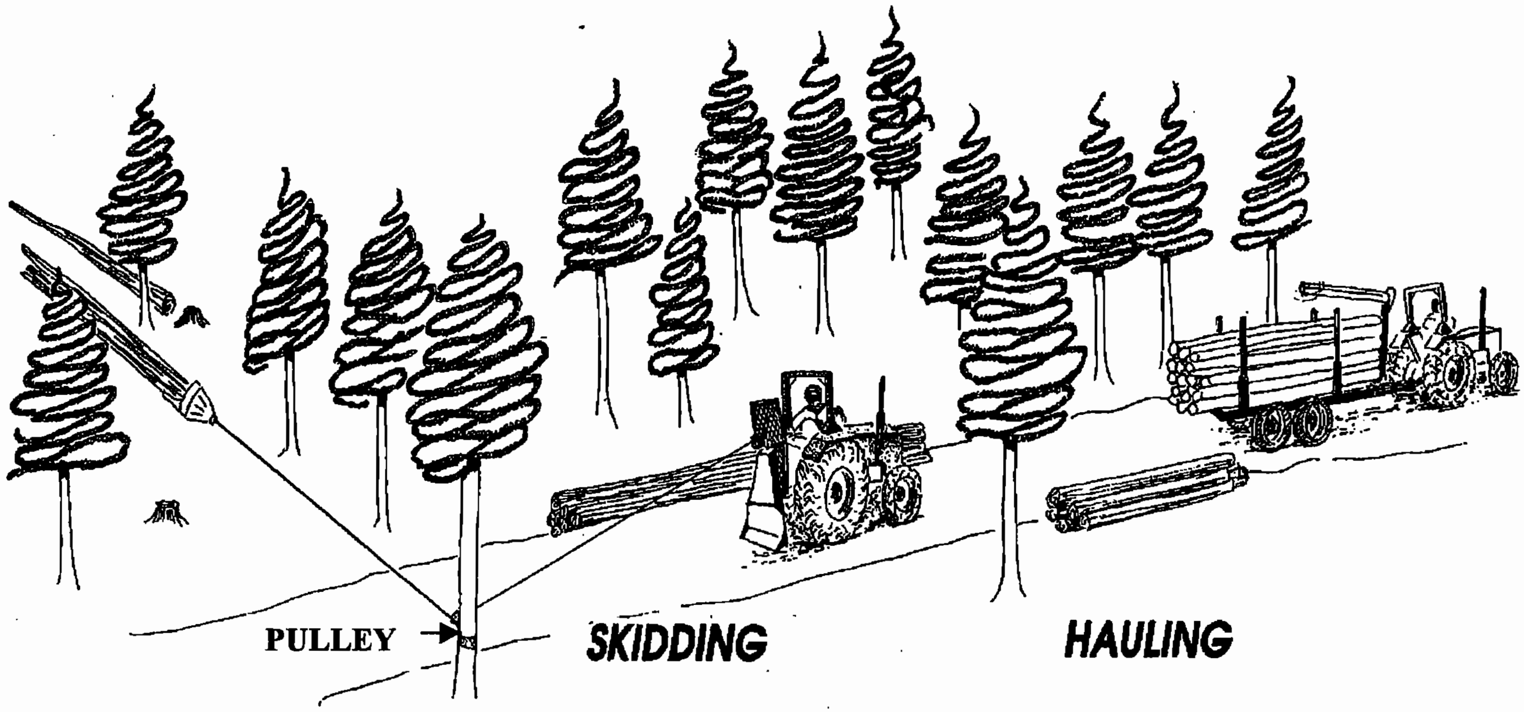


FIGURE 16. Using pully increases the towing capacity of a farm tractor during skidding operation (Adapted from Cadorette 1995.

efficiency may be increased and tractor operation can be adapted to various difficulties such as limited space on the skid road, obstacles, or inaccessible areas (Cadorette, 1995). The tractor may pull a trolley, a small trailer with two wheels, which can be used for winching or skidding on the forest floor, and for hauling on the skid road (Figure 17). When logs are pulled uphill, the trailer reduces friction on the floor. In the case where only one end of the logs drag on the ground and the other end is carried, the tractor-attached trolley (sulky) can haul the logs up to 200 m. If the logs are raised completely off the ground and ends of the logs are placed on the trolley, hauling distance can be increased up to 500 m. For long distances (up to 1000 m.), the hauling of sawlogs should be carried out

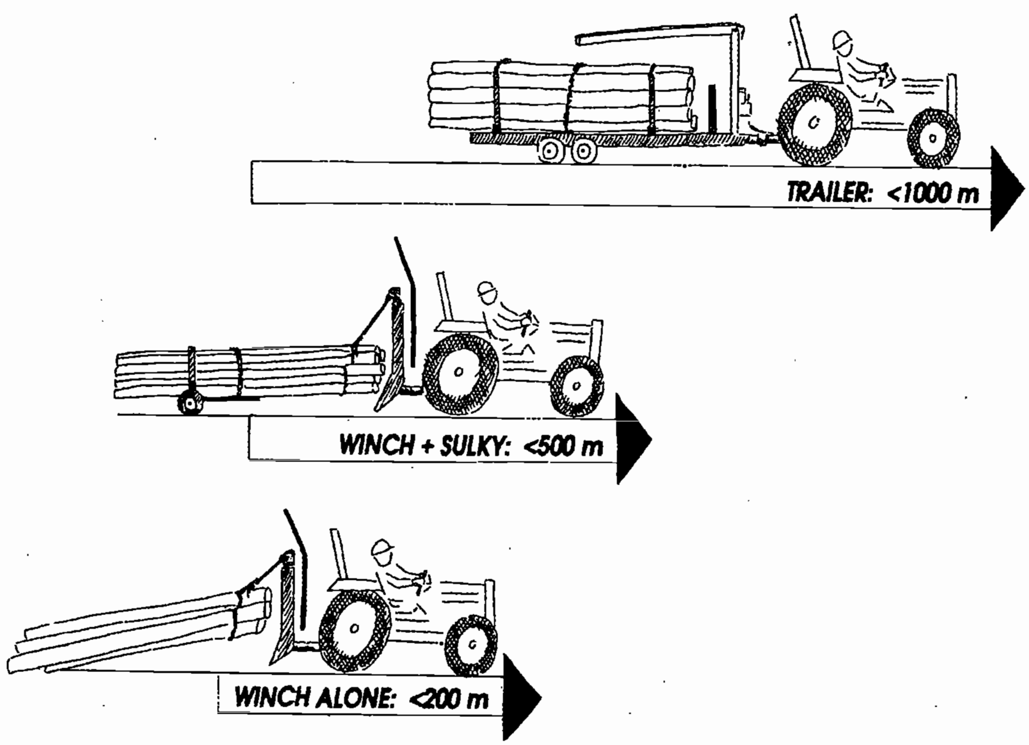


FIGURE 17. Hauling Distance for Skidding with Farm Tractor (Cadorette 1995).

with a forestry trailer (Cadorette, 1995). This type of operation requires a well established network and skid roads to make efficient transportation. Trailers are usually equipped with a self-loader for loading piled logs onto the trailer.

4.2.3. Forwarder

Forwarders are articulated vehicles used for transporting short wood or cut-to-length logs clear of the ground (Kellogg et al., 1992b). They are rubber-tired and equipped with hydraulic loading booms, which can pick up loads from the side of the trail and can load truck trailers at the landing (Figure 18). A forwarder travels at considerably higher

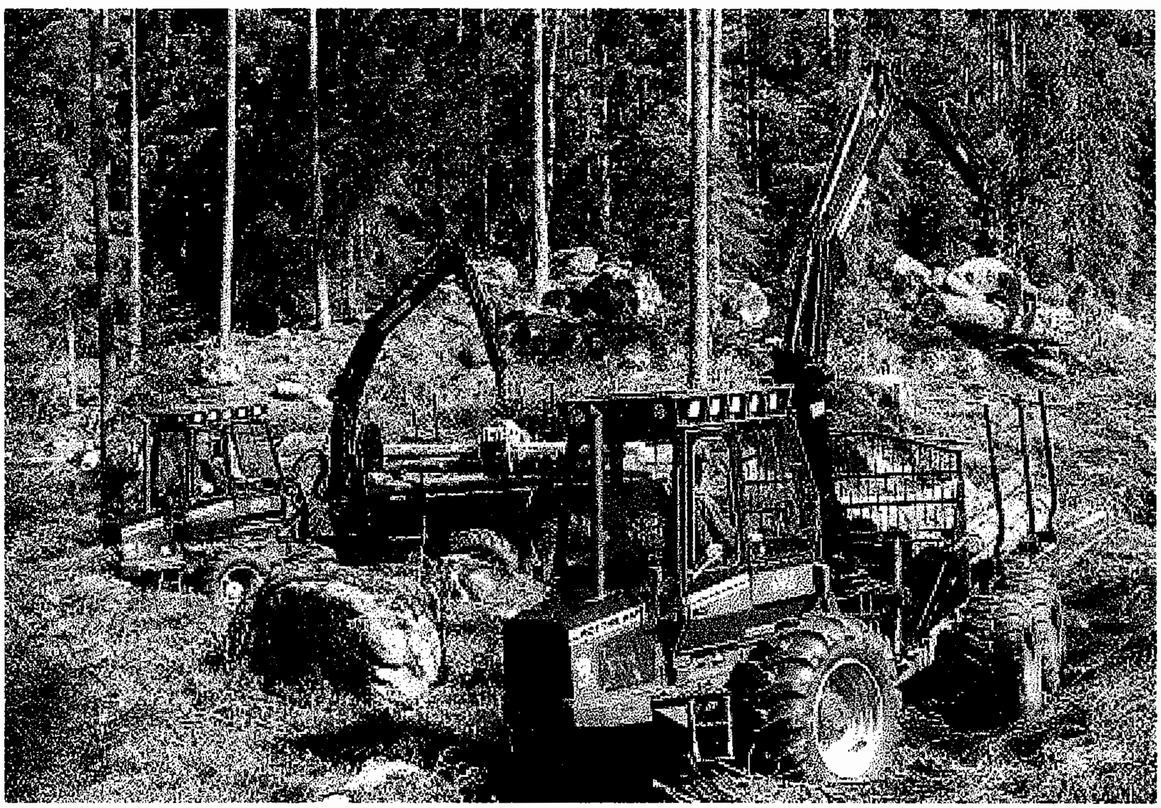


FIGURE 18. Wheeled Forwarders Equipped with a Hydraulic Grapple Loader.

speeds than a skidder of similar size. The forwarder requires a higher quality skid road than the skidder

The forwarder is commonly used in the cut-to-length system combined with a single-grip or double-grip harvester. Since limbs and tops are left in the unit, the harvester and forwarder can travel on the slash and reduce soil compaction and rutting. Residual stand damage from forwarders is very low because the load is off the ground, however, soil displacement (rutting) can occur on forwarder trails. A forwarder may cause more soil damage than a skidder per trip since they carry higher payloads. But higher payloads reduce the number of the trips (Kellogg et al., 1993). Therefore, it is not clear which system has the most potential to cause soil damage (Greene et al., 1987).

For longer travelling distances, larger payloads with a forwarder, compared to skidders and crawlers, may produce wood at a lower cost. In the study conducted by Greene et al. (1987), the forwarder systems produced wood at a lower cost than the cable skidder systems, but a higher cost than the grapple skidder systems. They found that the forwarder systems using manual delimbing and bucking produced wood at a lower cost with a higher capital efficiency, and it was less sensitive to changes in average tree size compared with the processor-forwarder system. Both forwarder systems are more efficient than cable skidder systems for thinning applications.

4.3. TIME ELEMENTS

The time elements of skidding with a cable skidder (Kellogg et al., 1984) and tractor-attached winch are: position time, hook time, travel loaded time, unhook time, travel unloaded time, and deck time.

Position: Time spent on moving the skidder into position in preparation skidding a turn of logs.

Hook: Time spent on setting chokers on logs including rehooking.

Travel Loaded: Time spent on moving the skidder between the landing and the stand with a load at one or more logs.

Unhook: Time spent on releasing logs from the chokers at the landing.

Travel unloaded: Time spent on moving the skidder forward or backward between the landing and the stand with no load.

Deck: Time spent on stacking and adjusting logs into a suitable pile.

Time elements for the grapple skidder are:

Travel unloaded: Time begins when skidder starts to travel empty from the landing to the stand, ends when forwarder motion stops so that maneuvering or loading can begin.

Position: Time begins at the end of travel empty, ends when loading grapple activities start.

Loading: Time begins at the end of positioning, ends when the skidder starts to move with a bunch in the grapple.

Reposition: Time begins at the end of loading, ends when forward motion stops and loading recommences.

Travel loaded: Time begins at the end of loading when a full load has been accumulated, ends when skidder enters landing.

Unloading: Time begins at the end of travel loaded, ends when skidder starts moving again so that travel empty may begin.

Decking: Time begins when skidder moves after the winch line is locked, ends when skidder leaves landing.

In addition to the time elements, independent variables of skidding operation are listed as follows (Kellogg et al., 1984):

- Number of logs per work cycle
- Percent slope
- Distance traveled
- Treatment area
- Volume per cycle

Time elements for the forwarder are (Kellogg et al., 1994):

Travel unloaded: Time begins when the forwarder leaves the landing area, and ends when it stops to begin loading or some other tusks.

Loading: Time begins when the forwarder starts to load logs, ends when its boom is rested and ready for a machine move.

Moving: Time begins when the boom is rested on the bunk, ends when the forwarder stops moving.

Travel loaded: Time begins when the boom is rested on the bunk, ends when the forwarder stops at the landing area.

Unloading: Time begins when the forwarder raises the boom for unloading, and ends when the boom is rested on the bunk for a return trip to the wood or some other task.

4.4. DETERMINING CYCLE TIME

Cycle time is divided into two parts: delay time and delay-free cycle time.

4.4.1. Delay Time

Delay time includes only delays that occur within the cycle and greater than 10 seconds. Delay time may be divided into two groups including mechanical delays and non-mechanical delays. Mechanical delay time components are overheating, repair or check, loose winch, and fuels; non-mechanical delay time components include personal delay during waiting for mechanic and getting instructions, stucks, clear branches, and others such as warm up and travel to site (Miyata et al., 1981).

4.4.2. Delay-Free Cycle Time

To estimate the cycle time in skidding operation, travel unloaded time, hooking time, travel loaded time, and unhooking time must be known. The following formula can be used to obtain the cycle time in skidding (Sessions, 1992):

$$T = a \times N + b_1 \times X_1 + b_2 \times X_2$$

Where;

T = Cycle time (min.)

a = Combined time for hooking and unhooking per log (min/log)

N = Number of logs per cycle

b_1 = Time spent on per meter for unloaded travel (min.)

X_1 = Skidding distance from the landing to load pick up point (m.)

b_2 = Time spent on per meter for loaded travel (min.)

X_2 = Skidding distance from the load pick up point to the landing (min.)

For the case where the outhaul distance and inhaul distance are the same, the cycle time can be obtained from the following formula:

$$T = a \times N + b \times X$$

Where;

b = Time per round-trip distance (min/m.)

X = One-way skidding distance (m.)

The coefficient b is computed as;

$$b = \frac{V1 + V2}{V1 \times V2}$$

Where;

V1 = Unloaded trail speed (m./min.)

V2 = Loaded trail speed (m./min.)

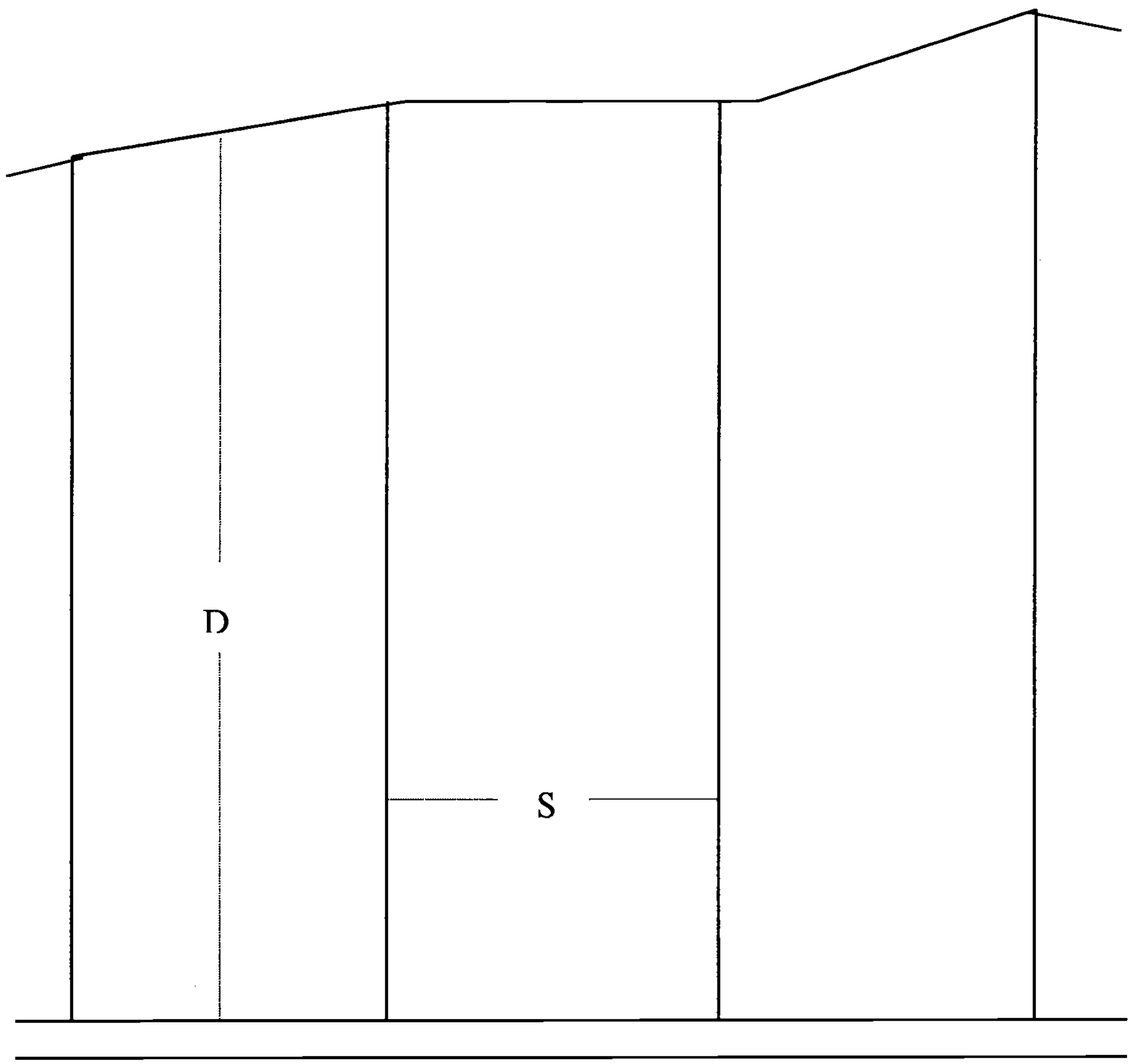
4.5. DETERMINING PRODUCTION

Skidding production is estimated by dividing the average volume of wood per cycle by the time per cycle including delays. Production rate in cubic meters per hour is obtained from the following equation (Kellogg et al., 1986):

$$\text{Production } (m^3/hr.) = \frac{Volume(m3 / cycle)}{\frac{hours}{cycle} + delay \,\&\, others(hr / cycle)}$$

4.6. ROAD SPACING

Road spacing between the spur roads is an important factor if logs are being skidded directly to the spur road (Figure 19). It varies with the road cost per unit length of road, skidding cost per unit length of skid distance per unit volume, and volume removed



D = Length of Spur Road

S = Spacing between Spur Roads

FIGURE 19. Road Spacing Among the Spur Roads for 2-ways Skidding in Continuous Landing System (Adapted from Sessions 1992).

per unit area. A derivation can be made to compute the road spacing, which minimizes the sum of road plus skidding costs for a single entry:

$$C = C \times (ASD) \times V + RL$$

$$C = C \times \left(\frac{S}{4}\right) \times (SLV) + RL$$

$$\frac{C}{SLV} = \frac{C \times (S/4) \times (SLV)}{SLV} + \frac{RL}{SLV}$$

$$\frac{C}{SLV} = \frac{CS}{4} + \frac{R}{SV}$$

$$\frac{dx}{dS} = \frac{C}{4} - \frac{R}{VS^2}$$

$$S = \sqrt{\frac{4R}{CV}}$$

Where;

ASD = Average skidding distance

S = Spacing between spur roads

R = Road cost per unit length of road

C = Skidding cost per unit length of skid distance per unit volume

V = Volume removed per unit area

SLV = Total volume removed from skidding area

Average skidding distance can be used to compute the average skidding cost only when the skidding unit cost does not change with distance. For example, C varies with distance with animal skidding since the animal become more tired with longer distance.

The following conclusions can be drawn from the road spacing equation;

- As road unit costs increase, the optimal spacing between skidding roads increases.

- As skidding unit costs increase, the optimal spacing between skidding roads decreases.
- As volume removed per unit area increases, the optimal road spacing decreases.
- As the spacing between skidding roads increases, road costs decrease, while skidding costs increase.
- As volume per turn increases, skidding unit costs decrease, and optimal road spacing increases.

4.7. UNIT COST OF SKIDDING

In order to define the unit cost of skidding per unit volume, production rate and machine rate including ownership cost, operating cost, and labor cost must be known. Then, the unit cost is estimated by dividing machine rate by the corresponding production rate.

For example, machine rate for a cable skidder (CAT 528, rubber tired) can be computed as following;

Delivered cost = $ 167,500	Life in hour = 8,000
Scheduled Machine Hour = 2000	Salvage rate = 10 %
Utilization = 60 %	Labor cost = $ 16.15/hr.
Depreciation = 50 %	Social cost rate = 41.5 %
Fuel consumption = 18.94 liter/hr.	Interest, Ins&Tax = 18 %
Fuel cost = $ 0.38 /liter	Cost of tires = $ 5,000
Percent of fuel cost for lubricant = 36.8 %	Life of tires = 3,000 hr.

$$\text{Depreciation Cost} = \frac{\$167{,}500 \times 0.90}{8{,}000 SMH} = \$18.83 \text{ /SMH}$$

A.A.I. $= \dfrac{\$167{,}500 \times 0.90 \times (4yr. + 1)}{2 \times 4yr.} + \$167{,}500 \times 0.10 = \$110{,}968/\text{yr.}$

The charge for interest, and Ins&Tax $= \dfrac{\$110{,}968/yr. \times 0.18}{2000SMH} = \$9.99/\text{SMH}$

Repair and Maintenance Cost = $\$18.83/SMH \times 0.50 = \$9.42/\text{SMH}$

Fuel Cost $= 18.94 liter/hr. \times \$0.38/liter \times 0.60 = \$4.32/\text{SMH}$

Oil and Lubricant Cost $= \$4.32/SMH \times 0.368 = \$1.60/\text{SMH}$

Tire Replacement Cost $= (\dfrac{\$15{,}000}{3{,}000hr.}) \times 0.60 = \$3.00/\text{SMH}$

Labor Cost = \$16.15/hr. × 1.415 = \$22.85/SMH

Total Ownership Cost = \$28.82/SMH

Total Operating Cost = \$18.34/SMH

Machine Rate (Ownership + Operating + Labor) = **\$ 70.00/SMH**

Unit cost of skidding with a cable skidder can be obtained from the following production and cost data;

UC = C / P

Where:

UC = The unit cost of the skidding (\$/m^3)

C = Machine rate for the equipment (\$/hr.)

P = Production rate (m^3/hr.)

