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C O S T C O N T R O L

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R O A D C O N S T R U C T I O N

(2nd draft)

by

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1. PRINCIPLES OF COST CONTROL

1.1 Introduction

Cost is of vital importance to all industry. Costs can be divided into two general classes; absolute costs and relative costs. Absolute cost measures the loss in value of assets. Relative cost measures the unfavorable side of any decision that is made. Relative cost always involves a comparison between the chosen course of action and the course of action that was rejected. This cost of the alternative action--the action not taken--is often called the "opportunity cost".

The financial accountant is primarily concerned with the absolute cost. However, the engineer, the planner, the alert manager needs to be concerned with the alternative cost--the cost of the lost opportunity. Management has to be able to make comparisons between the policy that should be chosen and the policy that should be rejected. Such comparisons require the ability to predict costs, rather than merely record costs.

The data of recorded cost are, of course, essential to the technique of cost prediction. However, the form in which much cost data are recorded is such that it limits accurate cost prediction to the field of comparable situations only. This limitation of accurate cost prediction may not be serious in industries where the environment of production changes little from month to month or year to year. In logging, however, identical production situations are the

exception rather than the rule. Unless the cost data are broken down and recorded as unit costs, and correlated with the factors that control their values, they are of little use in deciding between alternative procedures. In this paper, the approach to the problem of useful cost data is that of identification, isolation, and control of the factors affecting cost.

1.2 Basic Classification of Costs

Costs are divided into two types: variable costs, and fixed costs. Variable costs vary per unit of production. For example, they may be the cost per cubic meter of wood yarded, per cubic meter of dirt excavated, etc. Fixed costs, on the other hand, are incurred only once and as additional units of production are produced, the unit costs fall. Examples of fixed costs would be equipment move-in costs and road access costs.

1.3 Total Cost and Unit-Cost Formulas

As logging operations become more complicated and involve both fixed and variable costs, there usually is more than one way to accomplish a given task. It may be possible to change the quantity of one or both types of cost, and, thus, to arrive at a minimum total costs. Mathematically, the relationship existing between volume of production and costs can be expressed by the following equations:

$$\text{Total cost} = \text{fixed cost} + \text{variable cost} \times \text{output}$$

$$\text{Unit cost} = \frac{\text{fixed cost}}{\text{output}} + \text{variable cost}$$

In symbols using the first letters of the cost elements and N for the output or number of units of production, these simple formulas are

$$C = F + NV$$

$$UC = F/N + V.$$

1.4 Breakeven Analysis

A breakeven analysis determines the point at which one method becomes superior to another method of accomplishing some task or objective. Breakeven analysis is an extremely common and important part of cost control.

One illustration of a breakeven analysis would be to compare two methods of road construction for a road that involves a limited amount of cut-and-fill earthwork. It would be possible to do the earthwork by hand or by bulldozer. If the manual method were adopted, the fixed costs would be low or non-existent. Payment would be done on a daily basis and would call for direct supervision by a foreman. The cost would be calculated by estimating the time required and multiplying this time by the average wages of the men employed. The men could also be paid on a piece-work basis. Alternatively, this work could be done by a bulldozer which would have to be moved in from another site. Let us

assume that the cost of the hand labor would be $0.60 per cubic meter and the bulldozer would cost $0.40 per cubic meter and would require $100 to move in from another site. The move-in cost for the bulldozer is a fixed cost, and is independent of the quantity of the earthwork handled. If the bulldozer is used, no economy will result unless the amount of earthwork is sufficient to carry the fixed cost plus the direct cost of the bulldozer operation.

If, on a set of coordinates, the cost in dollars is plotted on the vertical axis and units of production on the horizontal axis, we can indicate fixed cost for any process by horizontal line parallel to the x-axis. If variable cost per unit output is constant, then the total cost for any number of units of production will be the sum of the fixed cost and the variable cost multiplied by the number of units of production, or F + NV. If the cost data for two processes or methods one of which has a higher variable cost, but lower fixed cost than other are plotted on the same graph, the total cost lines will intersect at some point. At this point the levels of production and total cost are the same. This point is known as the "break-even" point, since at this level one method is as economical as the other. Referring to Figure 1.1, the breakeven point at which quantity the bulldozer alternative and the manual labor alternative become equal is at 500 cubic meters. We could have found this same result algebraically by writing F + NV = F' + NV' where F and V are the fixed and variable costs for the