For example, a skidder brings in 3 logs with a volume of 4 m^3. Given unloaded speed and loaded speed are 200m/min. and 100m/min., respectively. Hook time is 1.5 min. per log and the unhook and decking time is 1.1. min. per log. Skidding distance is 500 m. and the outhaul distance and the inhaul distance are assumed as the same. The machine rate for the skidder including labor was already computed in the previous page as $70/SMH.

$$T = (1.5\,\text{min.} + 1.1\,\text{min.}) \times (3) + \left(\frac{200m/\text{min} + 100m/\text{min.}}{200m/\text{min.} \times 100m/\text{min.}}\right) \times 500m$$

$T = (2.6\text{min}) \times (3) + (0.015\text{min/m}) \times (500\text{m}) = 15.3\ \text{min.} = 0.255\ \text{hr.}$

$P = 4\ m^3 / 0.255\text{hr.} = 15.69\ m^3/\text{hr.}$

$UC = \$70/SMH / 15.69\ m^3/\text{hr.} = \$4.46/m^3$

An alternative way, unit cost of skidding is computed as function of skidding distance, and then the cost of hooking , unhooking, and decking is added separately since these costs are constant and don't change with the skidding distance. However, in the case where choker setters are waiting for the skidder (if the skidding distance is long) or the skidder is waiting for chokers because the skidding distance is short, these costs can be computed depending on skidding distance.

$UCF = (C / 60) \times a \times N / V$

$= (\$70/SMH/60) \times (1.5\ \text{min.} + 1.1\ \text{min.}) \times 3 / 4\ m^3 = \$2.275m^3$

Where;

UCF = The cost of hook, unhook, and decking

The cost per cubic meter of wood per unit skidding distance is:

$UCV = (C / 60) \times 1m \times b / V$

$= (\$70/SMH/60) \times 1m \times 0.015 / 4m^3 = \$\ 0.004375/m^3\text{-m}$

At a skidding distance of 500 m:

$UC = UCV + UCF$

$= \$0.004375/m^3\text{-m} \times 500m + \$2.275/m^3 = \$4.46/m^3$

5. SKIDDING WITH OXEN

Some studies have been done on skidding with oxen. Ersenhauer (1969) studied skidding with oxen in a forest of radiata pine with the following conditions; average dbh of 32 cm., skidding an a slope of 11 percent and over a distance of 125 m., and bucked log length of between 3 and 7 m. He found the time per m^3 was 36.86 minutes and the output was 1.48 m^3/ha. Jelves (1977) obtained an output of 0.89 m^3/ha by using ox-dram cants over an average distance of 25 m. on the basis of information collected in a forest of radiata pine during the selective thinning.

The most recent study was undertaken mainly to demonstrate the use of oxen to skid logs in plantation and natural forests by Rodriguez (1986). This research was conducted in a region of Chile where oxen have traditionally been used in forestry operations. The conclusions drawn from the research were that oxen could be used with positive result in plantation forest where clear cut or thinning applied, and also in natural forests where, whether on level ground or on steep slopes. In this paper, skidding with oxen is discussed in the following topics: time elements, determining time, determining production, and the unit cost of animal skidding.

5.1. TIME ELEMENTS

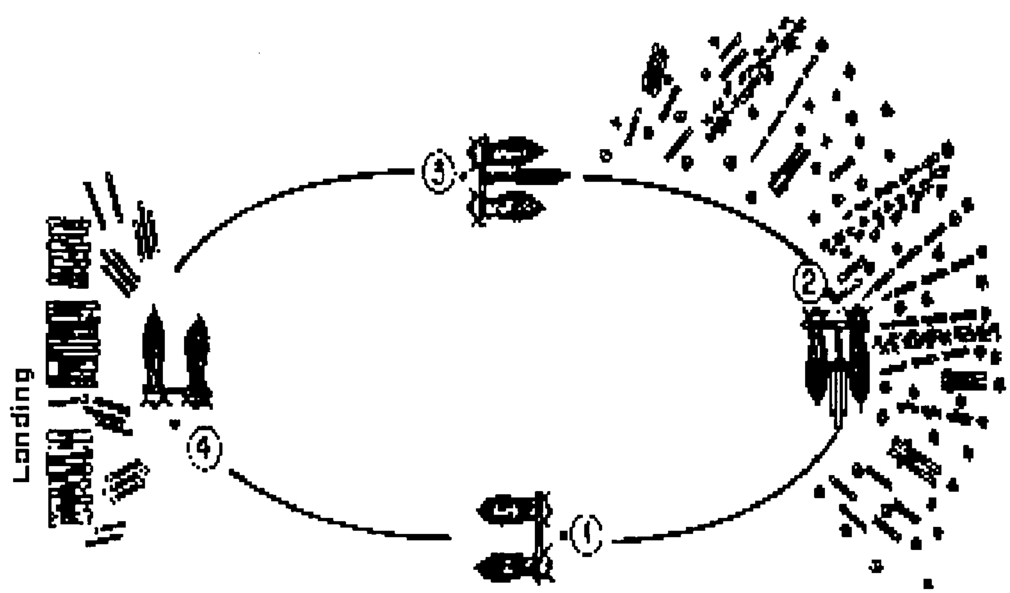
The time elements considered in the work cycles include outhaul time, inhaul time, hook time, unhook time. Similar phases have been mentioned in various studies. Figure 20 adapted from Rodriguez 1986 shows the stages of the cycle and cycle time elements.

Outhaul time: Time spent by the oxen when they covered the distance from the landing to the stump area without a load.

Hook time: Time spent from the moment the team and oxen arrives the stump until the moment it leaves. It includes the maneuvering the oxen to take up the loads, arranging the logs and to hook them.

Inhaul time: Time spent from the moment the team of oxen starts to move with the log from the stump until it arrives at the landing.

Unhook time: Time spent from the moment oxen arrives the landing to deliver the load until the chain is recovered and remained on the yoke.



1. Outhaul
2. Loading
3. Inhaul
4. Unloading

FIGURE 20. Movements in Skidding Cycle.

5.2. DETERMINING CYCLE TIME

Cycle time is divided into two parts: delay time and delay-free cycle time.

5.2.1. Delay Time

Delay time may or may not be predictable. In the first case, incidental delays during skidding include receiving work instructions, setting up equipment on the work site, preparing ox-teams in the skidding area, changing parts, removing obstacles which make movement difficult, adjusting the chain (Rodriguez, 1986).

The second case covered non-predictable delays may be accidental or unnecessary losses of time, such as forgetting tools, conversation between the workers, and all delays outside the normal process (Rodriguez, 1986). In this paper, delay time for skidding per cycle is computable and is assumed as 2 min. and 3 min. for both products including pulpwood and sawlog with skidding distance less than 100 m. and more than 100 m., respectively.

5.2.2.Delay-Free Cycle Time

This is the total time spent per work cycle. In order to compute cycle time, following parameters must be known; outhaul velocity, hook time, inhaul velocity, unhook time, average skidding distance, and delay time.

Table 11 shows the average values of speed and load in skidding sawlogs and pulpwood of radiata pine over different types of slope. This table is adapted from the research of skidding with oxen studied by Rodriguez (1986). The area studied was in the Pinchum Estate on the coastal range of mountains. The terrain was generally very rough, with slopes in some places above 30 %. The soil comes from granite rock.

The study was made in a forest of radiata pine where 20 percent of the extraction of raw timber was skidded by wheeled farm tractor and 80 percent by oxen. Tree characteristics: age of 22 years, average height of 30 m., average dbh of 26 cm., 380 trees/ha, average volume of 448 m^3/ha.

TABLE 11. Average Speed and Load in Volume in Skidding Sawlogs and Pulpwood with Oxen Over Different Types of Slopes (Adapted from Rodriguez 1986).

Log Classes	Ground Slope	Average Velocity (m/min)		Average volume per (Per cycle)	
	(%)	Outhaul	Inhaul	m^3	ft^3
Sawlogs	- 25.1 to - 30	30.43	29.69	0.794	0.2804
Sawlogs	- 20.1 to - 25	30.05	28.91	0.679	0.2398
Sawlogs	- 15 to - 20	28.87	25.39	0.718	0.2535
Sawlogs	+ 10 to + 30	38.75	27.53	0.386	0.1363
Pulpwood	> than - 30	28.45	24.38	0.509	0.1797
Pulpwood	- 10.1 to - 20	39.44	22.3	0.509	0.1797
Pulpwood	0 to - 10	43.41	25.4	0.509	0.1797

The dimensions of the logs transported for sawlogs were: 4 m. length, 18 cm. dbh; and for pulpwood 2.44 m., minimum 10 cm. and maximum 18 or 20 cm. dbh This study took 10 working days and the seven ox teams were studied. Each ox weighed between 500 and 700 kg.

Another area studied in the same research was 125 m. above sea level with slopes no steeper than 3 percent. The predominant soils were sandy. Skidding was studied over six working days, using three ox teams. Each ox weighed 650 kg., and had a minimum of two years' experience. The specific situations studied for skidding pulpwood after thinning; the forest was 16 years old, average length of bolts transported was 7.44 m., average dbh was 10 cm., the density was 800 tree/ha, and average volume was 85 m^3/ha. Tree characteristics for transporting sawlogs were; 19 years old forest, 1,662 trees/ha, minimum bh of 26 cm. , and minimum length of 4 m. Average speed and load during skidding of sawlogs and pulpwood with oxen on level ground with clear cuts and thinning systems listed in Table 12 (Adapted from Rodriguez 1986).

TABLE 12. Average Speed and Load in Volume in Skidding Sawlogs and Pulpwood with Oxen on Level Ground with Different Felling Systems.

Log Classes	Felling Systems	Average Velocity (m/min)		Average volume (per cycle)	
		Outhaul	Inhaul	m^3	ft^3
Sawlogs	Clearcuts	33.95	21.92	0.417	0.1472
Pulpwood	Clearcuts	40.87	30.89	0.367	0.1296
Pulpwood	Thinning	46.06	32.75	0.289	0.102

Hook times per cycle for pulpwood and sawlog are estimated as 3 minutes and 2 minutes, respectively. Unhook time, on the other hand, is less than hook time and assumed as 2 minutes for both products. Under these assumptions, time spent per cycle in skidding sawlogs and pulpwoods with oxen on various ground slopes is listed in Appendix C.1, by different skidding distances range from 50 m. to 200 m.

The data from Table 11 and 12 provide us to compute total cycle time by following equation:

$$\text{Cycle time} = \frac{\text{Skidding Distince}}{\text{Outhaul Velocity}} + \frac{\text{Skidding Distance}}{\text{Inhaul Velocity}} + \text{Unhook T.} + \text{Hook T.} + \text{Delay T.}$$

5.3. DETERMINING PRODUCTION

Production is expressed in cubic meters per hour calculated on the basis of the relationship between the average volume of load per cycle and number of cycles per hour. Number of cycles per hour is computed by dividing 60 minutes by the cycle time including delays in minutes. Then production per hour can be determined as follows:

Production (m^3 /hr) = Load volume (m^3 / cycle) × Number of cycles (cycle/hr)

Production per cycle is also listed on Appendix C.2 by different various distances range from 50 m. to 200 m.

5.4. UNIT COST OF SKIDDING WITH OXEN

In order to calculate unit cost skidding with oxen per unit volume, firstly animal rate including fixed cost, operating cost, and labor cost must be known, then the unit cost is basically estimated by dividing animal rate by the production.

Table 13 shows the summary of the cycle time, productivity, and unit cost of skidding with oxen over different types of slopes and on level ground for clear cutting and thinning under various skidding distance categories. The unit cost of skidding with oxen is obtained by using the production and cost data as follows:

$$UC = C / P$$

Where: UC = The unit cost of animal skidding ($\$/m^3$)

C = Animal rate for skidding (\$/hr)

P = Production rate (m^3/hr)

TABLE 13. Summary of the cycle time, productivity, and unit cost for skidding with oxen.

Log Classes	Ground Slope	Av.tree D.B.H.	Log Length	Cycle time (min.) for Skidding Distance (m)				Production (m^3/hr.) for Skidding Distances (m)				Unit Cost ($/$m^3$) for Skidding Distances (m)			
	(%)	(cm.)	(m.)	50	100	150	200	50	100	150	200	50	100	150	200
Sawlogs	- 25.1 to - 30	18	4.00	10.33	13.65	17.98	21.31	4.61	3.49	2.65	2.24	3.75	4.95	6.52	7.72
Sawlogs	- 20.1 to - 25	18	4.00	10.39	13.79	18.18	21.57	3.92	2.95	2.24	1.89	4.41	5.86	7.72	9.15
Sawlogs	- 15 to - 20	18	4.00	10.70	14.40	19.10	22.80	4.03	2.99	2.26	1.89	4.29	5.78	7.65	9.15
Sawlogs	+10 to + 30	18	4.00	10.11	13.21	17.32	20.43	2.29	1.75	1.34	1.13	7.55	9.88	12.90	15.30
Pulpwood	> than - 30	10-20	2.44	9.81	13.62	18.42	22.23	3.11	2.24	1.66	1.37	5.56	7.72	10.42	12.62
Pulpwood	- 10.1 to - 20	10-20	2.44	9.51	13.02	17.53	21.04	3.21	2.35	1.74	1.45	5.39	7.36	9.94	11.92
Pulpwood	0 to - 10	10-20	2.44	9.12	12.24	16.36	19.48	3.35	2.50	1.87	1.57	5.16	6.92	9.25	11.01
Sawlogs[1]	< than 3	26	4.00	10.75	14.51	19.26	23.02	2.33	1.72	1.30	1.09	7.42	10.05	13.30	15.86
Pulpwood[1]	< than 3	10	2.44	8.84	11.68	15.53	18.37	2.49	1.89	1.42	1.20	6.94	9.15	12.18	14.41
Pulpwood[2]	< than 3	10	2.44	8.61	11.22	14.84	17.45	2.01	1.55	1.17	0.99	8.60	11.15	14.78	17.46

[1]Clear-Felling
[2]Thinning

5.5. CONCLUSIONS AND RECOMMENDATIONS:

Figure 21 shows that cycle time of skidding on slope of + 10 % to + 20 % is less than for skidding downhill since the number of logs skidded was reduced due to the greater effort required from the oxen when skidding uphill. With a steeper downhill slope, the number of logs skidded may be dropped, thus cycle time of skidder decreases. It is also seen from this figure that the cycle time increases considerably as the skidding distance increases.

In skidding sawlogs on level ground (less than 3 %) with clear-felling, cycle time was greater than those skidded downhill since on the level ground speed with load drops because of the friction factor, in comparison with the loaded trip downhill which has gravity assistance. The number of logs skidded downhill are greater than those skidded on level ground.

Skidding sawlogs after clear-felling, cycle time is shorter because relatively fewer pieces to be handled. In skidding pulpwood after thinning, cycle time of skidding is greater than those skidded after clear-felling since the average number of logs skidded are very high by comparing with the skidding puplwood after clear-felling.

It is observed from Figure 22 that the production rate in skidding logs uphill decreases as the distance increases. Production rate in skidding pulpwood is greater than in skidding sawlogs, since more time is spent in loading. On the level ground, on the other hand, skidding sawlogs after clear-felling has the highest production rate due to the greater volume of load and lower number of logs transported. The unit cost in skidding with oxen over different skidding distance and slope conditions is shown in Figure 23.

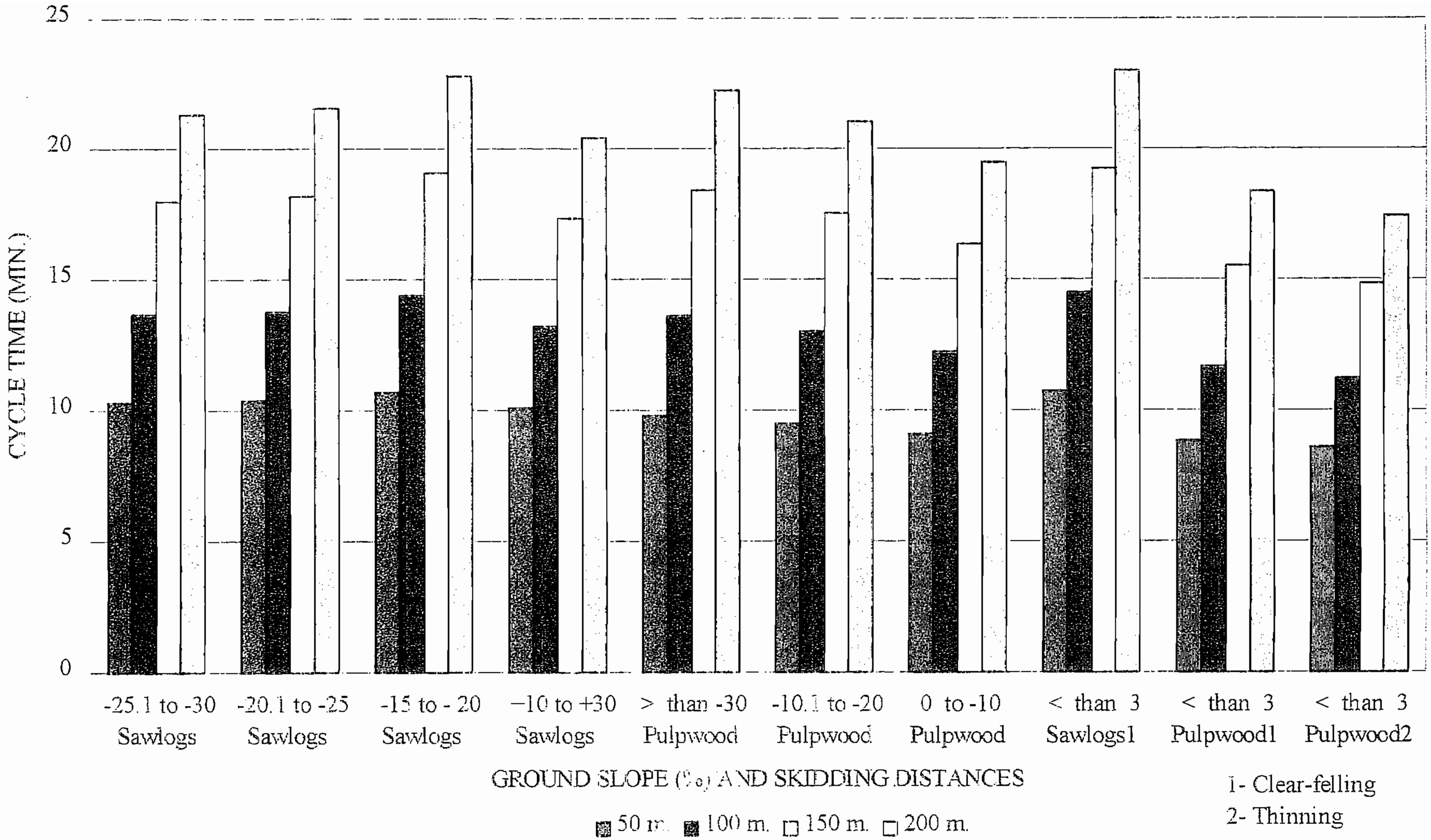


FIGURE 21. Cycle Time in Skidding Sawlogs and Pulpwood with Oxen over Different Skidding Distances and Slope Conditions.

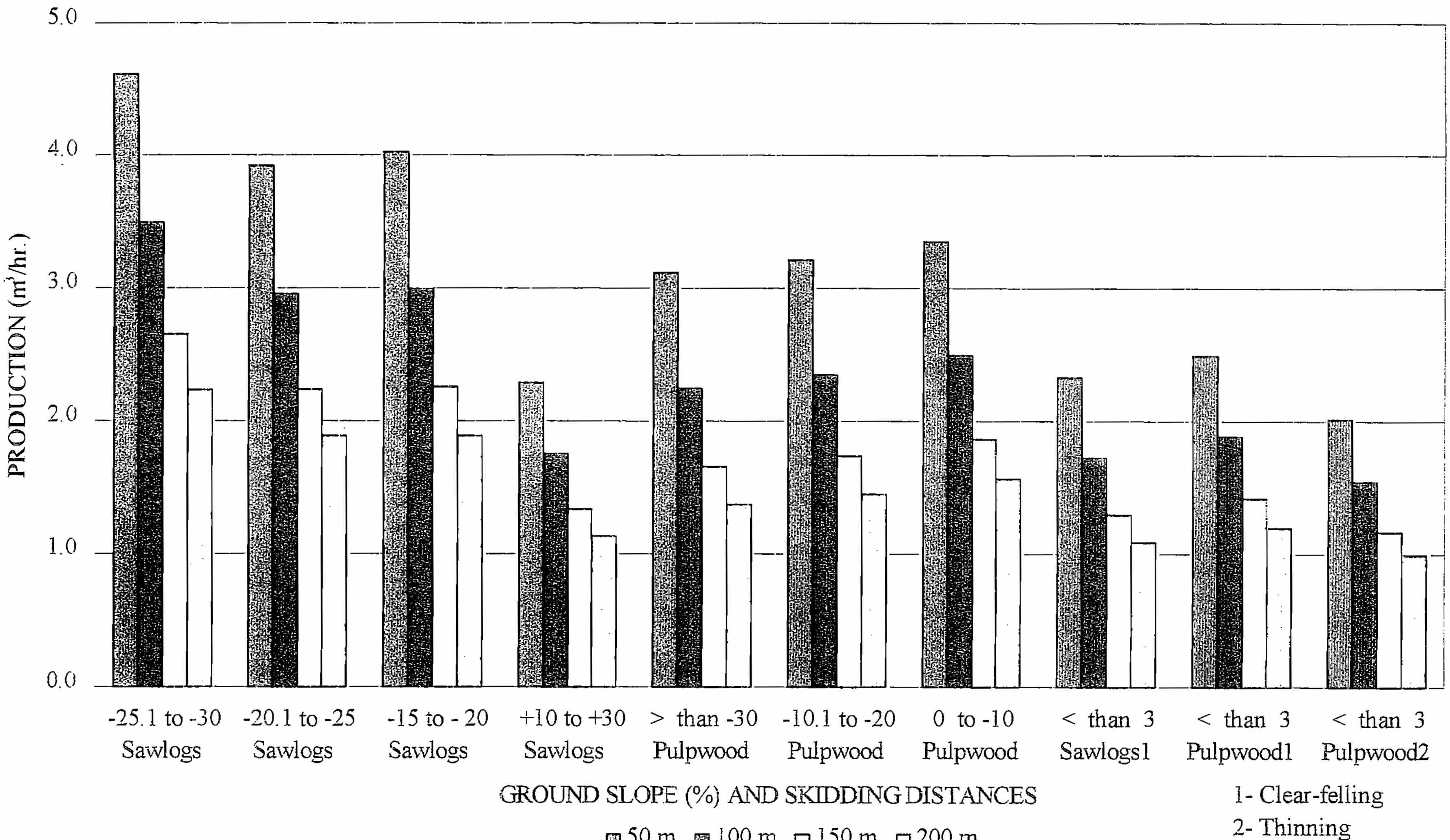


FIGURE 22. Production Rate in Skidding Sawlogs and Pulpwood with Oxen over Different Skidding Distances and Slope Conditions.

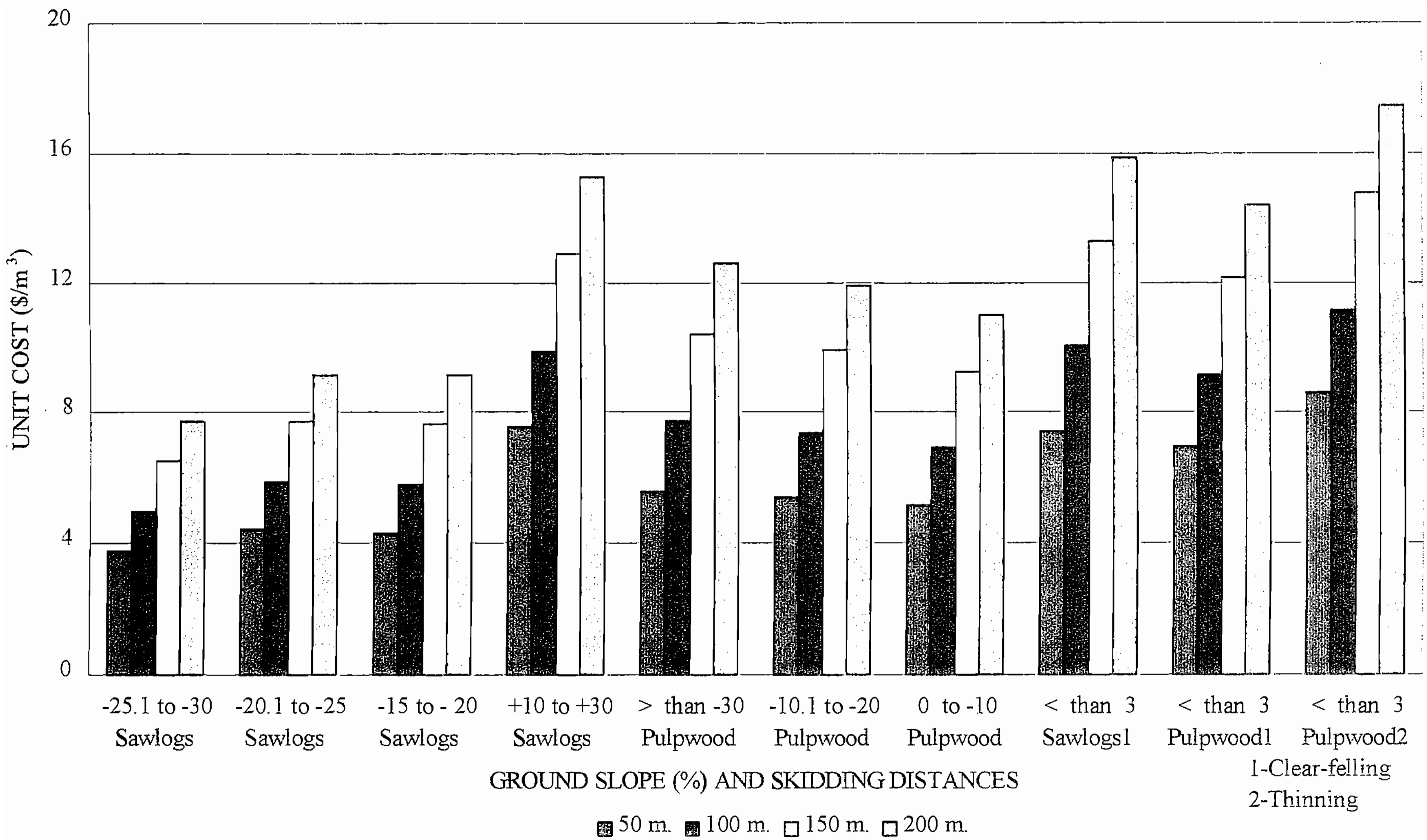


FIGURE 23. Unit Cost in Skidding Sawlogs and Pulpwood with Oxen over Different Skidding Distances and Slope Conditions.

6. CABLE SYSTEMS

In some areas where the terrain is too steep for ground-based harvesting, or ground-based machines may cause unacceptable environmental damage, cable logging can be a viable solution. Cable logging systems are very sensitive to span length, tree size and average payload. (Kellogg et al., 1992b). In order to improve productivity of cable systems in stands with small size trees, felling and bunching might be done mechanically, and then grapple yarding could be used to yard the bunched trees.

The cable logging systems considered in this section are highlead system, skyline systems including standing skyline, live skyline, running skyline, and multispan skyline, and prebunching and swinging system.

6.1. HIGHLEAD SYTEM

Highlead cable logging had been the most widely used yarding system in the United States (Studier et al., 1974). It is now decreasing. This system includes a two-drum yarder, and a spar tower mounted on a carrier. Logs are pulled to the landing by mainline, and the haul back line is used to pull the mainline, and the rigging back to where logs can be choked (Figure 24).

The term "highlead" comes from the location of the mainline block elevated above the ground by a metal or wooden spar. The vertical lift, provided by the high block, allows the logs to override obstacles. Maximum yarding distance is generally 800 ft (244 m) (Studier et al., 1974). Although highlead cable logging is not a skyline system, it is very popular since it is simple, and required two drums on yarder.

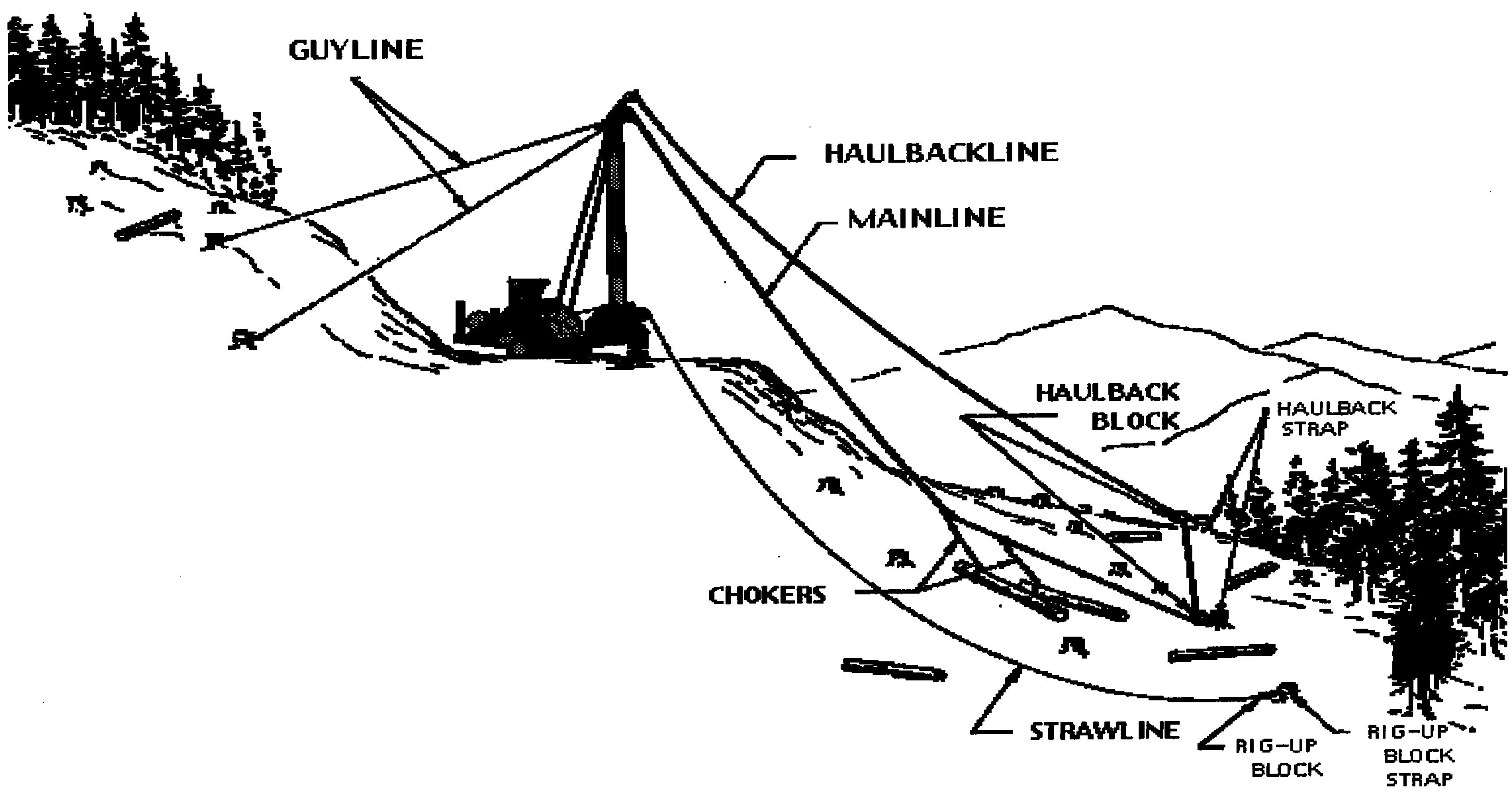


FIGURE 24. Uphill Cable Yarding with Highlead System (Adapted from Studier, 1974).

6.2. SKYLINE SYSTEMS

In skyline systems, the skyline position provides lift to the logs, not just the spar, and the load is pulled by a simple block or by a more complex carriage on the skyline (Studier et al., 1974).

Standing Skyline: In this system, the skylines are fixed at both ends, so, it can not be moved during the operating cycle for each turn of log (Figure 25). The maximum yarding distance is 4,000 - 5,000 ft (1372 m) (Studier et al., 1974).

Putnam et al. (1984) determined production rates and costs of a standing skyline for harvesting small wood by different methods of yarding including whole-tree (yarding with limb, tops), tree-length (bucking done at the landing), and log-length (limbing, topping, and bucking done in the woods). The whole-tree system transfers the limbing and bucking process to the prepared area at the landing. On steeper slopes, limbing and bucking at the stump is very difficult and less productive.

According to this study, there was no significant difference in the production rate between tree-length and whole-tree yarding, and both systems were more productive (6 %) than log length yarding. Fewer numbers of pieces per turn did result in a higher production rate. Although, felling and yarding costs were reduced with the whole-tree system, the use of a skidder for swinging made this system more costly than the log-length system without the swinging operation.

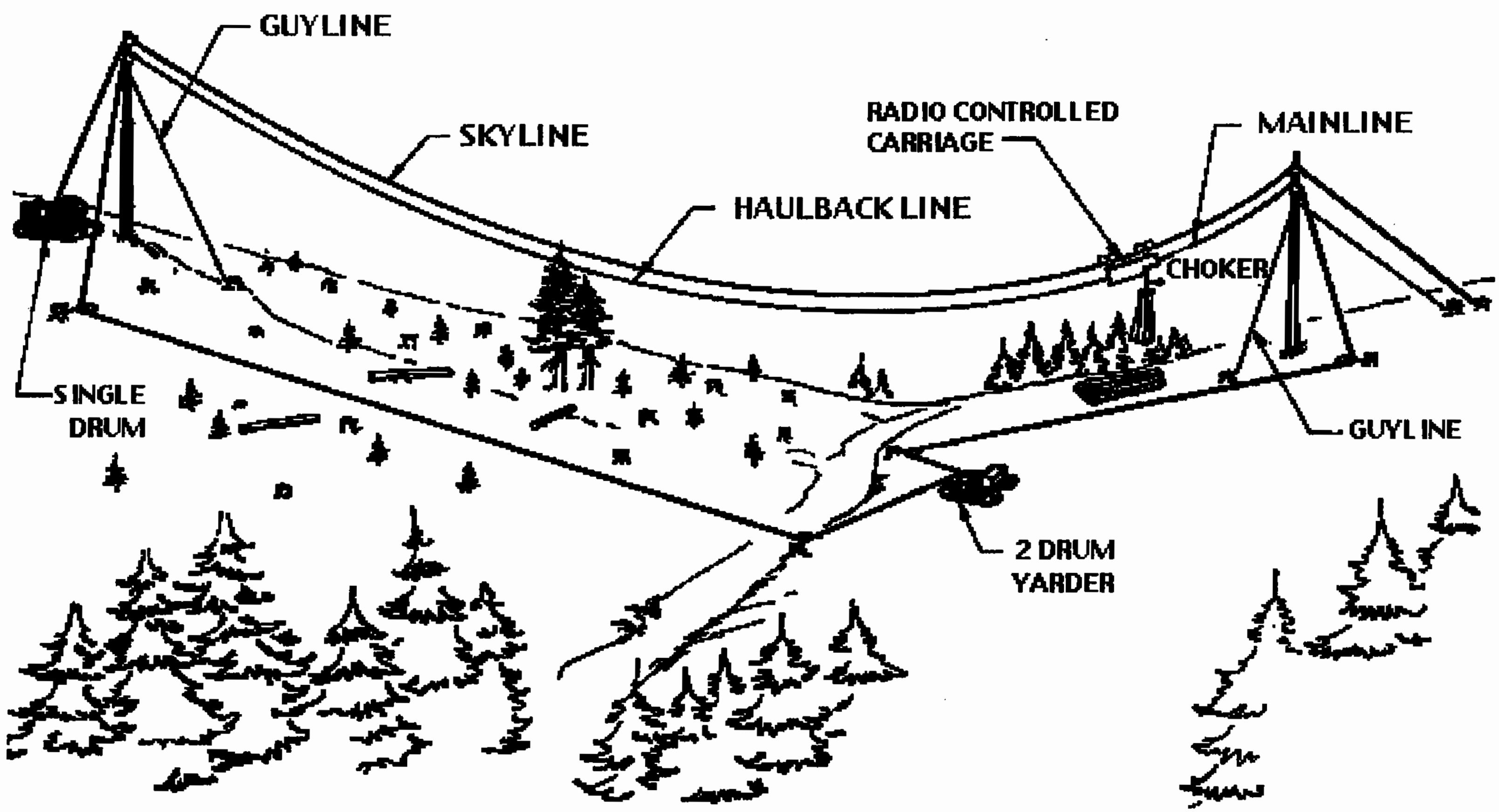


FIGURE 25. Standing Skyline with Radio Controlled Carriage (Adapted from Studier, 1974).

Live Skyline: The live skyline system without haulback is an uphill yarding system with landing at the top. If a haulback is used an a live skyline, it can beused uphill or downhill. The most common live skyline system is the shotgun system, or also referred to as slackline system (Figure 26). The mainline is used as a skyline, and the haulback is used as a skidding line or mainline to move the carriage up and down the skyline. The lines are not fixed at the ends, so, they can be raised and lowered with each turn of logs. The maximum yarding distance is up to 2,000 ft (610 m) (Studier et al., 1974).

When shotgun carriages are used, the skyline road must be changed often since they cannot skid laterally. If slackpulling carriages are used, skyline roads are up to 300 ft (91 m) apart (Studier et al., 1974). In a case where tailholds are expensive to rig, there is an advantage in using a slackpulling carriage. The live skyline can also be operated with radio controlled grapples, which may provide both labor intensive and safer job.

Running Skyline: This system has two lines that support the load and move in and out with the payload and carriage (Studier et al., 1974). Running skylines can yard uphill as well as downhill. These machines are very popular for yarding clearcuts, especially with a grapple carriage (Figure 27). When a grapple carriage is used, two men are enough for yarding. It is easy to move running skylines since they have only two or three guylines. The maximum yarding distance is about 1,000 ft (305 m) uphill, and 600 ft (183 m) downhill (Studier et al., 1974).

Multispan Skyline: This system has one or more intermediate supports that allow machines with relatively short towers to yard convex or broken slopes and longer distances

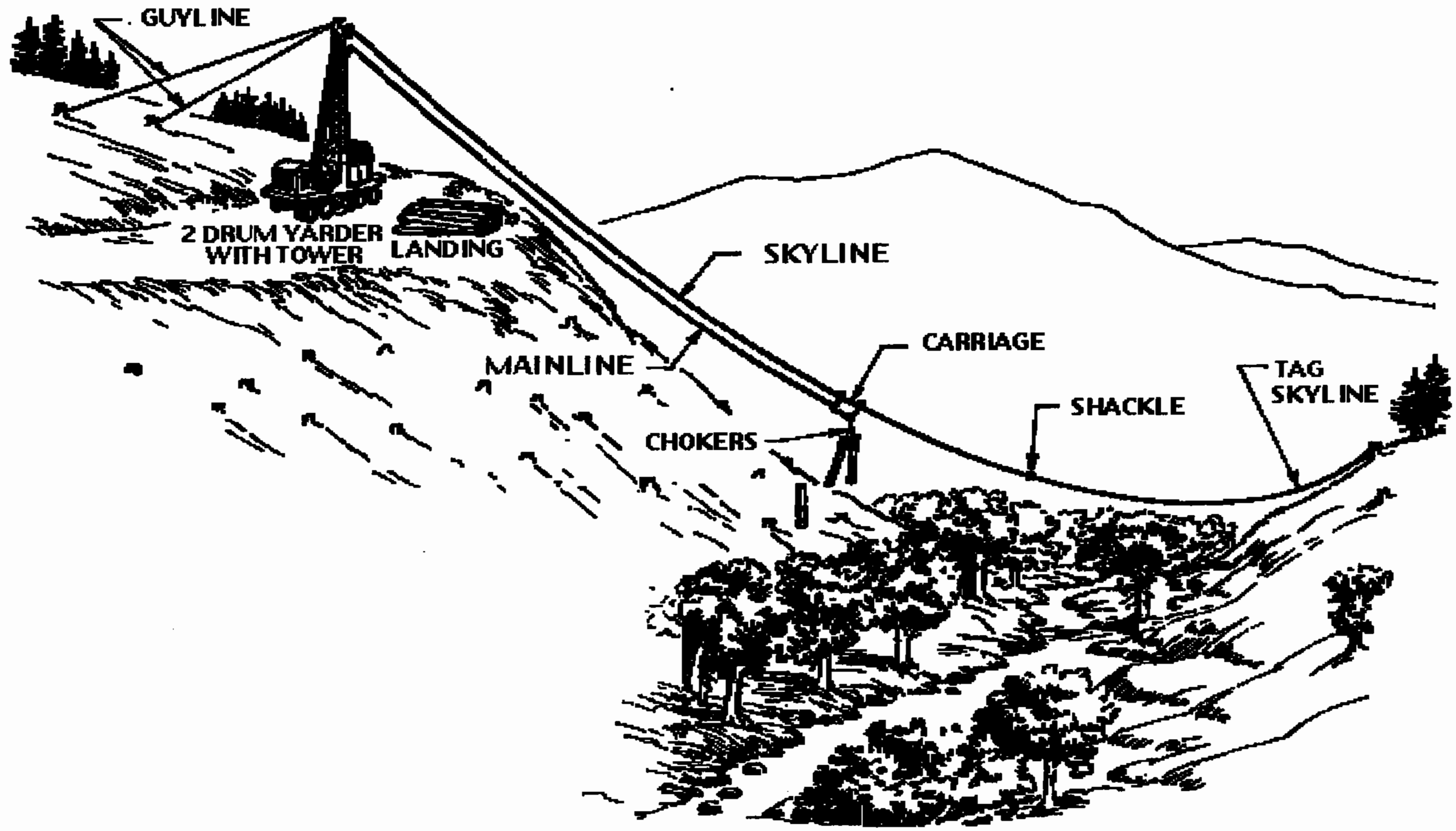


FIGURE 26. Live Skyline Cable System with Two Drum Tower Yarder (Adapted from Studier, 1974).

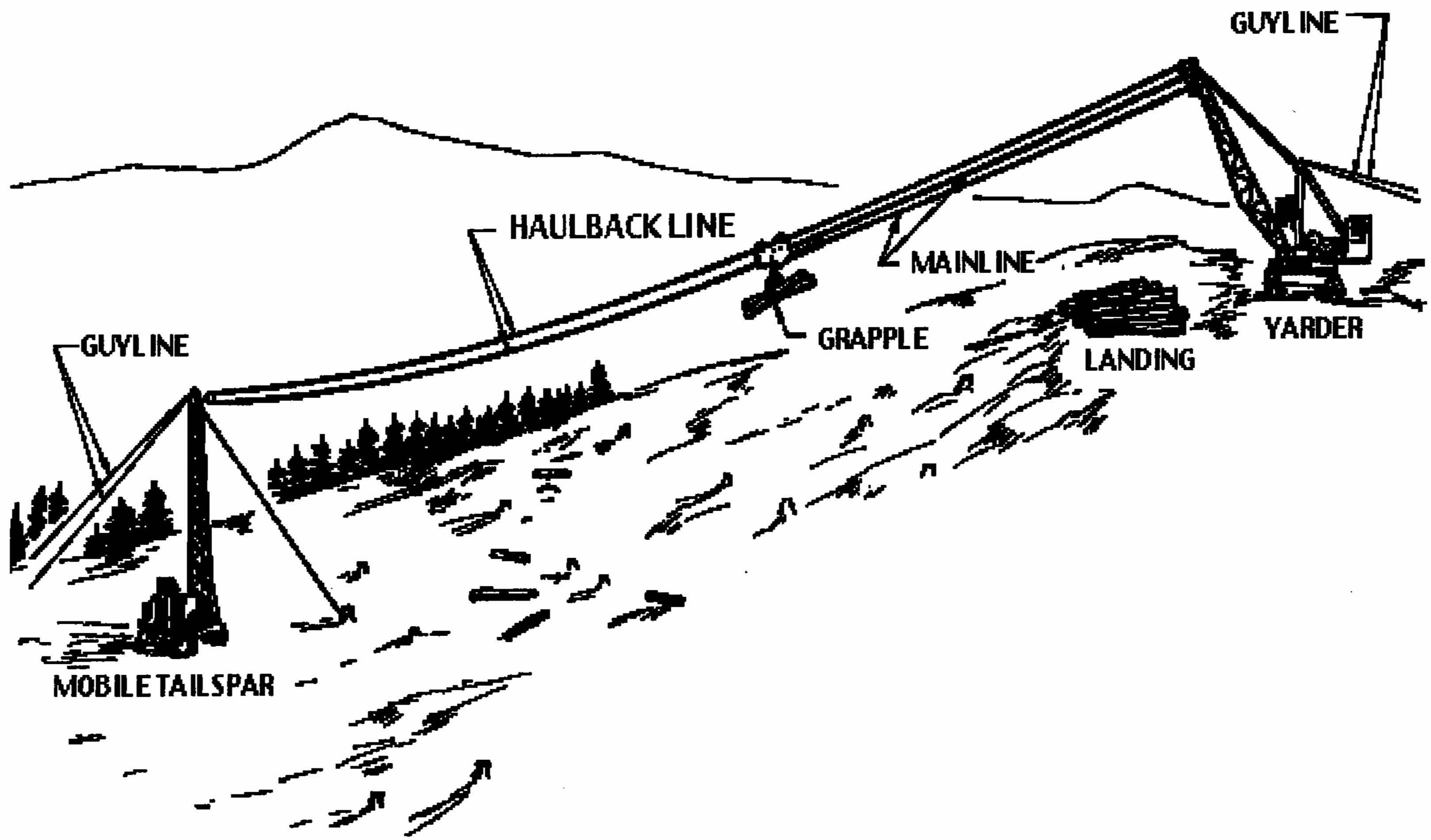


FIGURE 27. Running skyline with Mechanical Grapple (Adapted from Studier, 1974).

(Figure 28). The carriages used in this system are capable of passing the intermediate support jack. They usually use self-clamping carriages that can be used in a gravity system or with a haulback line (Kellogg, 1981).

In the multispan skyline system, intermediate supports keep the skyline elevated well above ground level, which improves deflection, payload, log lift, and reduces hangups during lateral yarding. Intermediate supports can reduce stand damage, and ground disturbance. Using a multispan system may also extend yarding distance up to 5,000 ft (1524 m), and increase road spacing (Studier et al., 1974).

Intermediate supports are typically divided into three categories (Mann, 1984):

- The single, leaning tree, partially severed at the stump.
- The single, vertical tree, applied successfully in both thinning and clearcuts.
- The double tree, commonly used in thinning operations.

6.3. PREBUNCHING AND SWINGING SYSTEM

Much of the yarding time (46%; Kellogg, 1980a) in skyline thinning is spent in the lateral yarding sequence (lateral out, hook, lateral in) during the operating cycle for each turn. If a costly yarder is used, lateral yarding time becomes very expensive.

Prebunching and swinging has been developed for bringing logs into the corridor with lower cost (Kellogg, 1980a). This system is divided into two stages:

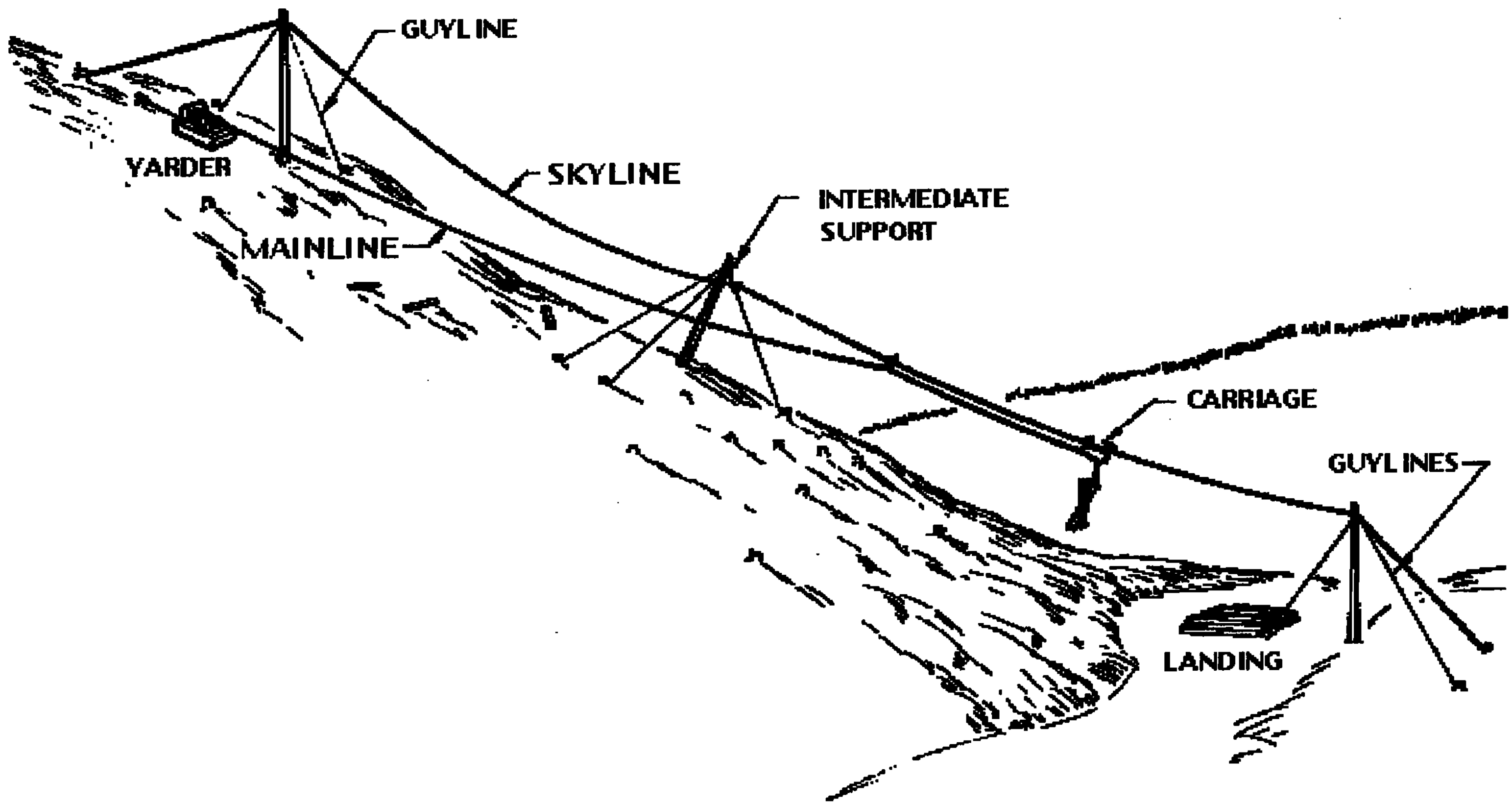


FIGURE 28. Multispan Skyline with Intermediate Support (Adapted from Studier, 1974).

prebunching and swinging, and each done with a different piece of equipment (Kellogg, 1981). For prebunching, equipment investment is low, and crew size is small. By using a prebunching system, more logs can be yarded to the landing per turn than with full-cycle thinning without prebunching. Since lateral slackpulling is eliminated from the skyline cycle, crew size often is reduced. In order to make this system cost efficient, lower investment perbunching system must be usesd, and load size per turn must be larger than normally achived by a full-cycle thinning system (Kellogg, 1981).

6.4. TIME ELEMENTS

The time elements of yarding considered in the yarding cycle include outhaul, drop, lateral outhaul, hook, lateral inhaul, inhaul, and unhook (Brown et al., 1995).

Outhaul: Time begins when carriage leaves landing, ends when it is stopped at location of turn.

Drop: Time begins when outhaul ends, and ends when rigging slinger has the load hook and the chokers are taken off.

Lateral Outhaul: Time begins when drop ends, and ends when the mainline toggle has been placed through the choker rig on the first present log.

Hook: Time begins when lateral outhaul ends, and ends when the rigging slinger gives the whistle signal to the yarding engineer.

Lateral inhaul: Time begins when hook ends, and ends when the load reaches the carriage and the whistle is blown to release the skyline brake.

Inhaul: Time begins when lateral inhaul ends, and ends when the carriage reaches the landing.

Unhook: Time begins when inhaul ends, and ends when carriage leaves the landing for another turn.

In addition to the time elements, independent variables of yarding are listed as follows (Brown, 1995, and Kellogg et al., 1986):

Logs per turn: Total number of logs yarded in each turn.

Yarding distance: Distance along the skyline corridor from the landing to the carriage position during lateral outhaul.

Lateral yarding distance: Straight line distance from the corridor center line to the point where the furthest log in the turn attached by the choker.

Lead angle: Angle in degrees between the log axis and the skyline during lateral inhaul.

Slope: Ground steepness in percent measured perpendicularly to the contour.

Turn volume: Total volume in cubic meter of the logs in each turn.

Ground clearance: Vertical distance from the carriage bottom to the ground during lateral inhaul.

Yarding resets: The number of times a turn of logs is stopped for resetting the chokers during lateral inhaul.

6.5. DETERMINING CYCLE TIME

Cycle time is divided into two parts: delay time and delay-free cycle time.

6.5.1. Delay Time

Delay time components during yarding are operating delays, repair delays, personal delays, and other delays including pick up lost logs from previous turns before finishing a skyline road, and moving obstructions (Kellogg et al., 1986). Operating delays include hangups, limbing and clearing logs from the landing, felling and bucking during yarding, and pulling anchor stumps or tailtrees.

6.5.2.Delay-Free Cycle Time

An example of a formula to obtain the cycle time in yarding is:

$$T = \frac{OHD}{OHV} + DT + \frac{LOHD}{LOHV} + HT + \frac{LIHD}{LIHV} + \frac{IHD}{IHV} + UT + RT$$

Where:

T = Yarding cycle time (min/cycle)

OHD = Outhaul distance (m/cycle)

OHV = Outhaul velocity (m/min)

DT = Chokers dropping time (min/cycle)

LOHD = Lateral outhaul distance (m/cycle)

LOHV = Lateral outhaul velocity (m/min)

HT = Hook time (min/cycle)

LIHD = Lateral inhaul distance (m/cycle)

LIHV = Lateral inhaul velocity (m/min)

IHD = Inhaul distance (equal to outhaul distance) (m/cycle)

IHV = Inhaul velocity (m/min)

UT = Unhook time (min/cycle)

RT = Road changing time (min/cycle)

6.6. DETERMINING PRODCUTION

The production rate is calculated by dividing the average volume of wood per cycle by the time per cycle including delays. Production rate in cubic meters per hour can be obtained from following equation:

$$\text{Production } (m^3/hr) = \frac{\text{Volume}(m^3/\text{ cycle})}{\text{hr/cycle} + \text{delay(hr / cycle)}}$$

The yarding production rate is highly affected by turn volume and slope yarding distance. Figure 29 and Figure 30 indicate production rate differences as influenced by turn volume and slope yarding distance, respectively. In areas with low volume per ha, the road change time can also reduce average productivity.

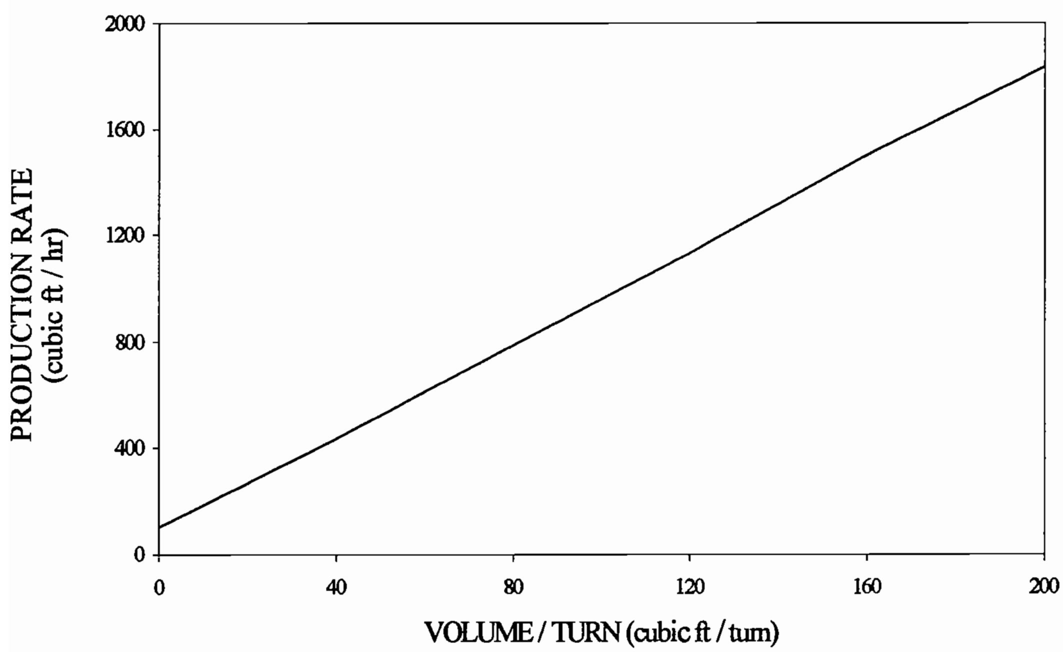


FIGURE 29. Yarding Production rate by Average Turn Volume (Kellogg, 1986).

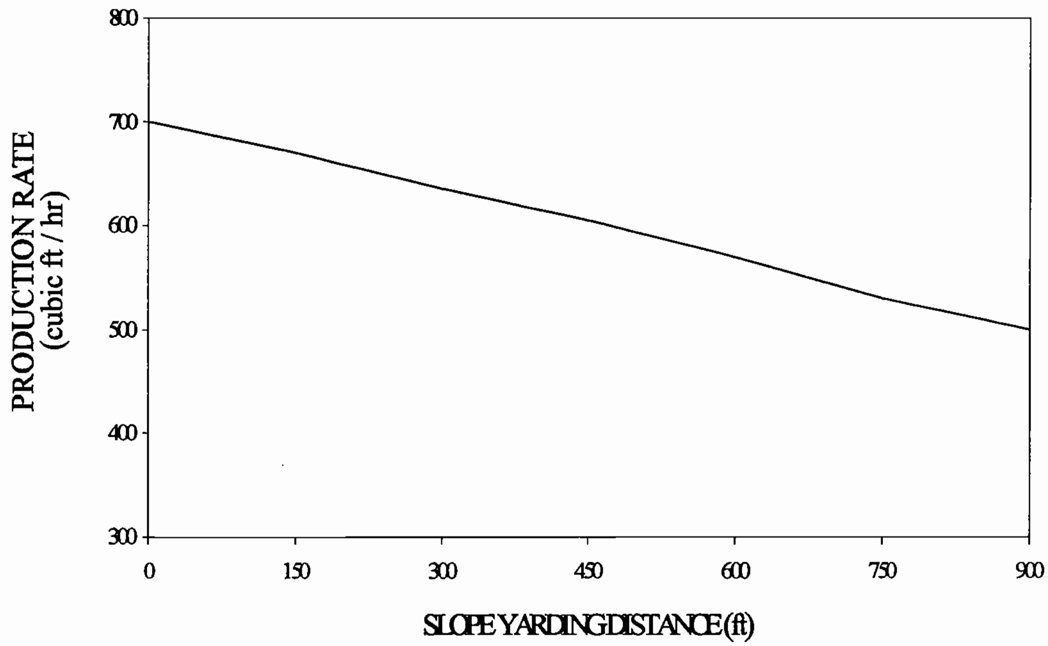


FIGURE 30. Yarding Production Rate by Slope Yarding Distance (Kellogg, 1986).

6.7. UNIT COST OF YARDING

In order to calculate unit cost of yarding per unit volume, the production rate and machine rate including ownership cost, operating cost, and labor cost must be known. Then, the unit cost can be obtained by dividing machine rate by the corresponding production. For example, machine rate for the small cable yarder (Koller K501 Three Drum Yarder) including the Eagle Eaglet Carriage can be computed as follows:

Delivered costs = $ 140,000 Salvage rate = 30 %

Life in hour = 12,000 hr Depreciation rate = 50 %

Working time per day = 10 hr Interest, Insurance, and Tax rate = 13 %

Fuel consumption = 311.25 liter/hr	Cost of lines = $ 4,000
Fuel cost = $ .38/liter	Life of lines = 2,000 hr
Percent of fuel cost for lubricant = .30	Cost of rigs = $ 1,600
Tire and track replacement cost = 1100	Life of rigs = 4,000 hr
Life of tires = 6000 hr	Direct labor = $ 89.53 (4 men crew)

$$\text{Depreciation cost } = \frac{\$140{,}000 \times (0.70)}{12000} = \$8.17/\text{SMH}$$

$$\text{A.A.I. } = \frac{\$140{,}000 \times 0.70 \times (1+6)}{2 \times 6} + \$140{,}000 \times (.30) = \$99{,}167 \text{ /yr}$$

$$\text{Interest, Insurance, and Tax Cost } = \frac{\$99{,}167 \times 0.13}{2000hr} = \$6.45 \text{ /SMH}$$

Repair and Maintenance cost = $8.17/SMH × 0.50 = $4.085 /SMH

Fuel cost = $0.38/liter × 11.25 liter/hr = $4.28 /SMH

Oil and Lubricant cost = $4.28 × 0.30 = $1.28/SMH

Lines and Rigging cost = $2.4/SMH

Tire and Track cost = 4.18/SMH

Labor cost = $89.53 × (1.15) = $102.96/SMH

Ownership cost = $14.62/SMH

Operating cost = $12.23

Total Machine Rate (Ownr. + Opert. + Labor) = $129.81/SMH

Machine rate for the selected carriage was estimated as \$7.05/SMH. Therefore, the total machine rate for both machines became \$13.86/hr. In order to compute production rate and unit costs, a yarding study table was developed by Brown (1995) for the same type of yarder and carriage combination (Table 14).

TABLE 14. Yarding Time Study Summary

CYCLE TIME ELEMENTS		AVERAGES (cmin)
Outhaul		31.49
Drop		20.30
Lateral outhaul		26.67
Hook		63.62
Lateral inhaul		63.77
Inhaul		53.86
Unhook		82.36
TURN TIME	(cmin)	342.60
	(min)	3.43

The number of logs per turn and average volume per log was 8 and 0.13 m^3, respectively. The Production rate is equal to 18.2 m^3/hr (60 min/hr ÷ 3.43 min/cycle × 8 logs/cycle × 0.13 m^3/log). Therefore, the unit cost of yarding can be obtained by using the production and cost data as follows:

$$UC = C / P$$

$$UC = \$\ 129.81/\text{hr} \div 18.2\ m^3/\text{hr} = \$\ 7.13/m^3$$

Where:

UC = The unit cost of yarding ($\$/m^3$)

C = Machine rate for yarding and carriage

P = Production rate (m^3/hr)

7. LOADING

Loading is one of the most challenging, costly, and dangerous operations in harvesting. Many different systems of loading have been used from manual loading to highly mechanized loading. In manual loading, stored logs up off the ground are rolled, one by one, over the bridging logs from front of the skidway to the truck bed.

In order to reduce loading time and labor, various kinds of loaders have been built. Loaders are either mounted on the log hauling truck or on a separate vehicle equipped with wheels or tracks. The loader selection for harvesting operation depends on the timber size, size of operation, and method of loading.

Pallets: In short log systems, steel pallets have sometimes been used. They are loaded in the woods for later pick up by forwarder or skidder, and could be left for loading onto a hauling truck (Bromley, 1968). Whether pallets are loaded by hand or mechanically, it is still an efficient way to load a truck. After a prehauler vehicle brings the pallet out of the woods to the landing, it is winched onto a pallet highway truck for hauling.

Big-Stick Loading: A short, rotatable horizontal boom attached to a center post mounted on the back of the truck cab is often called as "Big Stick" loader (Mifflin et al., 1979). In gentle terrain where small on-highway trucks can travel easily, the big-stick loader, equipped with a small winch, can drag in logs from distances up to 100 feet away.

Cable loader (Crane Loader): Cable loaders are equipped with a rigid type boom, winch drums, and cable. They can drag in pieces to be loaded from considerable distances, as much as 200 feet (Simmons, 1979). A disadvantage of this system is the need for three workers including operator, top-loader, and tong-setter to operate it. Besides, both the tong-setter and the top-loader are working in highly hazardous situations much of the time.

Front-end Loader: The front-end loader is either a wheeled or tracked vehicle with a pair of lifting arms at the front end (Figure 31). It can raise several long wood stems at one time on the arms, and place them on the haul truck unit. A front-end loader requires considerable area of firm ground to move around. Under wet weather conditions, it stops loading while a knuckle-boom or cable loader can continue to operate from its fixed position (Simmons, 1979).

Hydraulic Grapple Boom Loading: The most versatile loader is the hydraulic grapple boom loader since it gives positive control of the products ranging from short length to full-length material (Figure 32). Hydraulic grapple boom loaders can pick the material either as single sticks or several pieces, and place it very accurately wherever desired on a truck (Bromley, 1968). They are only limited by weight of the load and the size of the grapple.

Hydraulic grapple boom loaders are generally divided into two types including knuckle-boom type and heel-boom type. The knuckle-boom loader mounted either on hauling truck or on separate vehicle is equipped with a hydraulically operated loading boom whose mechanical action imitates the human arm (Mifflin et al., 1979). For loading heavier and larger lengths, heel-boom loaders equipped with either a grapple or tongs have been

FIGURE 31. Rubber-tired front-end loader.

FIGURE 32. Hydraulic Knuckle-boom loader.

used. The grapple is the more versatile since it is operated by the operator in the cab of the loader (Simmons, 1979).

Grapple-equipped loader operations are more economical, and much safer than the cable controlled loaders (Simmons, 1979). However, hydraulic-boom grapple loader can not reach out very far to pick up the load, and its load capacity is reduced at the limits of reaching distance.

7.1.TIME ELEMENTS

The work cycle of loading is separated into five elements including positioning, loading, sorting, trimming, and binding (Lanford et al., 1990).

Positioning: Time spent on placing the trailer where it can be loaded by the loader.

Loading: Time spent on lifting the logs from the deck and placing it onto the trailer.

Sorting: Time spent on sorting the products other loaded logs.

Trimming: Time spent on removing excess length or limbs with chain saw.

Binding: Time spent on putting the chains around the load to secure it to the trailer.

In addition to the time elements, independent variables at loading are (Kellogg et al., 1984, and Lanford et al., 1990):

Stems: Number of piece swing per cycle.

Volume: Gross cubic foot volume of the piece swung by the loader.

Average diameter: Average large and small-end diameter of each log in the loading cycle.

Log length: Average log length in the loading cycle.

7.2. DETERMINING CYCLE TIME

Cycle time is divided into two parts: delay time and delay-free cycle time.

7.2.1. Delay Time

Delay time is divided into three groups including personal delay, operational delay, and mechanical delay (Lanford et al, 1990). Personal delays include getting water, talking to the supervisor, resting, and other activities necessary for operator's health. Operational delay is the time spent on waiting for skidder, forwarder, or haul trucks. Mechanical delays, on the other hand are breakdowns, repair time, servicing, or other delays due to loader not being available to load.

7.2.2. Delay-Free Cycle Time

The time per log for loading single logs is usually estimated as (Sessions, 1992):

$$T = a$$

Where: a = time per cycle

For example, suppose that, a hydraulic knuckle-boom loader is loading 1 m^3 logs at an average rate of 2 per minute. It also spends 30 minutes per hour for sorting logs at the landing.

$$T = 1 \text{ min} / 2 \text{ cycle} = 0.5 \text{ min} / \text{cycle}$$

However, the loading cycle time for actual working time is 1 min / cycle since half of the time is spent on sorting, so that the logs are ready for loading efficiently when the trailer arrives.

7.3. DETERMINING PROUCTION AND UNIT COST OF LOADING

Loading production is calculated by dividing the volume per cycle by the minutes per cycle including delays. For the previous example;

$P = (1\ m^3 / cycle \div 1\ min / cycle) \times 60\ min / hr. = 60\ m^3 / hr.$

In order to calculate the unit cost of loading per unit volume, the production rate and machine rate including ownership cost, operating cost, and labor cost must be known. Then, unit cost is estimated by dividing machine rate by the production rate. For example, machine rate for a hydraulic knuckle-boom loader (CAT 330B, tracked) can be computed as following:

Delivered cost = \$ 447,550	Life in hour = 10,000
Scheduled Machine Hour = 2,000	Salvage rate = 30 %
Utilization = 65 %	Labor cost = \$ 17.52/hr.
Depreciation = 50 %	Social cost rate = 41.5 %
Fuel consumption = 22.73 liter/hr.	Interest, Ins&Tax = 18 %
Fuel cost = \$ 0.38 /liter	Cost of track = \$ 15,000
Percent of fuel cost for lubricant = 36.8 %	Life of track = 5,000 hr.

$$\text{Depreciation Cost} = \frac{\$447{,}550 \times 0.70}{10{,}000\,SMH} = \$31.33\ /\text{SMH}$$

$$\text{A.A.I.} = \frac{\$447{,}550 \times 0.70 \times (5yr. + 1)}{2 \times 5yr.} + \$447{,}550 \times 0.30 = \$322{,}236/\text{yr.}$$

$$\text{The charge for interest, and Ins\&Tax} = \frac{\$322{,}236 / yr. \times 0.18}{2{,}000\,SMH} = \$29.00/\text{SMH}$$

$$\text{Repair and Maintenance Cost} = \$31.33 / SMH \times 0.50 = \$15.67/\text{SMH}$$

Fuel Cost $= 18.94 liter/hr. \times \$0.38/liter \times 0.65 = \$4.68$/SMH

Oil and Lubricant Cost $= \$4.68/SMH \times 0.368 = \$1.81$/SMH

Tire Replacement Cost $= (\frac{\$15{,}000}{5{,}000 hr.}) \times 0.65 = \$1.95$/SMH

Labor Cost = \$17.52/hr. × 1.415 = \$24.79/SMH

Total Ownership Cost = \$60.33/SMH

Total Operating Cost = \$24.11/SMH

Machine Rate (Ownership + Operating + Labor) = **\$ 109.23/SMH**

Suppose that hauling is done with 20 ton logging truck, and 20 pieces (20 m^3) are being loaded per turn. Estimated total load time per truck for a hydraulic loader can be obtained from the following equation (Schneider, 1978):

TLT = 505.75 + 35.100 × Pieces

TLT = 505.75 + 35.100 × 20 = 1207.75 second = 20.13 min.

Estimated production (m^3/hr) without equipment delays is:

P = Volume / TLT

P = (20 m^3 / 20.13) × 60 = 59.6 m^3/hr

For the same loader example, the unit cost for loading is obtained by using the production and cost data as follows:

UC = C / P

Where:

UC = The unit cost of loading (\$/m^3)

C = Machine rate for the loader (\$/hr.)

P = Production rate (m^3/hr.)

8. ESTIMATING PRODUCTION RATE OF HARVESTING MACHINES

It is difficult to evaluate productivity of systems and equipment under a wide rage of conditions due to the many different variables influencing production rate, such as timber size, stand density, terrain conditions, soil type, and water (Gardner, 1982). Operator skill and motivation also affect logging production. In this study, most of the production equations are based on past studies that have provided useful data to analyze productivity of systems and equipment under various harvesting conditions.

Production equations are usually expressed by regression models developed by using the study data. These equations give an opportunity to predict equipment productivity and to estimate the cost of logging. In order to estimate production, the approach taken here is to calculate cycle time from an equation as a dependent variable, and then convert to production using log size, volume, or weight. Machine categories studied in this section include skidders, feller-bunchers, harvesters, loaders, and forwarders. An alternative approach is to derive a regression equation for production directly from the independent variables.

8.1. SKIDDER

The following regression equations can be used to predict productivity on the basis of indicator variables for number of logs per turn, volume per turn, and total distance traveled by the skidder on average 35 percent of ground slope (Gardner, 1982).

Rubber-Tired Cable Skidders with brake hp rating of 110-150:

Turn time in minutes = $- 0.1971 + 1.1287 \times NL + 0.0045 \times VOL + 0.0063 \times DITOT$

Rubber-Tired Cable Skidders with brake hp rating of 70-150:

Turn time in minutes = $2.57 + 0.8828 \times NL + 0.0054 \times VOL + 0.0078 \times DITOT$

Where: NL = Number of logs per turn

VOL = Volume per turn (ft^3, or m^3)

DITOT = Total distance traveled by the skidder (ft, or m)

The equation for calculating rubber-tired grapple skidder time was derived as a function of distance, machine horsepower, load weight, and number of bunches (Tufts et al., 1988). Total cycle time equations were developed for skidding whole-tree and tree-length systems as follows:

Skidding Whole-trees to deck time (min) =

$- 0.5988 + 0.004539 \times DIST + 0.01119 \times HP - 0.00001554 \times DIST \times HP$

$+ 0.0003782 \times DIST \times NBNCH + 1.616 \times NBNCH - 0.005599 \times NBNCH \times HP$

$+ 0.1398 \times NBNCH \times NTREES$

Skidding tree-length to deck time (min) =

$- 0.0158 + 0.005234 \times DIST - 0.000443 \times HP + 1.650 \times NBNCH +$

$- 0.0000002581 \times HP \times LOAD - 0.000003336 \times DIST \times HP +$

$- 0.01398 \times NBNCH \times NTREES - 0.005599 \times NBNCH \times HP$

Where:

DIST = One-way distance traveled in feet

LOAD = Load weight in pounds

HP = Machine flywheel horsepower

NBNCH = Number of bunches grappled

NTREES = Number of trees per load

Cycle time for rubber-tired clumbank skidder is estimated by using the data from past studies providing number of trips per hour (Table 15).

TABLE 15. Cycle Time Parameters For a Clambunk Skidder (Average slope = 30 %).

Make	Model Number	ASD (M)	Load (m^3/cy)	Volume m^3/log	Number of trips Trip/hr	Cycle Time . (min/cycle)
TJ	933-D	300	18	.68	1.087	55.20

Tracked skidders studied in this project are equipped with chokers. Cycle time for these tractors can be predicted by using following equations (Gardner, 1982):

Turn time in minutes = $14 - 0.1446 \times SL + 0.0714 \times DI + 0.3360 \times NL$

Where: SL = Ground slope (percent)

DI = Skidding distance (ft or m)

NL = Number of logs per turn

The capacity of the skidder is highly dependent on its drawbar horsepower, weight, and traction obtainable under the ground conditions during operation. Skid distance is generally the most important variable since it affects cycle time more than any other variables. If the skid distance increases, travel time will increase too. In some cases where skid trail is quite straight, the longer the distance, the faster the travel speed without load.

In the case where ground slope on the skid trail is steep, vehicle travel with the lower speed, which means that cycle time will be longer. Greater load weight also reduces the travel speed slightly. The load size variables including weight, number of bunches grappled, or number of trees hooked is also important in skidding. As number of bunches grappled per turn increases, the time spent on grappling increases, which will increase the cycle time.

8.2. FELLER-BUNCHER AND HARVESTER

Cycle time for specific feller-bunchers are estimated using studies, which provide number of trees cut per machine hour (Table 16). The equation for solving single-grip

TABLE 16. Cycle Time Parameters for Specific Feller-Bunchers (Average slope = 35 %).

Machine Make	Model Number	Volume m^3/log	Number of trees Trees/hr	CYCLE TIME (min/tree)
PRENTICE	720	.68	70	.86
PRENTICE	730	.68	75	.80
TJ	2618	.68	50	1.20
TJ	2628	.68	60	1.00
TIMBCO	T225-B	.68	60	1.00
TIMBCO	T445-B	.68	70	.86

harvester time is a function of volume, and slope class. Total cycle time for the harvester can be calculated on the basis of Lilleberg (1990) or Grammel (1995) which provides the correlation of the productivity in m^3 per tree ranked by slope class. Cycle time for a single-grip harvester as a function of stem size (Lilleberg, 1990):

$$Chklov = 34.7 + 0.13 \times (vk) + 0.125 \times 10^{-5} \times (vk)^2$$

Where:

Chklov = Time expenditure in thinning of conifers by one-grip harvester (10 t), cmin/tree.

Vk = Stem volume, dm^3 (cubic decimeter)

Single-grip harvester time in cmin/m^3 by the slope ranges from 26-40 % (Grammel, 1995):

$$Y = 56.62 \, Ln \, (X) + 322.09$$

Where:

Y = Cycle time per tree (cmin/m^3)

X = Volume per tree (m^3)

Since the felling head attached on the feller-buncher can cut various sizes of trees in approximately the same amount of time regardless of their diameter, relatively large tree size is a factor that allows the machine to produce greater volumes of wood per productive machine hour. Trees per unit area (TPA) also affect the time to process trees. The time spent on moving, cutting, and accumulating trees decreases when TPA increases.

The harvester productivity generally is closely related to tree size. As tree volume increases, production rate will increase since processing time for big trees is bout the same as the small size trees. Steep slopes cause difficulties to harvester operation, which may increase the time per tree. However, according to the study conducted by Grammel (1995), even with very steep conditions, the harvester can work on thinnings at comparable costs to gentle terrain.

8.3. HYDRAULIC TRACKED LOADER

The equation for calculating hydraulic loader time can be derived as a function of load capacity of a hauling truck, volume per tree, and number of pieces per truck. The number of pieces per truck can be obtained by dividing truck load capacity (m^3) by volume per tree (m^3). Then, total load time will be calculated by the equation developed by Schneider (1978):

$$TLTT = 505.75 + 35.100 \text{ PIECES}$$

Where: TLTT = Estimate total load time per truck (sec)

PIECES = Number of pieces per truck load

8.4. FORWARDER

Cycle time of a forwarder includes travel time, loading time, and other time elements such as delay time, brushing time, repositioning time, and sorting time.

8.4.5. Travel Time

Travel time is computed as a function of distance, machine horsepower, load weight, and vehicle speed. Travel time is divided into two segments: unloaded travel time and loaded travel time.

Unloaded Travel Time: It is assumed that forwarder travels uphill without load, and downhill with load. The forwarder operator can change the position of the seat in the cab, and drive uphill unloaded (Figure 33). When the machine is loaded, he turns the seat back to its normal position, and drives downhill loaded (Figure 34). That eliminates the time spending on changing travel direction of the forwarder after loading, which might be very dangerous in woods under steep slope conditions. Return trails, also known as "go-back trails", may be used to overcome this problem, but, it requires a longer transportation distance from landing to landing.

The force diagram shown in Figure 33 indicates tractive effort and resistance that are two primary opposing forces determine the non-turning performance of the machine. Tractive effort is basically the force available at the roadway surface to perform work (Mannering et al., 1990).

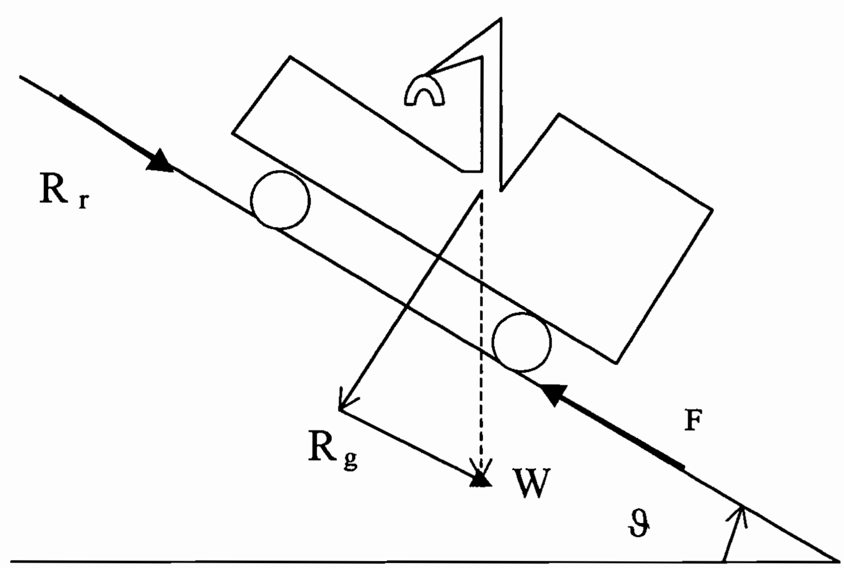


FIGURE 33. Forces acting on a forwarder, travelling uphill without load.

Two major sources of resistance considered during operation are rolling resistance and grade resistance. Acceleration is assumed to be zero. Aerodynamic resistance is ignored since it cannot have any significant impacts on forestry machines at low speed. In Figure 1, R_r is the total rolling resistance of both axles (in lb), R_g is the grade resistance (in lb), F is the tractive effort of axles (in lb), W is the total vehicle weight (in lb), and ϑ is the slope angle (in degrees). Since the forwarder is the all-wheel drive vehicle, Tractive effort (F) and rolling resistance (R_r) are of all tires.

Summing the forces along the machine's longitudinal axis provides the basic equation of vehicle motion as follows:

$$F \geq R_r + R_g$$

where F is the sum of the available tractive effort, R_r is the sum of the rolling resistance, and R_g is the grade resistance and is equal to W sinϑ. The rolling resistance is represented by the coefficient of the rolling resistance ($f_{r\ (Loose\ soil)}$ = 10 %, CAT Handbook, 1996) multiplied by W cosϑ, the vehicle weight acting normal to the roadway surface:

$$R_r = f_r W \cos\vartheta$$

The maximum tractive effort that the roadway surface / tire contact can support must be greater or equal to sum of vehicle resistance ($R_r + R_g$). To determine uphill unloaded vehicle speed, the following equation limited by the net horsepower (HP) of the vehicle can be used:

$$V = \frac{HP \times 33000}{R_r + R_g}$$

Where: HP = Net horsepower rate of vehicle (hp)

F = Maximum allowable tractive effort (lb)

V = Vehicle speed (ft/min)

Therefore, unloaded travel time will be calculated by dividing V by the forwarding distance.

Loaded Travel Time: Figure 34 illustrates the vehicle force diagram for a forwarder travelling downhill with load on it. In this case, vehicle speed is limited by two factors including desired stopping distance and maximum allowable thrust as the sustainable braking force of the vehicle. In order to determine downhill speed for a loaded forwarder, vehicle speed must be computed according to both stopping distance and braking horsepower approaches, separately. Thus, the lower speed will give the vehicle speed by

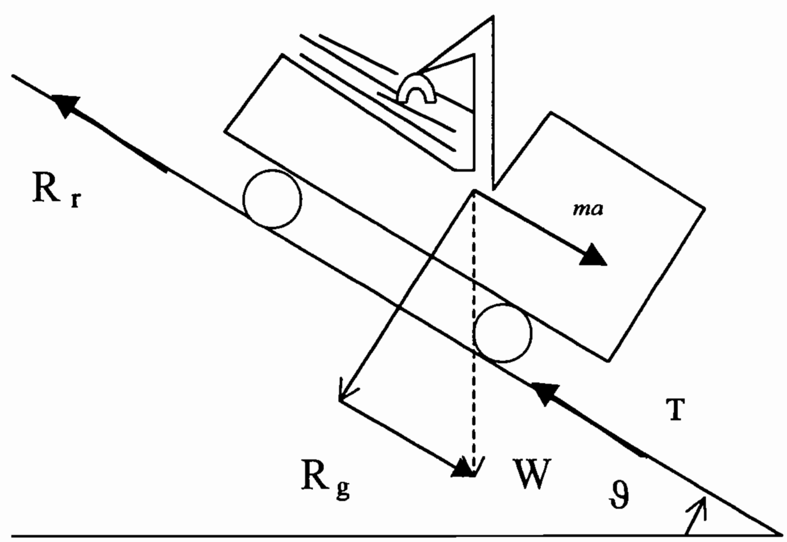


FIGURE 34. Forces acting on a forwarder, travelling downhill with load.

that vehicle can travel downhill safely and stop in a desired stopping distance without slipping.

In stopping distance approach, summing the forces along the vehicle's longitudinal axis provides the following equation of vehicle motion:

$$T \geq R_g - R_r$$

T is the sum of the available braking force and is equal to μ W cosϑ. μ, coefficient of traction factor, is assumed as .45 in this study ($\mu_{\text{(Loose soil)}}$ = 45 %, Cat Handbook, 1996). W is the total weight of vehicle including load (lb), m is the vehicle mass and is equal to W/32.2. Since all the parameters except a are known, equation can be solved for a. It is also known that:

$$V_S^2 = V_0^2 + 2aS$$

where V_s is the vehicle speed when it stops and is equal to zero. The desired stopping distance, and is assumed as 10 ft in this study. Therefore, V_0, initial speed of the vehicle, can be computed from this equation by using a from the previous equation.

To determine vehicle speed in terms of braking horsepower of the vehicle following equation must be satisfied:

$$V = \frac{BHP \times 33000}{R_g - R_r}$$

Where:

V = Vehicle speed (ft/min)

BHP = Braking horsepower rate of vehicle (hp, assumed as 75 % of max. HP)

$R_g - R_r$ = Required braking force to maintain constant velocity (lb)

Therefore, loaded travel time will be calculated by dividing V by the forwarding distance.

8.4.6. Loading Time

In order to determine loading time per cycle, grapple loading capacity (m^3/cycle), grapple unloading capacity (m^3/cycle), forwarder's load capacity (m^3), and average grapple cycle time must be known. According to FAO (1977), grapple loading capacity can be estimated as:

$$LC = Area \times L \times F$$

Where:

LC = Grapple load capacity (m^3/cycle)

Area = Area in closed grapple (m^2)

L = Log length (m)

F = Factor f, varies somewhat with log length since longer logs tend to lie less closely together when grouped.

They also estimate that average grapple loading and unloading capacity are 0.7LC, and 0.9LC, respectively. If average grapple cycle time is known, then, loading time can be obtained from following equation:

$$LT = \left(\frac{FLC}{0.7LC} + \frac{FLC}{0.9LC}\right) \times GT$$

Where:

LT = Loading time (min/load)

FLC = Forwarder load capacity (m^3)

LC = Average load capacity (m^3/cycle)

GT = Average grapple cycle time (estimated as .50 min/cycle)

Forwarding is more difficult as the ground slope increases since the higher center of gravity of the load results in lower stability, which increases the risk of sliding side ways, and grade resistance increases requiring greater braking forces. It is also difficult to pick the logs up from the ground and putting them onto the forwarder in steep slopes.

9. HARVESTING COSTS UNDER REPRESENTATIVE CONDITIONS IN TURKEY

The most economical machine combinations, which minimize the stump-to-truck harvesting, were estimated for three different regions of Turkey. These geographic regions are the Mediterranean, Black Sea, and Aegean regions. Analytical methods were used to estimate machine cost and productivity for different harvesting system combinations. The unit cost of logging is estimated by dividing hourly equipment cost by hourly production. The data collected from the regions as representative conditions included topographic data, road data, tree and log data, soil data, and economic data.

Most of the ground-based harvesting machines analyzed in this paper are not commonly used in forest operations in Turkey. However, a small number of mechanized harvesting systems have been used in intensively managed forests. In many regions of Turkey, chainsaws and axes have been used for felling and bucking. Farm tractors equipped with a winch and animals are the energy sources for forestry work and transportation.

9.1. REGION DESCRIPTIONS

Average timber stand characteristics of these regions are summarized in the tables. Table 17 indicates the stand characteristics in the Mediterranean region, which is located in southern Turkey. Stand characteristics for the Black Sea region (in the north), and the Aegean region (in the west) are in Table 18 and Table 19, respectively. Four sample plots were selected by the Alanya Forestry Management Office and Odemis Forestry Management Office to determine representative stand characteristics in the Mediterranean

TABLE 17. Average Timber Stand Characteristics for Mediterranean Region.

Stand Characteristics	ITEMS
Species	Cedar, Pine, Fir.
dbh	36 cm. (14.2 in.)
Volume per removal tree	.68 m^3 (24 ft^3)
Trees/Hectare	413
Slope	35 %

TABLE 18. Average Timber Stand Characteristics for Black Sea Region.

Stand Characteristics	ITEMS
Species	Pine, Beech, Oak
dbh	28 cm. (11 in.)
Volume per removal tree	.41 m^3 (14.5 ft^3)
Trees/Hectare	487
Slope	35-40%

TABLE 19. Average Timber Stand Characteristics for Aegean Region.

Stand Characteristics	ITEMS
Species	Pines
dbh	22 cm. (8.7 in.)
Volume per removal tree	.25 m^3 (8.8 ft^3)
Trees/Hectare	501
Slope	30-35%

and Aegean regions, respectively. In the Black Sea region, six sample plots were selected by the Kurdese Forest Management Office to represent stand characteristics in the region.

9.2. HARVESTING SYSTEMS

Six thinning systems were examined to determine their cost efficiency in selected Regions with various timber stand characteristics. The systems were balanced with the configurations shown in Table 20. Use of a single-grip harvester and one forwarder balanced the cut-to-length system A. A Timber Jack 1270-B Single-grip Harvester fells and processes (delimbs and crosscuts) the trees at the deck, and then, a Timber Jack 1210-B Forwarder transports them clear of the ground. Set-out trailers are placed at the landing for loading.

In the second cut-to-length system, one forwarder and four men for manual felling, bucking, and delimbing are required. Timberjack 1210-B Forwarder transports the logs processed by the sawyers in the woods. Set-out trailers are placed at the landing for loading.

TABLE 20. Harvesting Systems Configurations.

Systems	Configurations
Cut-to-length	
A	1 Single-Grip Harvester 1 Forwarder Set-out trailers placed at the landing for loading
B	4 Sawyers for manual felling, delimbing, and bucking in the woods 1 Forwarder Set-out trailers placed at the landing for loading
Tree-length	
A	3 Sawyers for manual felling and delimbing 1 Crawler tractor with chokers 3 Sawyers for manual bucking at the landing 1 Loader
B	1 Feller-buncher 2 Sawyers for manual delimbing, and topping in the woods 1 Grapple Skidder 1 Loader
Whole-tree	
A	1 Feller-buncher 1 Grapple Skidder 4 Sawyers for manual delimbing and bucking at the landing 1 Loader
B	1 Feller-buncher 1 Clambunk Skidder 4 Sawyers for manual delimbing and bucking at the landing 1 Loader

In tree-length system A, three men for felling and delimbing, three men for bucking and one cable skidder are involved the operation. The trees are felled and delimbed at the stump, and transported by CAT D4HCS Tracked-Skidder with chokers to the landing. Bucking is done at the landing by three sawyers. CAT 335-B Loader is operating at the landing for loading trees onto the trucks.

Alternative tree-length system requires a feller-buncher, one grapple skidder, and five sawyers to balance the system. A Timbco 225-B Feller-buncher fells the trees, accumulates and places them in a selected location. Trees are delimbed by two sawyers before being transported by CAT 515 Grapple Skidder to the landing. The skidder worked approximately twice the time of the feller-buncher to balance the productivity of the operation. Three sawyers crosscut the trees at the landing, and CAT 325-B Loader places them onto the truck.

Whole-tree system A requires a feller-buncher, one grapple skidder, and four sawyers to balance the system. A Timbco 225-B Feller-buncher fells the trees, accumulates and places them in a selected location next to the skidding trail. Then, a CAT 515 Grapple Skidder transports them to the landing. The skidder worked approximately twice the time of the feller-buncher to balance the productivity of the system. At the landing, four sawyers remove limbs from trees and crosscut them. Loading is done by CAT 325-B Loader at the landing.

In the second whole-tree system, one feller-buncher, one clambunk skidder, and four men for manual bucking and delimbing are involved the operation. The trees are felled and bunched by a Timbco 225-B Feller-buncher, and transported by a TJ 933-D Clambunk Skidder to the landing. In the Mediterranean region, the clambunk skidder worked twice the hours of the feller-buncher while in the Black Sea region, it worked 50 % more hours than the feller-buncher to balance the productivity of the system. Four sawyers remove limbs from the trees and crosscut them. CAT 335-B Loader is operating at the landing for loading trees onto the trucks.

9.3. UNIT COST SUMMARY

Machine rates used in this section are estimated by using the data representing economic conditions in Turkey, and listed in Appendix D. Appendix E indicates the cycle time and productivity parameters for specific skidders, crawler tractors, feller-bunchers, harvester, loader, and forwarder. Unit costs of all the harvesting equipment considered in the project are estimated by dividing the estimated machine rate by the estimated production rate (Appendix F).

The most economical machine combinations and their unit cost summary for the harvesting systems including cut-to-length, tree-length, and whole-tree were listed in Appendix G. Cut-to-length system using a forwarder and four sawyers produced wood at the lowest cost in both Black Sea, and Aegean region, while the whole-tree system balanced with a feller-buncher, a grapple skidder, a loader, and four sawyers was the most cost efficient system in the Mediterranean region (Table 21).

In the Black Sea region, the least cost efficient system was whole-tree system using a feller-buncher, a clambunk skidder, a loader, and four sawyers. The tree-length system using a crawler with chokers, a loader, and six sawyers was the most expensive system in the Aegean region. The system balanced with a harvester and a forwarder was more expensive than both tree-length and whole-tree logging system in the Mediterranean region.

TABLE 21. The Most Economical Machine Combinations for Each Region.

REGIONS	UNIT COST ($/M^3)					COST
	Felr-Bnch	Skidder	Manual P.	Forwarder	Loader	($/M^3)
BLACK SEA	-	-	3.03	8.15	-	11.18
MEDITERRANEAN	2.49	3.07	0.71	-	2.93	9.20
AEGEAN	-	-	4.40	9.48	-	13.88

In the cut-to-length system, use of the mechanical processor (harvester) instead of manual felling and bucking increased the logging cost in three regions. The system using a clambunk skidder produced wood at a higher cost than the systems using grapple skidder. in whole-tree system. The crawler tractor system producing tree-lengths was less cost efficient than the tree-length system using the grapple skidder in all three regions.

Use of the grapple skidder in the tree-length system produced wood at a higher cost than in the whole-tree system The tree-length system using grapple skidder, a loader, and five sawyers was slightly more expensive than the whole-tree system balanced with a feller-buncher, a skidder, a loader, and four sawyers.

The current harvesting system in Turkey using four sawyers for manual processing, a team of oxen for skidding, and three men for manual loading is estimated to be \$ 1-3/m^3 less than the mechanized harvesting system. The unit cost estimates for current oxen skidding system used in the sample plots selected from the Black Sea, Aegean, and Mediterranean regions are listed in Appendix H.

CONCLUSIONS

Machine rates were estimated for selected forest harvesting machines under representative conditions in both the western United States and in Turkey. Even though labor cost is lower in Turkey compared to the western United States, machine rate estimates of selected machines for both countries were comparable because of the higher rate of interest, insurance, tax, and fuel cost in Turkey.

In the sample plots selected from Black Sea and Aegean regions, the cut-to-length system using four sawyers and a forwarder produced wood at the lowest cost as \$11.18/m^3, and \$13.88/m^3, respectively. In the sample plots selected from Mediterranean region, the whole-tree system using four sawyers, a grapple skidder, and a loader produced wood at the lowest cost (\$9.20/m^3). If these machine combinations were actually used in the selected regions, the initial cost of logging would be expected to be higher than the estimated costs in this project until machine operators, maintenance staff, and supervisors gain experience.

According to the unit cost estimates for current harvesting systems used in Turkey, the system using four sawyers for manual processing, a team of oxen for skidding, and three men for manual loading produced wood at \$ 9.96/m^3, \$ 10.08/m^3, and \$ 7.20/m^3 in the sample plots selected from the Black Sea, Aegean, and Mediterranean regions, respectively. Therefore, the mechanized harvesting systems are more expensive than the current oxen skidding system used in Turkey.

The mechanized harvesting systems analyzed in this study are not common in current logging operations in Turkey because they are very expensive, energy consuming, and highly correlated with the price of the fuel that is a limiting factor. They are also not favorable due to less in-woods labor to conduct the operation, which may cause unemployment. Approximately 98 % 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.

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.

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APPENDICES

APPENDIX A.1. Equipment Cost Calculation with Straight-Line Method.

OWNERSHIP COSTS

Initial Purchase Price (P)

Salvage Value (S), some % of P

Economic Life in year (N)

Straight-line Depreciation (D)

$$D = \frac{(P-S)}{N}$$

Scheduled Machine Hour (SMH = 2000 hr.)

Productive Machine Hour (PMH= SMH x Utilization)

Average Annual Investment (AAI)

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

Interest Rate (or Rate of Opportunity Cost) 12 %

Property Tax Rate 3%

Insurance Rate 3%

Interest per year = AAI × 12 %

Property Tax per year = AAI × 3%

Insurance per year = AAI × 3%

$$\text{Total Ownership Cost per SMH} = \frac{Depreciation + Interest + Tax + Insurance}{2000SMH}$$

OPERATING COSTS

Percent of Equipment Depreciation for Maintenance and Repair (50 %)

Maintenance and Repair Cost per SMH $= \frac{50\% \times D}{2000SMH}$

Fuel Consumption per machine hour (Liters /Hr.)

Actual Machine Hours per day (6 Hr.)

Scheduled Machine Hour per day (8 Hr.)

Fuel Consumption per hour (F) (Liters /Hr.)

Cost of Fuel per Liter ($/Liter)

Fuel Cost per SMH = F × ($/Liter) × (6 ÷ 8)

Cost of Lubricant per Liter ($/Liter)

Percent of Fuel Cost for Lubricant (=36.8 %)

Lubricant Cost per SMH = Fuel Cost per SMH × (36.8 %)

Cost of Lines ($)

Estimate Life of Lines (MMBF or SMH)

Wire-Rope Replacement Cost per SMH = Cost of Lines ($) ÷ Life of Lines (SMH)

Cost of Tire or Track including labor ($)

Estimated Life of Tire or Track (PMH)

Tire or Track Replacement Cost per SMH = Cost of Tire($) ÷ Life of Tire (PMH)/Utilizt.

Total Operating Cost per SMH

= Maintenance and Repair Cost ($/SMH) + Fuel and Lubricant Cost ($/SMH) +

Tire, Track or Wire-Rope Replacement Cost ($/SMH)

LABOR COST

Hourly Wages ($/SMH)

Labor Burden Factor (LB%)

Total Labor Cost ($/SMH) = Hourly Wages ($/SMH) × (1+ LB%)

TOTAL MACHINE RATE = OPR. COST + OWN. COST + LABOR COST

APPENDIX A.2. Equipment Cost Calculation with Marginal-Cost Method.

OWNERSHIP COST

Current Market Value (CMV), tire and wire-rope include

Market value at the end of year (U)

Depreciation per year = CMV – U

Scheduled Machine Hour (SMH = 200 days/yr. × 8-hr./day shifts = 1600 hr./yr.)

Interest Rate-rate of Opportunity Cost: 12 %; Property Tax Rate 3%; Insurance Rate 3%

Interest = CMV × 12%; Property Tax = CMV × 3%; Insurance =CMV × 3%

Total Ownership Cost per SMH $= \dfrac{Depreciation + Interest + Tax + Insurance}{1600 SMH}$

OPERATING COSTS

Mintenance and Repair Cost per SMH (Estimates of Actual Cost)

Fuel Consumption per machine hour (Liters /Hr.)

Actual Machine Hours per day (6 Hr.)

Scheduled Machine Hour per day (8 Hr.)

Fuel Consumption per hour (F) (Liters /Hr.)

Cost of Fuel per Liter ($/Liter)

Fuel Cost per SMH = F × ($/Liter) × (6 ÷ 8)

Cost of Lubricant per Liter ($/Liter)

Percent of Fuel Cost for Lubricant (36.5 %)

Lubricant Cost per SMH = Fuel Cost per SMH × (36.5 %)

Cost of Lines ($)

Estimate Life of Lines (MMBF or SMH)

Wire-Rope Replacement Cost per SMH = Cost of Lines ($) ÷ Life of Lines (SMH)

Cost of Tire or Track including labor ($)

Estimated Life of Tire or Track (SMH)

Tire or Track Replacement Cost per SMH = Cost of Tire($) ÷ Life of Tire (SMH)

Total Operating Cost per SMH

= Maintenance and Repair Cost ($/SMH) + Fuel and Lubricant Cost ($/SMH) +

Tire, Track or Wire-Rope Replacement Cost ($/SM)

APPENDIX B.1. Basic Input Data for Specific Harvesting Machines.

No.	Machine Make	Model Number	Machine Type	Classification	Mobility	Attachment Type	Machine HP
1	CAT	515	SKIDDER	ARTICULATED	RTIRE	CABLE	140
2	CAT	515	SKIDDER	ARTICULATED	RTIRE	GRPL	140
3	CAT	525	SKIDDER	ARTICULATED	RTIRE	CABLE	160
4	CAT	525	SKIDDER	ARTICULATED	RTIRE	GRPL	160
5	CAT	528	SKIDDER	ARTICULATED	RTIRE	CABLE	185
6	CAT	530	SKIDDER	ARTICULATED	RTIRE	GRPL	175
7	JD	540-G	SKIDDER	ARTICULATED	RTIRE	CABLE	115
8	JD	548-G	SKIDDER	ARTICULATED	RTIRE	GRPL	115
9	JD	640-G	SKIDDER	ARTICULATED	RTIRE	CABLE	151
10	JD	648-G	SKIDDER	ARTICULATED	RTIRE	GRPL	151
11	JD	740-G	SKIDDER	ARTICULATED	RTIRE	CABLE	165
12	JD	748-G	SKIDDER	ARTICULATED	RTIRE	GRPL	165
13	TJ	240	SKIDDER	ARTICULATED	RTIRE	CABLE	116
14	TJ	360	SKIDDER	ARTICULATED	RTIRE	CABLE	148
15	TJ	360	SKIDDER	ARTICULATED	RTIRE	GRPL	148
16	TJ	460	SKIDDER	ARTICULATED	RTIRE	CABLE	174
17	TJ	460	SKIDDER	ARTICULATED	RTIRE	GRPL	174
18	TJ	933-D	SKIDDER	ARTICULATED	RTIRE	CLMBNK	209
19	TJ	1210-B	FORWAR	ARTICULATED	RTIRE	KNUCKBM	172
20	TJ	1270-B	SNGHARV	ARTICULATED	RTIRE	SNG-GRIP	204
21	HYDROAX	411-EX	FB	ARTICULATED	RTIRE	SHEAR	140
22	HYDROAX	511-EX	FB	ARTICULATED	RTIRE	SHEAR	180
23	HYDROAX	611-EX	FB	ARTICULATED	RTIRE	SHEAR	205
24	PRENTICE	620	FB	TRACK	TRACK	SHEAR	215
25	PRENTICE	720	FB	TRACK	TRACK	SHEAR	260
26	PRENTICE	730	FB	TRACK	TRACK	SHEAR	270
27	TJ	2618	FB	TRACK	TRACK	SHEAR	205
28	TJ	2628	FB	TRACK	TRACK	SHEAR	230
29	TIMBCO	T225-B	FB	TRACK	TRACK	SAW	250
30	TIMBCO	T445-B	FB	TRACK	TRACK	SAW	250
31	PRENTICE	T210	LOADER	7599LB	TRUCK	KNUCBM	145
32	PRENTICE	T410	LOADER	10370LB	TRUCK	KNUCBM	169
33	PRENTICE	T610	LOADER	14850LB	TRUCK	KNUCBM	207
34	CAT	320A	LOADER	58700LB	TRUCK	KNUCBM	128
35	CAT	322B	LOADER	73400LB	TRUCK	KNUCBM	153
36	CAT	325B	LOADER	81200LB	TRUCK	KNUCBM	168
37	CAT	330B	LOADER	99500LB	TRUCK	KNUCBM	222
38	CAT	D4HCS	CRAWLER	TRACK	TRACK	CABLE	90
39	CAT	D4HCS	CRAWLER	TRACK	TRACK	GRAPPLE	90
40	CAT	D4HCS	CRAWLER	TRACK	TRACK	DRAWBAR	80
41	CAT	D5HCS	CRAWLER	TRACK	TRACK	CABLE	120
42	CAT	D5HCS	CRAWLER	TRACK	TRACK	GRAPPLE	120

APPENDIX B.2. Investment Parameters for Specific Harvesting Machines.

No.	Machine Make	Model Number	Machine Type	Price ($) 1997	Life (yr)	Salvage Rate	Util. Rate (%)	R&M Rate	Interest, Ins$Tax
1	CAT	515	SKIDDER	133500	5	0.15	0.60	0.75	0.18
2	CAT	515	SKIDDER	148070	5	0.25	0.60	0.75	0.18
3	CAT	525	SKIDDER	153000	5	0.10	0.60	0.75	0.18
4	CAT	525	SKIDDER	169980	5	0.25	0.60	0.75	0.18
5	CAT	528	SKIDDER	167500	5	0.10	0.60	0.75	0.18
6	CAT	530	SKIDDER	199000	5	0.25	0.60	0.75	0.18
7	JD	540-G	SKIDDER	105000	5	0.15	0.60	0.75	0.18
8	JD	548-G	SKIDDER	134000	5	0.25	0.60	0.75	0.18
9	JD	640-G	SKIDDER	125000	5	0.10	0.60	0.75	0.18
10	JD	648-G	SKIDDER	156000	5	0.25	0.60	0.75	0.18
11	JD	740-G	SKIDDER	146000	5	0.10	0.60	0.75	0.18
12	JD	748-G	SKIDDER	180000	5	0.25	0.60	0.75	0.18
13	TJ	240	SKIDDER	94395	5	0.15	0.60	0.75	0.18
14	TJ	360	SKIDDER	119500	5	0.10	0.60	0.75	0.18
15	TJ	360	SKIDDER	168000	5	0.25	0.60	0.75	0.18
16	TJ	460	SKIDDER	148000	5	0.10	0.60	0.75	0.18
17	TJ	460	SKIDDER	199500	5	0.25	0.60	0.75	0.18
18	TJ	933-D	SKIDDER	502000	5	0.15	0.65	0.70	0.18
19	TJ	1210-B	FORWAR	354000	5	0.21	0.65	0.70	0.18
20	TJ	1270-B	SNGHARV	488000	5	0.20	0.65	0.70	0.18
21	HYDROAX	411-EX	FB	143000	4	0.20	0.65	0.75	0.18
22	HYDROAX	511-EX	FB	153000	4	0.20	0.65	0.75	0.18
23	HYDROAX	611-EX	FB	161000	4	0.20	0.65	0.75	0.18
24	PRENTICE	620	FB	297000	5	0.15	0.60	0.75	0.18
25	PRENTICE	720	FB	328000	5	0.15	0.60	0.75	0.18
26	PRENTICE	730	FB	400000	5	0.15	0.60	0.75	0.18
27	TJ	2618	FB	366000	5	0.15	0.60	0.75	0.18
28	TJ	2628	FB	399000	5	0.15	0.60	0.75	0.18
29	TIMBCO	T425-B	FB	261310	5	0.15	0.60	0.75	0.18
30	TIMBCO	T445-B	FB	329650	5	0.15	0.60	0.75	0.18
31	PRENTICE	T210	LOADER	76000	5	0.30	0.65	0.70	0.18
32	PRENTICE	T410	LOADER	122000	5	0.30	0.65	0.70	0.18
33	PRENTICE	T610	LOADER	140000	5	0.30	0.65	0.70	0.18
34	CAT	320A	LOADER	397670	5	0.30	0.65	0.70	0.18
35	CAT	322B	LOADER	357140	5	0.30	0.65	0.70	0.18
36	CAT	325B	LOADER	388155	5	0.30	0.65	0.70	0.18
37	CAT	330B	LOADER	447550	5	0.30	0.65	0.70	0.18
38	CAT	D4HCS	CRAWLER	184000	5	0.20	0.60	0.75	0.18
39	CAT	D4HCS	CRAWLER	205000	5	0.20	0.60	0.75	0.18
40	CAT	D4HCS	CRAWLER	199000	5	0.20	0.60	0.75	0.18
41	CAT	D5HCS	CRAWLER	249000	5	0.20	0.60	0.75	0.18
42	CAT	D5HCS	CRAWLER	275000	5	0.20	0.60	0.75	0.18

APPENDIX B.3. Operational Parameters for Specific Harvesting Machines.

No.	Machine Make	Model Number	Machine Type	K kg/hp hr.	LF Load factor	KPL	Fuel Co. liter/SMH	Fuel c. $/liter	Lube&oil Rate
1	CAT	515	SKIDDER	0.21	0.54	0.72	13.23	0.3831	0.368
2	CAT	515	SKIDDER	0.21	0.54	0.72	13.23	0.3831	0.368
3	CAT	525	SKIDDER	0.21	0.54	0.72	15.12	0.3831	0.368
4	CAT	525	SKIDDER	0.21	0.54	0.72	15.12	0.3831	0.368
5	CAT	528	SKIDDER	0.21	0.54	0.72	17.48	0.3831	0.368
6	CAT	530	SKIDDER	0.21	0.54	0.72	16.54	0.3831	0.368
7	JD	540-G	SKIDDER	0.21	0.54	0.72	10.87	0.3831	0.368
8	JD	548-G	SKIDDER	0.21	0.54	0.72	10.87	0.3831	0.368
9	JD	640-G	SKIDDER	0.21	0.54	0.72	14.27	0.3831	0.368
10	JD	648-G	SKIDDER	0.21	0.54	0.72	14.27	0.3831	0.368
11	JD	740-G	SKIDDER	0.21	0.54	0.72	15.59	0.3831	0.368
12	JD	748-G	SKIDDER	0.21	0.54	0.72	15.59	0.3831	0.368
13	TJ	240	SKIDDER	0.21	0.54	0.72	10.96	0.3831	0.368
14	TJ	360	SKIDDER	0.21	0.54	0.72	13.99	0.3831	0.368
15	TJ	360	SKIDDER	0.21	0.54	0.72	13.99	0.3831	0.368
16	TJ	460	SKIDDER	0.21	0.54	0.72	16.44	0.3831	0.368
17	TJ	460	SKIDDER	0.21	0.54	0.72	16.44	0.3831	0.368
18	TJ	933-D	SKIDDER	0.21	0.54	0.72	21.40	0.3831	0.368
19	TJ	1210-B	FORWAR	0.21	0.54	0.72	17.61	0.3831	0.368
20	TJ	1270-B	SNGHARV	0.21	0.54	0.72	20.88	0.3831	0.368
21	HYDROAX	411-EX	FB	0.21	0.54	0.72	14.33	0.3831	0.368
22	HYDROAX	511-EX	FB	0.21	0.54	0.72	18.43	0.3831	0.368
23	HYDROAX	611-EX	FB	0.21	0.54	0.72	20.99	0.3831	0.368
24	PRENTICE	620	FB	0.21	0.54	0.72	20.32	0.3831	0.368
25	PRENTICE	720	FB	0.21	0.54	0.72	24.57	0.3831	0.368
26	PRENTICE	730	FB	0.21	0.54	0.72	25.52	0.3831	0.368
27	TJ	2618	FB	0.21	0.54	0.72	19.37	0.3831	0.368
28	TJ	2628	FB	0.21	0.54	0.72	21.74	0.3831	0.368
29	TIMBCO	T225-B	FB	0.21	0.54	0.72	23.63	0.3831	0.368
30	TIMBCO	T445-B	FB	0.21	0.54	0.72	23.63	0.3831	0.368
31	PRENTICE	T210	LOADER	0.21	0.54	0.72	14.84	0.3831	0.368
32	PRENTICE	T410	LOADER	0.21	0.54	0.72	17.30	0.3831	0.368
33	PRENTICE	T610	LOADER	0.21	0.54	0.72	21.19	0.3831	0.368
34	CAT	320A	LOADER	0.21	0.54	0.72	13.10	0.3831	0.368
35	CAT	322B	LOADER	0.21	0.54	0.72	15.66	0.3831	0.368
36	CAT	325B	LOADER	0.21	0.54	0.72	17.20	0.3831	0.368
37	CAT	330B	LOADER	0.21	0.54	0.72	22.73	0.3831	0.368
38	CAT	D4HCS	CRAWLER	0.21	0.54	0.72	8.51	0.3831	0.368
39	CAT	D4HCS	CRAWLER	0.21	0.54	0.72	8.51	0.3831	0.368
40	CAT	D4HCS	CRAWLER	0.21	0.54	0.72	7.56	0.3831	0.368
41	CAT	D5HCS	CRAWLER	0.21	0.54	0.72	11.34	0.3831	0.368
42	CAT	D5HCS	CRAWLER	0.21	0.54	0.72	11.34	0.3831	0.368

APPENDIX B.4. Annual Cost Parameters for Specific Harvesting Machines.

No.	Machine Make	Model Number	Machine Type	Fuel C. $/SMH	Oil&Lubr $/SMH	Depretn. $/yr.	A.A.I. $/yr.	Int.Ins&T $/yr.	M&R $/yr.
1	CAT	515	SKIDDER	5.07	1.87	22695	88110	15860	17021
2	CAT	515	SKIDDER	5.07	1.87	22211	103649	18657	16658
3	CAT	525	SKIDDER	5.79	2.13	27540	97920	17626	20655
4	CAT	525	SKIDDER	5.79	2.13	25497	118986	21417	19123
5	CAT	528	SKIDDER	6.70	2.46	30150	107200	19296	22613
6	CAT	530	SKIDDER	6.34	2.33	29850	139300	25074	22388
7	JD	540-G	SKIDDER	4.16	1.53	17850	69300	12474	13388
8	JD	548-G	SKIDDER	4.16	1.53	20100	93800	16884	15075
9	JD	640-G	SKIDDER	5.47	2.01	22500	80000	14400	16875
10	JD	648-G	SKIDDER	5.47	2.01	23400	109200	19656	17550
11	JD	740-G	SKIDDER	5.97	2.20	26280	93440	16819	19710
12	JD	748-G	SKIDDER	5.97	2.20	27000	126000	22680	20250
13	TJ	240	SKIDDER	4.20	1.55	16047	62301	11214	12035
14	TJ	360	SKIDDER	5.36	1.97	21510	76480	13766	16133
15	TJ	360	SKIDDER	5.36	1.97	25200	117600	21168	18900
16	TJ	460	SKIDDER	6.30	2.32	26640	94720	17050	19980
17	TJ	460	SKIDDER	6.30	2.32	29925	139650	25137	22444
18	TJ	933-D	SKIDDER	8.20	3.02	85340	331320	59638	59738
19	TJ	1210-B	FORWAR	6.75	2.48	55932	242136	43584	39152
20	TJ	1270-B	SNGHARV	8.00	2.94	78080	331840	59731	54656
21	HYDROAX	411-EX	FB	5.49	2.02	28600	100100	18018	21450
22	HYDROAX	511-EX	FB	7.06	2.60	30600	107100	19278	22950
23	HYDROAX	611-EX	FB	8.04	2.96	32200	112700	20286	24150
24	PRENTICE	620	FB	7.78	2.86	50490	196020	35284	37868
25	PRENTICE	720	FB	9.41	3.46	55760	216480	38966	41820
26	PRENTICE	730	FB	9.77	3.60	68000	264000	47520	51000
27	TJ	2618	FB	7.42	2.73	62220	241560	43481	46665
28	TJ	2628	FB	8.33	3.06	67830	263340	47401	50873
29	TIMBCO	T225-B	FB	9.05	3.33	44423	172465	31044	33317
30	TIMBCO	T445-B	FB	9.05	3.33	56041	217569	39162	42030
31	PRENTICE	T210	LOADER	5.69	2.09	10640	54720	9850	7448
32	PRENTICE	T410	LOADER	6.63	2.44	17080	87840	15811	11956
33	PRENTICE	T610	LOADER	8.12	2.99	19600	100800	18144	13720
34	CAT	320A	LOADER	5.02	1.85	55674	286322	51538	38972
35	CAT	322B	LOADER	6.00	2.21	50000	257141	46285	35000
36	CAT	325B	LOADER	6.59	2.42	54342	279472	50305	38039
37	CAT	330B	LOADER	8.71	3.20	62657	322236	58002	43860
38	CAT	D4HCS	CRAWLER	3.26	1.20	29440	125120	22522	22080
39	CAT	D4HCS	CRAWLER	3.26	1.20	32800	139400	25092	24600
40	CAT	D4HCS	CRAWLER	2.90	1.07	31840	135320	24358	23880
41	CAT	D5HCS	CRAWLER	4.34	1.60	39840	169320	30478	29880
42	CAT	D5HCS	CRAWLER	4.34	1.60	44000	187000	33660	33000

APPENDIX B.5. Labor Cost Parameters for Specific Harvesting Machines.

No.	Machine Make	Model Number	Machine Type	Wage $/SMH	Labor Burden	Labor C. $/SMH	SMH	PMH	Labor C. $/PMH
1	CAT	515	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
2	CAT	515	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
3	CAT	525	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
4	CAT	525	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
5	CAT	528	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
6	CAT	530	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
7	JD	540-G	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
8	JD	548-G	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
9	JD	640-G	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
10	JD	648-G	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
11	JD	740-G	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
12	JD	748-G	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
13	TJ	240	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
14	TJ	360	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
15	TJ	360	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
16	TJ	460	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
17	TJ	460	SKIDDER	16.15	0.415	22.85	2000	1200	38.09
18	TJ	933-D	SKIDDER	16.15	0.415	22.85	2000	1300	35.16
19	TJ	1210-B	FORWAR	17.75	0.415	25.12	2000	1300	38.64
20	TJ	1270-B	SNGHARV	18.62	0.415	26.35	2000	1300	40.53
21	HYDROAX	411-EX	FB	17.79	0.415	25.17	2000	1300	38.73
22	HYDROAX	511-EX	FB	17.79	0.415	25.17	2000	1300	38.73
23	HYDROAX	611-EX	FB	17.79	0.415	25.17	2000	1300	38.73
24	PRENTICE	620	FB	17.79	0.415	25.17	2000	1200	41.95
25	PRENTICE	720	FB	17.79	0.415	25.17	2000	1200	41.95
26	PRENTICE	730	FB	17.79	0.415	25.17	2000	1200	41.95
27	TJ	2618	FB	17.79	0.415	25.17	2000	1200	41.95
28	TJ	2628	FB	17.79	0.415	25.17	2000	1200	41.95
29	TIMBCO	T225-B	FB	17.79	0.415	25.17	2000	1200	41.95
30	TIMBCO	T445-B	FB	17.79	0.415	25.17	2000	1200	41.95
31	PRENTICE	T210	LOADER	17.52	0.415	24.79	2000	1300	38.14
32	PRENTICE	T410	LOADER	17.52	0.415	24.79	2000	1300	38.14
33	PRENTICE	T610	LOADER	17.52	0.415	24.79	2000	1300	38.14
34	CAT	320A	LOADER	17.52	0.415	24.79	2000	1300	38.14
35	CAT	322B	LOADER	17.52	0.415	24.79	2000	1300	38.14
36	CAT	325B	LOADER	17.52	0.415	24.79	2000	1300	38.14
37	CAT	330B	LOADER	17.52	0.415	24.79	2000	1300	38.14
38	CAT	D4HCS	CRAWLER	16.43	0.415	23.25	2000	1200	38.75
39	CAT	D4HCS	CRAWLER	16.43	0.415	23.25	2000	1200	38.75
40	CAT	D4HCS	CRAWLER	16.43	0.415	23.25	2000	1200	38.75
41	CAT	D5HCS	CRAWLER	16.43	0.415	23.25	2000	1200	38.75
42	CAT	D5HCS	CRAWLER	16.43	0.415	23.25	2000	1200	38.75

APPENDIX B.6. Total Machine Cost Summary for Specific Harvesting Machines.

No.	Machine Make	Model Number	Machine Type	Own. C. $/SMH	Own. C. $/PMH	Oper. C. $/SMH	Oper. C. $/PMH	Machine Rate/SMH	Machine Rate/PMH
1	CAT	515	SKIDDER	19.28	32.13	15.44	25.74	57.57	95.96
2	CAT	515	SKIDDER	20.43	34.06	15.26	25.44	58.55	97.58
3	CAT	525	SKIDDER	22.58	37.64	18.25	30.42	63.69	106.14
4	CAT	525	SKIDDER	23.46	39.10	17.49	29.14	63.79	106.32
5	CAT	528	SKIDDER	24.72	41.21	20.47	34.11	68.04	113.41
6	CAT	530	SKIDDER	27.46	45.77	19.86	33.10	70.17	116.96
7	JD	540-G	SKIDDER	15.16	25.27	12.39	20.65	50.40	84.01
8	JD	548-G	SKIDDER	18.49	30.82	13.23	22.05	54.58	90.96
9	JD	640-G	SKIDDER	18.45	30.75	15.92	26.53	57.22	95.36
10	JD	648-G	SKIDDER	21.53	35.88	16.25	27.09	60.63	101.06
11	JD	740-G	SKIDDER	21.55	35.92	18.03	30.04	62.43	104.05
12	JD	748-G	SKIDDER	24.84	41.40	18.30	30.49	65.99	109.98
13	TJ	240	SKIDDER	13.63	22.72	11.76	19.60	48.25	80.41
14	TJ	360	SKIDDER	17.64	29.40	15.40	25.66	55.89	93.14
15	TJ	360	SKIDDER	23.18	38.64	16.78	27.97	62.82	104.69
16	TJ	460	SKIDDER	21.84	36.41	18.61	31.01	63.30	105.51
17	TJ	460	SKIDDER	27.53	45.89	19.84	33.07	70.22	117.04
18	TJ	933-D	SKIDDER	72.49	111.52	41.08	63.20	136.42	209.88
19	TJ	1210-B	FORWAR	49.76	76.55	28.80	44.31	103.68	159.51
20	TJ	1270-B	SNGHARV	68.91	106.01	38.27	58.88	133.53	205.42
21	HYDROAX	411-EX	FB	23.31	35.86	18.24	28.06	66.72	102.64
22	HYDROAX	511-EX	FB	24.94	38.37	21.13	32.51	71.24	109.61
23	HYDROAX	611-EX	FB	26.24	40.37	23.07	35.50	74.49	114.60
24	PRENTICE	620	FB	42.89	71.48	29.58	49.30	97.64	162.74
25	PRENTICE	720	FB	47.36	78.94	33.79	56.31	106.32	177.20
26	PRENTICE	730	FB	57.76	96.27	38.87	64.79	121.80	203.01
27	TJ	2618	FB	52.85	88.08	33.48	55.81	111.51	185.85
28	TJ	2628	FB	57.62	96.03	36.83	61.38	119.62	199.36
29	TIMBCO	T225-B	FB	37.73	62.89	29.04	48.40	91.95	153.24
30	TIMBCO	T445-B	FB	47.60	79.34	33.40	55.66	106.17	176.95
31	PRENTICE	T210	LOADER	10.24	15.76	11.50	17.70	46.54	71.60
32	PRENTICE	T410	LOADER	16.45	25.30	15.05	23.15	56.28	86.59
33	PRENTICE	T610	LOADER	18.87	29.03	17.97	27.64	61.63	94.81
34	CAT	320A	LOADER	53.61	82.47	26.35	40.54	104.75	161.15
35	CAT	322B	LOADER	48.14	74.07	25.71	39.55	98.64	151.76
36	CAT	325B	LOADER	52.32	80.50	28.03	43.13	105.15	161.76
37	CAT	330B	LOADER	60.33	92.81	33.84	52.06	118.96	183.02
38	CAT	D4HCS	CRAWLER	25.98	43.30	15.50	25.83	64.73	107.88
39	CAT	D4HCS	CRAWLER	28.95	48.24	16.76	27.93	68.95	114.92
40	CAT	D4HCS	CRAWLER	28.10	46.83	15.90	26.50	67.25	112.08
41	CAT	D5HCS	CRAWLER	35.16	58.60	20.88	34.80	79.29	132.15
42	CAT	D5HCS	CRAWLER	38.83	64.72	22.44	37.40	84.52	140.87

APPENDIX B.7. Labor Cost Parameter for Various Logging Positions.

OPERATION	TITLE	LABOR NOTES	WAGE[2]	INF. RATE	WAGE	LABOR BURDEN RATES[3]		LABOR COST
			$/HR	%/YR	(1997) $/HR	WORKERS C.	OTHER ITEMS	(1997) $/HR
FALL&BUCK	FALLER[1]		25.56	3.00	32.38	0.3600	0.14	48.57
"	BUCKER[1]		19.92	3.00	25.23	0.3600	0.14	37.85
YARD&LOAD	CHASER	LANDING	12.12	3.00	15.35	0.2750	0.14	21.72
"	CHOKER SETTER		11.48	3.00	14.54	0.2750	0.14	20.58
"	RIGGING SLINGER	CABLE	12.94	3.00	16.39	0.2750	0.14	23.19
"	HOOK TENDER	CABLE	14.01	3.00	17.75	0.2750	0.14	25.11
"	YARDER ENGINEER	CABLE	13.48	3.00	17.08	0.2750	0.14	24.16
"	TRACTOR OPERATOR	GRAPPLE	12.97	3.00	16.43	0.2750	0.14	23.25
"	SKIDDER OPERATOR	GRAPPLE	12.75	3.00	16.15	0.2750	0.14	22.85
"	LOADER OPERATOR		13.83	3.00	17.52	0.2750	0.14	24.79
"	FELLER-BUNCHER	SHEAR OR SAW	14.04	3.00	17.79	0.2750	0.14	25.17
"	PROCESSOR OPR.	DELIMB/BUCK	14.70	3.00	18.62	0.2750	0.14	26.35
"	FORWARDER OPR.		14.01	3.00	17.75	0.2750	0.14	25.11
TRANSPORT.	GRADER OPERATOR		13.50	3.00	17.10	0.1215	0.14	21.57
"	LOG TRUCK DRIVER	LONG LOGS	11.00	3.00	13.93	0.1560	0.14	18.06
"	LOG TRUCK DRIVER	SHORT LOGS	10.80	3.00	13.68	0.1560	0.14	17.73
"	LOG TRUCK DRIVER	SELF-LOADER	12.46	3.00	15.78	0.1560	0.14	20.46
"	LOW BOY DRIVER		12.07	3.00	15.29	0.1560	0.14	19.82
"	MECHANIC		13.08	3.00	16.57	0.0640	0.14	19.95
"	MECHANICS HELPER		10.06	3.00	12.74	0.0640	0.14	15.34

[1]Rate includes chainsaws, equipment and transportation.

[2]Associated Oregon Loggers 1996 Annual Wage Survey

[3]Workmen's comp.(Table 8) + other items include Social Security (7%), S.U.Tax (4%), F.U.Tax (1%), and Health Ins.(2%).

APPENDIX C.1. Cycle Time in Skidding with Oxen.

LOG CLASSES	GROUND SLOPE (%)	Outhaul Speed (m/min)	Inhaul Speed (m/min)	Hook Time (min.)	Unhook Time (min.)	CYCLE TIME (MIN) SKIDDING DISTANCES 50 m.	100 m.	150 m.	200 m.
Sawlogs	-25.1 to -30	30.43	29.69	3	2	10.33	13.65	17.98	21.31
Sawlogs	-20.1 to -25	30.05	28.91	3	2	10.39	13.79	18.18	21.57
Sawlogs	-15 to - 20	28.87	25.39	3	2	10.70	14.40	19.10	22.80
Sawlogs	+10 to +30	38.75	27.53	3	2	10.11	13.21	17.32	20.43
Pulpwood	> than -30	28.45	24.38	2	2	9.81	13.62	18.42	22.23
Pulpwood	-10.1 to -20	39.44	22.3	2	2	9.51	13.02	17.53	21.04
Pulpwood	0 to -10	43.41	25.4	2	2	9.12	12.24	16.36	19.48
Sawlogs1	< than 3	33.95	21.92	3	2	10.75	14.51	19.26	23.02
Pulpwood1	< than 3	40.87	30.89	2	2	8.84	11.68	15.53	18.37
Pulpwood2	< than 3	46.06	32.75	2	2	8.61	11.22	14.84	17.45

1 Clear-Felling,
2 Thinning

APPENDIX C.2. Production Rate in Skidding with Oxen.

LOG CLASSES	GROUND SLOPE (%)	Volume per cycle M^3	CYCLE TIME (MIN) SKIDDING DISTANCES 50 m.	100 m.	150 m.	200 m.	PRODUCTION (M3 /HR) SKIDDING DISTANCES 50 m.	100 m.	150 m.	200 m.
Sawlogs	-25.1 to -30	0.794	10.33	13.65	17.98	21.31	4.61	3.49	2.65	2.24
Sawlogs	-20.1 to -25	0.679	10.39	13.79	18.18	21.57	3.92	2.95	2.24	1.89
Sawlogs	-15 to - 20	0.718	10.70	14.40	19.10	22.80	4.03	2.99	2.26	1.89
Sawlogs	+10 to +30	0.386	10.11	13.21	17.32	20.43	2.29	1.75	1.34	1.13
Pulpwood	> than -30	0.509	9.81	13.62	18.42	22.23	3.11	2.24	1.66	1.37
Pulpwood	-10.1 to -20	0.509	9.51	13.02	17.53	21.04	3.21	2.35	1.74	1.45
Pulpwood	0 to -10	0.509	9.12	12.24	16.36	19.48	3.35	2.50	1.87	1.57
Sawlogs[1]	< than 3	0.417	10.75	14.51	19.26	23.02	2.33	1.72	1.30	1.09
Pulpwood[1]	< than 3	0.367	8.84	11.68	15.53	18.37	2.49	1.89	1.42	1.20
Pulpwood[2]	< than 3	0.289	8.61	11.22	14.84	17.45	2.01	1.55	1.17	0.99

[1] Clear-Felling
[2] Thinning

APPENDIX D.1. Investment Parameters Representing Conditions in Turkey.

No.	Machine Make	Model Number	Machine Type	Price ($) 1997	Life (yr)	Salvage Rate	Util. Rate (%)	R&M Rate	Interest, Ins$Tax
1	CAT	515	SKIDDER	133500	5	0.15	0.60	0.75	0.34
2	CAT	515	SKIDDER	148070	5	0.25	0.60	0.75	0.34
3	CAT	525	SKIDDER	153000	5	0.10	0.60	0.75	0.34
4	CAT	525	SKIDDER	169980	5	0.25	0.60	0.75	0.34
5	CAT	528	SKIDDER	167500	5	0.10	0.60	0.75	0.34
6	CAT	530	SKIDDER	199000	5	0.25	0.60	0.75	0.34
7	JD	540-G	SKIDDER	105000	5	0.15	0.60	0.75	0.34
8	JD	548-G	SKIDDER	134000	5	0.25	0.60	0.75	0.34
9	JD	640-G	SKIDDER	125000	5	0.10	0.60	0.75	0.34
10	JD	648-G	SKIDDER	156000	5	0.25	0.60	0.75	0.34
11	JD	740-G	SKIDDER	146000	5	0.10	0.60	0.75	0.34
12	JD	748-G	SKIDDER	180000	5	0.25	0.60	0.75	0.34
13	TJ	240	SKIDDER	94395	5	0.15	0.60	0.75	0.34
14	TJ	360	SKIDDER	119500	5	0.10	0.60	0.75	0.34
15	TJ	360	SKIDDER	168000	5	0.25	0.60	0.75	0.34
16	TJ	460	SKIDDER	148000	5	0.10	0.60	0.75	0.34
17	TJ	460	SKIDDER	199500	5	0.25	0.60	0.75	0.34
18	TJ	933-D	SKIDDER	502000	5	0.15	0.65	0.70	0.34
19	TJ	1210-B	FORWAR	354000	5	0.21	0.65	0.70	0.34
20	TJ	1270-B	SNGHARV	488000	5	0.20	0.65	0.70	0.34
21	HYDROAX	411-EX	FB	143000	4	0.20	0.65	0.75	0.34
22	HYDROAX	511-EX	FB	153000	4	0.20	0.65	0.75	0.34
23	HYDROAX	611-EX	FB	161000	4	0.20	0.65	0.75	0.34
24	PRENTICE	620	FB	297000	5	0.15	0.60	0.75	0.34
25	PRENTICE	720	FB	328000	5	0.15	0.60	0.75	0.34
26	PRENTICE	730	FB	400000	5	0.15	0.60	0.75	0.34
27	TJ	2618	FB	366000	5	0.15	0.60	0.75	0.34
28	TJ	2628	FB	399000	5	0.15	0.60	0.75	0.34
29	TIMBCO	T425-B	FB	261310	5	0.15	0.60	0.75	0.34
30	TIMBCO	T445-B	FB	329650	5	0.15	0.60	0.75	0.34
31	PRENTICE	T210	LOADER	76000	5	0.30	0.65	0.70	0.34
32	PRENTICE	T410	LOADER	122000	5	0.30	0.65	0.70	0.34
33	PRENTICE	T610	LOADER	140000	5	0.30	0.65	0.70	0.34
34	CAT	320A	LOADER	397670	5	0.30	0.65	0.70	0.34
35	CAT	322B	LOADER	357140	5	0.30	0.65	0.70	0.34
36	CAT	325B	LOADER	388155	5	0.30	0.65	0.70	0.34
37	CAT	330B	LOADER	447550	5	0.30	0.65	0.70	0.34
38	CAT	D4HCS	CRAWLER	184000	5	0.20	0.60	0.75	0.34
39	CAT	D4HCS	CRAWLER	205000	5	0.20	0.60	0.75	0.34
40	CAT	D4HCS	CRAWLER	199000	5	0.20	0.60	0.75	0.34
41	CAT	D5HCS	CRAWLER	249000	5	0.20	0.60	0.75	0.34
42	CAT	D5HCS	CRAWLER	275000	5	0.20	0.60	0.75	0.34

APPENDIX D.2.. Operational Parameters Representing Conditions in Turkey.

No.	Machine Make	Model Number	Machine Type	K kg/hp hr.	LF Load factor	KPL	Fuel Co. liter/SMH	Fuel c. $/liter	Lube&oil Rate
1	CAT	515	SKIDDER	0.21	0.54	0.72	13.23	0.8673	0.368
2	CAT	515	SKIDDER	0.21	0.54	0.72	13.23	0.8673	0.368
3	CAT	525	SKIDDER	0.21	0.54	0.72	15.12	0.8673	0.368
4	CAT	525	SKIDDER	0.21	0.54	0.72	15.12	0.8673	0.368
5	CAT	528	SKIDDER	0.21	0.54	0.72	17.48	0.8673	0.368
6	CAT	530	SKIDDER	0.21	0.54	0.72	16.54	0.8673	0.368
7	JD	540-G	SKIDDER	0.21	0.54	0.72	10.87	0.8673	0.368
8	JD	548-G	SKIDDER	0.21	0.54	0.72	10.87	0.8673	0.368
9	JD	640-G	SKIDDER	0.21	0.54	0.72	14.27	0.8673	0.368
10	JD	648-G	SKIDDER	0.21	0.54	0.72	14.27	0.8673	0.368
11	JD	740-G	SKIDDER	0.21	0.54	0.72	15.59	0.8673	0.368
12	JD	748-G	SKIDDER	0.21	0.54	0.72	15.59	0.8673	0.368
13	TJ	240	SKIDDER	0.21	0.54	0.72	10.96	0.8673	0.368
14	TJ	360	SKIDDER	0.21	0.54	0.72	13.99	0.8673	0.368
15	TJ	360	SKIDDER	0.21	0.54	0.72	13.99	0.8673	0.368
16	TJ	460	SKIDDER	0.21	0.54	0.72	16.44	0.8673	0.368
17	TJ	460	SKIDDER	0.21	0.54	0.72	16.44	0.8673	0.368
18	TJ	933-D	SKIDDER	0.21	0.54	0.72	21.40	0.8673	0.368
19	TJ	1210-B	FORWAR	0.21	0.54	0.72	17.61	0.8673	0.368
20	TJ	1270-B	SNGHARV	0.21	0.54	0.72	20.88	0.8673	0.368
21	HYDROAX	411-EX	FB	0.21	0.54	0.72	14.33	0.8673	0.368
22	HYDROAX	511-EX	FB	0.21	0.54	0.72	18.43	0.8673	0.368
23	HYDROAX	611-EX	FB	0.21	0.54	0.72	20.99	0.8673	0.368
24	PRENTICE	620	FB	0.21	0.54	0.72	20.32	0.8673	0.368
25	PRENTICE	720	FB	0.21	0.54	0.72	24.57	0.8673	0.368
26	PRENTICE	730	FB	0.21	0.54	0.72	25.52	0.8673	0.368
27	TJ	2618	FB	0.21	0.54	0.72	19.37	0.8673	0.368
28	TJ	2628	FB	0.21	0.54	0.72	21.74	0.8673	0.368
29	TIMBCO	T225-B	FB	0.21	0.54	0.72	23.63	0.8673	0.368
30	TIMBCO	T445-B	FB	0.21	0.54	0.72	23.63	0.8673	0.368
31	PRENTICE	T210	LOADER	0.21	0.54	0.72	14.84	0.8673	0.368
32	PRENTICE	T410	LOADER	0.21	0.54	0.72	17.30	0.8673	0.368
33	PRENTICE	T610	LOADER	0.21	0.54	0.72	21.19	0.8673	0.368
34	CAT	320A	LOADER	0.21	0.54	0.72	13.10	0.8673	0.368
35	CAT	322B	LOADER	0.21	0.54	0.72	15.66	0.8673	0.368
36	CAT	325B	LOADER	0.21	0.54	0.72	17.20	0.8673	0.368
37	CAT	330B	LOADER	0.21	0.54	0.72	22.73	0.8673	0.368
38	CAT	D4HCS	CRAWLER	0.21	0.54	0.72	8.51	0.8673	0.368
39	CAT	D4HCS	CRAWLER	0.21	0.54	0.72	8.51	0.8673	0.368
40	CAT	D4HCS	CRAWLER	0.21	0.54	0.72	7.56	0.8673	0.368
41	CAT	D5HCS	CRAWLER	0.21	0.54	0.72	11.34	0.8673	0.368
42	CAT	D5HCS	CRAWLER	0.21	0.54	0.72	11.34	0.8673	0.368

APPENDIX D.3.. Annual Cost Parameters Representing Conditions in Turkey.

No.	Machine Make	Model Number	Machine Type	Fuel C. $/SMH	Oil&Lubr $/SMH	Depretn. $/yr.	A.A.I. $/yr.	Int.Ins&T $/yr.	M&R $/yr.
1	CAT	515	SKIDDER	11.47	4.22	22695	88110	29957	17021
2	CAT	515	SKIDDER	11.47	4.22	22211	103649	35241	16658
3	CAT	525	SKIDDER	13.11	4.83	27540	97920	33293	20655
4	CAT	525	SKIDDER	13.11	4.83	25497	118986	40455	19123
5	CAT	528	SKIDDER	15.16	5.58	30150	107200	36448	22613
6	CAT	530	SKIDDER	14.34	5.28	29850	139300	47362	22388
7	JD	540-G	SKIDDER	9.43	3.47	17850	69300	23562	13388
8	JD	548-G	SKIDDER	9.43	3.47	20100	93800	31892	15075
9	JD	640-G	SKIDDER	12.38	4.55	22500	80000	27200	16875
10	JD	648-G	SKIDDER	12.38	4.55	23400	109200	37128	17550
11	JD	740-G	SKIDDER	13.52	4.98	26280	93440	31770	19710
12	JD	748-G	SKIDDER	13.52	4.98	27000	126000	42840	20250
13	TJ	240	SKIDDER	9.51	3.50	16047	62301	21182	12035
14	TJ	360	SKIDDER	12.13	4.46	21510	76480	26003	16133
15	TJ	360	SKIDDER	12.13	4.46	25200	117600	39984	18900
16	TJ	460	SKIDDER	14.26	5.25	26640	94720	32205	19980
17	TJ	460	SKIDDER	14.26	5.25	29925	139650	47481	22444
18	TJ	933-D	SKIDDER	18.56	6.83	85340	331320	112649	59738
19	TJ	1210-B	FORWAR	15.27	5.62	55932	242136	82326	39152
20	TJ	1270-B	SNGHARV	18.11	6.67	78080	331840	112826	54656
21	HYDROAX	411-EX	FB	12.43	4.57	28600	100100	34034	21450
22	HYDROAX	511-EX	FB	15.98	5.88	30600	107100	36414	22950
23	HYDROAX	611-EX	FB	18.20	6.70	32200	112700	38318	24150
24	PRENTICE	620	FB	17.62	6.48	50490	196020	66647	37868
25	PRENTICE	720	FB	21.31	7.84	55760	216480	73603	41820
26	PRENTICE	730	FB	22.13	8.14	68000	264000	89760	51000
27	TJ	2618	FB	16.80	6.18	62220	241560	82130	46665
28	TJ	2628	FB	18.85	6.94	67830	263340	89536	50873
29	TIMBCO	T225-B	FB	20.49	7.54	44423	172465	58638	33317
30	TIMBCO	T445-B	FB	20.49	7.54	56041	217569	73973	42030
31	PRENTICE	T210	LOADER	12.87	4.74	10640	54720	18605	7448
32	PRENTICE	T410	LOADER	15.01	5.52	17080	87840	29866	11956
33	PRENTICE	T610	LOADER	18.38	6.76	19600	100800	34272	13720
34	CAT	320A	LOADER	11.37	4.18	55674	286322	97350	38972
35	CAT	322B	LOADER	13.58	5.00	50000	257141	87428	35000
36	CAT	325B	LOADER	14.92	5.49	54342	279472	95020	38039
37	CAT	330B	LOADER	19.71	7.25	62657	322236	109560	43860
38	CAT	D4HCS	CRAWLER	7.38	2.71	29440	125120	42541	22080
39	CAT	D4HCS	CRAWLER	7.38	2.71	32800	139400	47396	24600
40	CAT	D4HCS	CRAWLER	6.56	2.41	31840	135320	46009	23880
41	CAT	D5HCS	CRAWLER	9.84	3.62	39840	169320	57569	29880
42	CAT	D5HCS	CRAWLER	9.84	3.62	44000	187000	63580	33000

APPENDIX D.4.. Labor Cost Parameters Representing Conditions in Turkey.

No.	Machine Make	Model Number	Machine Type	Wage $/SMH	Labor Burden	Labor C. $/SMH	SMH	PMH	Labor C. $/PMH
1	CAT	515	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
2	CAT	515	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
3	CAT	525	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
4	CAT	525	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
5	CAT	528	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
6	CAT	530	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
7	JD	540-G	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
8	JD	548-G	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
9	JD	640-G	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
10	JD	648-G	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
11	JD	740-G	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
12	JD	748-G	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
13	TJ	240	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
14	TJ	360	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
15	TJ	360	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
16	TJ	460	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
17	TJ	460	SKIDDER	4.25	0.28	5.44	2000	1200	9.07
18	TJ	933-D	SKIDDER	4.25	0.28	5.44	2000	1300	8.37
19	TJ	1210-B	FORWAR	4.25	0.28	5.44	2000	1300	8.37
20	TJ	1270-B	SNGHARV	4.25	0.28	5.44	2000	1300	8.37
21	HYDROAX	411-EX	FB	4.25	0.28	5.44	2000	1300	8.37
22	HYDROAX	511-EX	FB	4.25	0.28	5.44	2000	1300	8.37
23	HYDROAX	611-EX	FB	4.25	0.28	5.44	2000	1300	8.37
24	PRENTICE	620	FB	4.25	0.28	5.44	2000	1200	9.07
25	PRENTICE	720	FB	4.25	0.28	5.44	2000	1200	9.07
26	PRENTICE	730	FB	4.25	0.28	5.44	2000	1200	9.07
27	TJ	2618	FB	4.25	0.28	5.44	2000	1200	9.07
28	TJ	2628	FB	4.25	0.28	5.44	2000	1200	9.07
29	TIMBCO	T225-B	FB	4.25	0.28	5.44	2000	1200	9.07
30	TIMBCO	T445-B	FB	4.25	0.28	5.44	2000	1200	9.07
31	PRENTICE	T210	LOADER	4.25	0.28	5.44	2000	1300	8.37
32	PRENTICE	T410	LOADER	4.25	0.28	5.44	2000	1300	8.37
33	PRENTICE	T610	LOADER	4.25	0.28	5.44	2000	1300	8.37
34	CAT	320A	LOADER	4.25	0.28	5.44	2000	1300	8.37
35	CAT	322B	LOADER	4.25	0.28	5.44	2000	1300	8.37
36	CAT	325B	LOADER	4.25	0.28	5.44	2000	1300	8.37
37	CAT	330B	LOADER	4.25	0.28	5.44	2000	1300	8.37
38	CAT	D4HCS	CRAWLER	4.25	0.28	5.44	2000	1200	9.07
39	CAT	D4HCS	CRAWLER	4.25	0.28	5.44	2000	1200	9.07
40	CAT	D4HCS	CRAWLER	4.25	0.28	5.44	2000	1200	9.07
41	CAT	D5HCS	CRAWLER	4.25	0.28	5.44	2000	1200	9.07
42	CAT	D5HCS	CRAWLER	4.25	0.28	5.44	2000	1200	9.07

APPENDIX D.5.. Total Machine Cost Summary Representing Conditions in Turkey.

No.	Machine Make	Model Number	Machine Type	Own. C. $/SMH	Own. C. $/PMH	Oper. C. $/SMH	Oper. C. $/PMH	Machine Rate/SMH	Machine Rate/PMH
1	CAT	515	SKIDDER	26.33	43.88	24.21	40.35	55.97	93.29
2	CAT	515	SKIDDER	28.73	47.88	24.03	40.04	58.19	96.99
3	CAT	525	SKIDDER	30.42	50.69	28.27	47.11	64.12	106.87
4	CAT	525	SKIDDER	32.98	54.96	27.50	45.83	65.92	109.86
5	CAT	528	SKIDDER	33.30	55.50	32.05	53.41	70.79	117.98
6	CAT	530	SKIDDER	38.61	64.34	30.81	51.36	74.86	124.77
7	JD	540-G	SKIDDER	20.71	34.51	19.59	32.65	45.73	76.22
8	JD	548-G	SKIDDER	26.00	43.33	20.43	34.05	51.87	86.45
9	JD	640-G	SKIDDER	24.85	41.42	25.37	42.28	55.66	92.76
10	JD	648-G	SKIDDER	30.26	50.44	25.71	42.84	61.41	102.35
11	JD	740-G	SKIDDER	29.02	48.37	28.35	47.26	62.82	104.70
12	JD	748-G	SKIDDER	34.92	58.20	28.62	47.71	68.98	114.97
13	TJ	240	SKIDDER	18.61	31.02	19.02	31.71	43.08	71.80
14	TJ	360	SKIDDER	23.76	39.59	24.66	41.10	53.86	89.76
15	TJ	360	SKIDDER	32.59	54.32	26.04	43.41	64.08	106.79
16	TJ	460	SKIDDER	29.42	49.04	29.50	49.17	64.36	107.27
17	TJ	460	SKIDDER	38.70	64.51	30.73	51.22	74.87	124.79
18	TJ	933-D	SKIDDER	98.99	152.30	55.26	85.01	159.69	245.68
19	TJ	1210-B	FORWAR	69.13	106.35	40.47	62.26	115.04	176.98
20	TJ	1270-B	SNGHARV	95.45	146.85	52.11	80.16	153.00	235.38
21	HYDROAX	411-EX	FB	31.32	48.18	27.73	42.66	64.49	99.21
22	HYDROAX	511-EX	FB	33.51	51.55	33.34	51.29	72.29	111.21
23	HYDROAX	611-EX	FB	35.26	54.24	36.98	56.88	77.67	119.50
24	PRENTICE	620	FB	58.57	97.61	43.04	71.73	107.05	178.41
25	PRENTICE	720	FB	64.68	107.80	50.06	83.44	120.18	200.31
26	PRENTICE	730	FB	78.88	131.47	55.77	92.95	140.09	233.49
27	TJ	2618	FB	72.18	120.29	46.32	77.20	123.93	206.55
28	TJ	2628	FB	78.68	131.14	51.22	85.37	135.35	225.58
29	TIMBCO	T225-B	FB	51.53	85.88	44.69	74.48	101.66	169.43
30	TIMBCO	T445-B	FB	65.01	108.34	49.05	81.74	119.49	199.15
31	PRENTICE	T210	LOADER	14.62	22.50	21.34	32.83	41.40	63.69
32	PRENTICE	T410	LOADER	23.47	36.11	26.51	40.78	55.42	85.26
33	PRENTICE	T610	LOADER	26.94	41.44	32.00	49.24	64.38	99.04
34	CAT	320A	LOADER	76.51	117.71	35.03	53.90	116.98	179.98
35	CAT	322B	LOADER	68.71	105.71	36.08	55.51	110.24	169.60
36	CAT	325B	LOADER	74.68	114.89	39.43	60.65	119.55	183.92
37	CAT	330B	LOADER	86.11	132.47	48.90	75.22	140.44	216.07
38	CAT	D4HCS	CRAWLER	35.99	59.98	21.13	35.22	62.56	104.27
39	CAT	D4HCS	CRAWLER	40.10	66.83	22.39	37.32	67.93	113.21
40	CAT	D4HCS	CRAWLER	38.92	64.87	20.91	34.85	65.27	108.79
41	CAT	D5HCS	CRAWLER	48.70	81.17	28.39	47.32	82.54	137.56
42	CAT	D5HCS	CRAWLER	53.79	89.65	29.95	49.92	89.18	148.64

APPENDIX E.1. Cycle Time Parameters for Specific Rubber-tired Cable Skidders.

No	Make	Model	Machine	Mobility	Attachment	Machine	Slope	ASD	VOLUME per LOG (M^3)			Number of log per cycle			CYCLE TIME (min/cycle)		
		Number	Type		Type	HP	(%)	(M)	Medtn	Black S	Aegean	Medtn.	Black S	Aegean	Medtn	Black S	Aegean
1	CAT	515	SKIDDER	RTIRE	CABLE	140	35	300	0.68	0.41	0.25	4	5	7	13.68	14.50	16.14
2	CAT	525	SKIDDER	RTIRE	CABLE	160	35	300	0.68	0.41	0.25	4	5	7	10.63	11.76	14.01
3	CAT	528	SKIDDER	RTIRE	CABLE	185	35	300	0.68	0.41	0.25	4	5	7	10.63	11.76	14.01
4	JD	640-G	SKIDDER	RTIRE	CABLE	151	35	300	0.68	0.41	0.25	4	5	7	10.63	11.76	14.01
5	JD	740-G	SKIDDER	RTIRE	CABLE	165	35	300	0.68	0.41	0.25	4	5	7	10.63	11.76	14.01
6	TJ	360	SKIDDER	RTIRE	CABLE	148	35	300	0.68	0.41	0.25	4	5	7	13.68	14.50	16.14
7	TJ	460	SKIDDER	RTIRE	CABLE	174	35	300	0.68	0.41	0.25	4	5	7	10.63	11.76	14.01

APPENDIX E.2. Cycle Time Parameters for Specific Crawler Tractors with Chokers.

No	Make	Model	Machine	Mobility	Attachment	Machine	ASD	AVERAGE SLOPE (%)			Number of logs per cycle			CYCLE TIME (min/cycle)		
		Number	Type		Type	HP	(M)	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	CAT	D4HCS	CRAWLER	TRACK	CABLE	90	300	35	37.5	32.5	4	5	7	17.42	17.40	18.79
2	CAT	D5HCS	CRAWLER	TRACK	CABLE	120	300	35	37.5	32.5	4	5	7	17.42	17.40	18.79

APPENDIX E.3. Cycle Time Parameters for Specific Rubber-tired Grapple Skidders[1].

No	Make	Model	Machine	Mobility	Attachment	Machine	ASD	Avr.Load	Number of Trees / Load			Whole-Tree (Time/cycle)			Tree-Length (Time/cycle)		
		Number	Type		Type	HP	(FT)	(lb)	Medtn	Black S	Aegean	Medtn	Black S	Aegean	Medtn	Black S	Aegean
1	CAT	515	SKIDDER	RTIRE	GRPL	140	984	3212	4	5	7	8.60	9.14	9.63	8.64	9.76	10.93
2	CAT	525	SKIDDER	RTIRE	GRPL	160	984	3670	4	5	7	8.26	8.75	9.20	8.16	9.16	10.22
3	CAT	530	SKIDDER	RTIRE	GRPL	175	984	4015	4	5	7	8.00	8.46	8.88	7.79	8.71	9.69
4	JD	648-G	SKIDDER	RTIRE	GRPL	151	984	3464	4	5	7	8.42	8.92	9.39	8.37	9.43	10.54
5	JD	748-G	SKIDDER	RTIRE	GRPL	165	984	3785	4	5	7	8.18	8.65	9.09	8.03	9.01	10.05
6	TJ	360	SKIDDER	RTIRE	GRPL	148	984	3395	4	5	7	8.47	8.98	9.46	8.45	9.52	10.65
7	TJ	460	SKIDDER	RTIRE	GRPL	174	984	3992	4	5	7	8.02	8.48	8.90	7.82	8.74	9.73

[1]Average slope = 35 %

APPENDIX E.4. Cycle Time Parameters for a Specific Clambunk Skidder [1].

No	Make	Model	Machine	Mobility	Attachment	Machine	ASD	Avr.Load	Number of Trip per Hour			CYCLE TIME (min)		
		Number	Type		Type	HP	(M)	(m^3)	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	TJ	933-D	SKIDDER	RTIRE	CLMBNK	209	300	18	1.087	1	1.2	55.20	60	50

[1]Slope > 30 %

APPENDIX E.5. Cycle Time Parameters for a Specific Feller-buncher [1].

No	Make	Model	Machine	Mobility	Attachment	Machine	AVERAGE DBH (cm)			Number of Trees/hour			CYCLE TIME (min/tree)		
		Number	Type		Type	HP	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	PRENTICE	720	FB	TRACK	SHEAR	260	36	28	22	70	80	90	0.86	0.75	0.67
2	PRENTICE	730	FB	TRACK	SHEAR	270	36	28	22	75	85	95	0.80	0.71	0.63
3	TJ	2618	FB	TRACK	SHEAR	205	36	28	22	50	60	70	1.20	1.00	0.86
4	TJ	2628	FB	TRACK	SHEAR	230	36	28	22	60	70	80	1.00	0.86	0.75
5	TIMBCO	T225-B	FB	TRACK	SAW	250	36	28	22	60	70	80	1.00	0.86	0.75
6	TIMBCO	T445-B	FB	TRACK	SAW	250	36	28	22	70	80	90	0.86	0.75	0.67

[1] Average slope = 35 %

APPENDIX E.6. Cycle Time Parameters for a Specific Harvester [1].

No	Machine	Model	Machine	Mobility	Attachment	Machine	VOLUME per LOG (M^3)			CYCLE TIME (min/m^3)			CYCLE TIME (min/tree)		
	Make	Number	Type		Type	HP	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	TJ	1270-B	SNGHARV	RTIRE	SNG-GRIP	204	0.68	0.41	0.25	3.00	2.72	2.44	2.04	1.11	0.61

[1] Average Slope = 26-40 %

APPENDIX E.7. Cycle Time Parameters for a Specific Loader.

No	Machine Make	Model Number	Machine Type	Mobility	Attachment Type	Machine HP	VOLUME per LOG (M^3)			Load Time per Truck (min)			CYCLE TIME (min/tree)		
							Medtn.	Black S	Aegean	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	CAT	325B	LOADER	TRUCK	KNUCBM	168	0.68	0.41	0.25	25.64	36.97	55.23	0.87	0.76	0.69

APPENDIX E.8. Cycle Time Parameters for a Specific Forwarder.

No	Machine Make	Model Number	Machine Type	Mobility	Attachment Type	Machine HP	ASD (M)	AVERAGE SLOPE (%)			CYCLE TIME (min/cycle)		
								Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	TJ	1210-B	FORWAR	RTIRE	KNUCKBM	172	300	35	37.5	32.5	36.03	39.64	46.15

APPENDIX.E.9. Cycle Time and Unit Cost Parameters for Manual Processing.

REGIONS	dbh (cm.)	VOL m^3/log	Time (min) per cm.	Bucking time (min.)	Num. of bucking	CYCLE TIME (min/tree)			PRODUCTION (m^3/hr)			UNIT COST ($/$m^3$)		
						Felling	Bucking	Delmb.	Felling	Bucking	Delmb.	Felling	Bucking	Delmb.
Black Sea	28	0.41	0.005	2.00	1.00	9.92	2.00	1.00	2.48	12.30	24.60	0.40	0.08	0.04
Mediterranean	36	0.68	0.005	2.00	2.00	15.48	4.00	1.00	2.64	10.20	40.80	0.76	0.20	0.05
Aegean	22	0.25	0.005	2.00	1.00	8.42	2.00	1.00	1.78	7.50	15.00	0.56	0.13	0.07

APPENDIX F. 1. Unit Cost Summary for Specific Harvesting Machines.

No	Make	Model	Machine	Mobility	Attachment	Machine	Mach.C	CYCLE TIME (min/cycle)			PRODUCTION (m^3/hr)			UNIT COST (\$/m^3)		
		Number	Type		Type	HP	(\$/hr)	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	CAT	515	SKIDDER	RTIRE	CABLE	140	55.97	9.87	11.51	13.15	11.93	8.49	6.51	4.69	6.60	8.60
2	CAT	525	SKIDDER	RTIRE	CABLE	160	64.12	8.48	10.74	12.99	15.35	10.46	7.49	4.18	6.13	8.56
3	CAT	528	SKIDDER	RTIRE	CABLE	185	70.79	8.48	10.74	12.99	15.35	10.46	7.49	4.61	6.77	9.45
4	JD	640-G	SKIDDER	RTIRE	CABLE	151	55.66	8.48	10.74	12.99	15.35	10.46	7.49	3.63	5.32	7.43
5	JD	740-G	SKIDDER	RTIRE	CABLE	165	62.82	8.48	10.74	12.99	15.35	10.46	7.49	4.09	6.00	8.38
6	TJ	360	SKIDDER	RTIRE	CABLE	148	53.86	9.87	11.51	13.15	11.93	8.49	6.51	4.51	6.35	8.28
7	TJ	460	SKIDDER	RTIRE	CABLE	174	64.36	8.48	10.74	12.99	15.35	10.46	7.49	4.19	6.15	8.59
8	CAT	D4HCS	CRAWLER	TRACK	CABLE	90	62.56	17.42	17.40	18.79	9.37	7.07	5.59	6.68	8.85	11.20
9	CAT	D5HCS	CRAWLER	TRACK	CABLE	120	82.54	17.42	17.40	18.79	9.37	7.07	5.59	8.81	11.67	14.77
10	TJ	933-D	SKIDDER	RTIRE	CLMBNK	209	159.69	55.2	60.00	50.00	19.57	18.00	21.60	8.16	8.87	7.39
11	PRNT	720	FB	TRACK	SHEAR	260	120.18	0.86	0.75	0.67	47.44	32.80	22.39	2.53	3.66	5.37
12	PRNT	730	FB	TRACK	SHEAR	270	140.09	0.80	0.71	0.63	51.00	34.65	23.81	2.75	4.04	5.88
13	TJ	2618	FB	TRACK	SHEAR	205	123.93	1.20	1.00	0.86	34.00	24.60	17.44	3.65	5.04	7.11
14	TJ	2628	FB	TRACK	SHEAR	230	135.35	1.00	0.86	0.75	40.80	28.60	20.00	3.32	4.73	6.77
15	TMB	T225-B	FB	TRACK	SAW	250	101.66	1.00	0.86	0.75	40.80	28.60	20.00	2.49	3.55	5.08
16	TMB	T445-B	FB	TRACK	SAW	250	119.49	0.86	0.75	0.67	47.44	32.80	22.39	2.52	3.64	5.34
17	TJ	1270-B	SNGHARV	RTIRE	SNG-GRIP	204	153.00	2.04	1.11	0.61	20.00	22.16	24.59	7.65	6.90	6.22
18	TJ	1210-B	FORWAR	RTIRE	KNUCBM	172	115.04	36.03	39.64	46.15	23.31	21.19	18.20	4.93	5.43	6.32
19	CAT	325B	LOADER	TRUCK	KNUCBM	168	119.55	0.87	0.76	0.69	40.80	28.60	20.00	2.93	4.18	5.98

APPENDIX F.2. Unit Cost Summary for Skidders Transporting Whole-tree Lengths.

No	Make	Model	Machine	Mobility	Attachment	Machine	Mach.C	CYCLE TIME (min/cycle)			PRODUCTION (m^3/hr)			UNIT COST (\$/m^3)		
		Number	Type		Type	HP	(\$/hr)	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	CAT	515	SKIDDER	RTIRE	GRPL	140	58.19	8.60	9.14	9.63	18.98	13.46	10.90	3.07	4.32	5.34
2	CAT	525	SKIDDER	RTIRE	GRPL	160	65.92	8.26	8.75	9.20	19.76	14.06	11.41	3.34	4.69	5.78
3	CAT	530	SKIDDER	RTIRE	GRPL	175	74.86	8.00	8.46	8.88	20.40	14.54	11.82	3.67	5.15	6.33
4	JD	648-G	SKIDDER	RTIRE	GRPL	151	61.41	8.42	8.92	9.39	19.38	13.79	11.18	3.17	4.45	5.49
5	JD	748-G	SKIDDER	RTIRE	GRPL	165	68.48	8.18	8.65	9.09	19.95	14.22	11.55	3.43	4.82	5.93
6	TJ	360	SKIDDER	RTIRE	GRPL	148	64.08	8.47	8.98	9.46	19.27	13.70	11.10	3.33	4.68	5.77
7	TJ	460	SKIDDER	RTIRE	GRPL	174	74.87	8.02	8.48	8.90	20.35	14.50	11.80	3.68	5.16	6.35

APPENDIX F.3. Unit Cost Summary for Skidders Transporting Tree-lengths.

No	Make	Model	Machine	Mobility	Attachment	Machine	Mach.C	CYCLE TIME (min/cycle)			PRODUCTION (m^3/hr)			UNIT COST (\$/m^3)		
		Number	Type		Type	HP	(\$/hr)	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean	Medtn.	Black S	Aegean
1	CAT	515	SKIDDER	RTIRE	GRPL	140	58.19	8.64	9.76	10.93	18.89	12.60	9.61	3.08	4.62	6.06
2	CAT	525	SKIDDER	RTIRE	GRPL	160	65.92	8.16	9.16	10.22	20.00	13.43	10.27	3.30	4.91	6.42
3	CAT	530	SKIDDER	RTIRE	GRPL	175	74.86	7.79	8.71	9.69	20.95	14.12	10.84	3.57	5.30	6.91
4	JD	648-G	SKIDDER	RTIRE	GRPL	151	61.41	8.37	9.43	10.54	19.50	13.04	9.96	3.15	4.71	6.16
5	JD	748-G	SKIDDER	RTIRE	GRPL	165	68.48	8.03	9.01	10.05	20.32	13.65	10.45	3.37	5.02	6.55
6	TJ	360	SKIDDER	RTIRE	GRPL	148	64.08	8.45	9.52	10.65	19.31	12.92	9.86	3.32	4.96	6.50
7	TJ	460	SKIDDER	RTIRE	GRPL	174	74.87	7.82	8.74	9.73	20.87	14.07	10.79	3.59	5.32	6.94

APPENDIX G.1 Total Cost Summary for Cut-to-Length Systems.

SYSTEM A

REGIONS	UNIT COST ($/M^3)		TOTAL COST ($/M^3)
	HARVESTER	FORWARDER	
BLACK SEA	6.9	8.15	15.05
MEDITERRANIAN	7.65	7.40	15.05
AEGEAN	6.22	9.48	15.70

SYSTEM B

REGIONS	UNIT COST ($/M^3)		TOTAL COST ($/M^3)
	Manual Process	FORWARDER	
BLACK SEA	3.03	8.15	11.18
MEDITERRANIAN	2.90	7.40	10.30
AEGEAN	4.40	9.48	13.88

APPENDIX G.2. Total Cost Summary for Tree-Length Systems.

SYSTEM A

REGIONS	UNIT COST ($/M^3)				TOTAL COST
	Fell-Delm.	SKIDDER	Bucking	LOADER	($/M^3)
BLACK SEA	2.56	8.85	0.47	4.18	16.06
MEDITERRANIAN	2.33	6.68	0.57	2.93	12.51
AEGEAN	3.63	11.20	0.77	5.98	21.58

SYSTEM B

REGIONS	UNIT COST ($/M^3)					TOTAL COST
	Felr-Bnch	Delimbing	Skidder	Bucking	LOADER	($/M^3)
BLACK SEA	3.55	0.23	4.62	0.47	4.18	13.05
MEDITERRANIAN	2.49	0.14	3.08	0.57	2.93	9.21
AEGEAN	5.08	0.39	6.06	0.77	5.98	18.28

APPENDIX G.3. Total Cost Summary for Whole-Tree Systems.

SYSTEM A

REGIONS	NIT COST ($/M^3)				TOTAL COST ($/M^3)
	Felr-Bnch	SKIDDER	Manual P.	LOADER	
BLACK SEA	3.55	4.32	0.70	4.18	12.75
MEDITERRANIAN	2.49	3.07	0.71	2.93	9.20
AEGEAN	5.08	5.34	1.16	5.98	17.56

SYSTEM B

REGIONS	UNIT COST ($/M^3)				TOTAL COST ($/M^3)
	Felr-Bnch	SKIDDER	Manual P.	LOADER	
BLACK SEA	3.55	8.87	0.70	4.18	17.30
MEDITERRANIAN	2.49	8.16	0.71	2.93	14.29
AEGEAN	5.08	7.39	1.16	5.98	19.61

APPENDIX H. Unit Cost Summary for the Current Oxen Skidding System in Turkey.

REGIONS	UNIT COST ($/M^3)			TOTAL COST
	Manual P.	Oxen Skidding	Manual loading	($/M^3)
BLACK SEA	2.64	6.12	1.20	9.96
MEDITERRANIAN	2.50	3.66	1.05	7.20
AEGEAN	3.81	4.77	1.50	10.08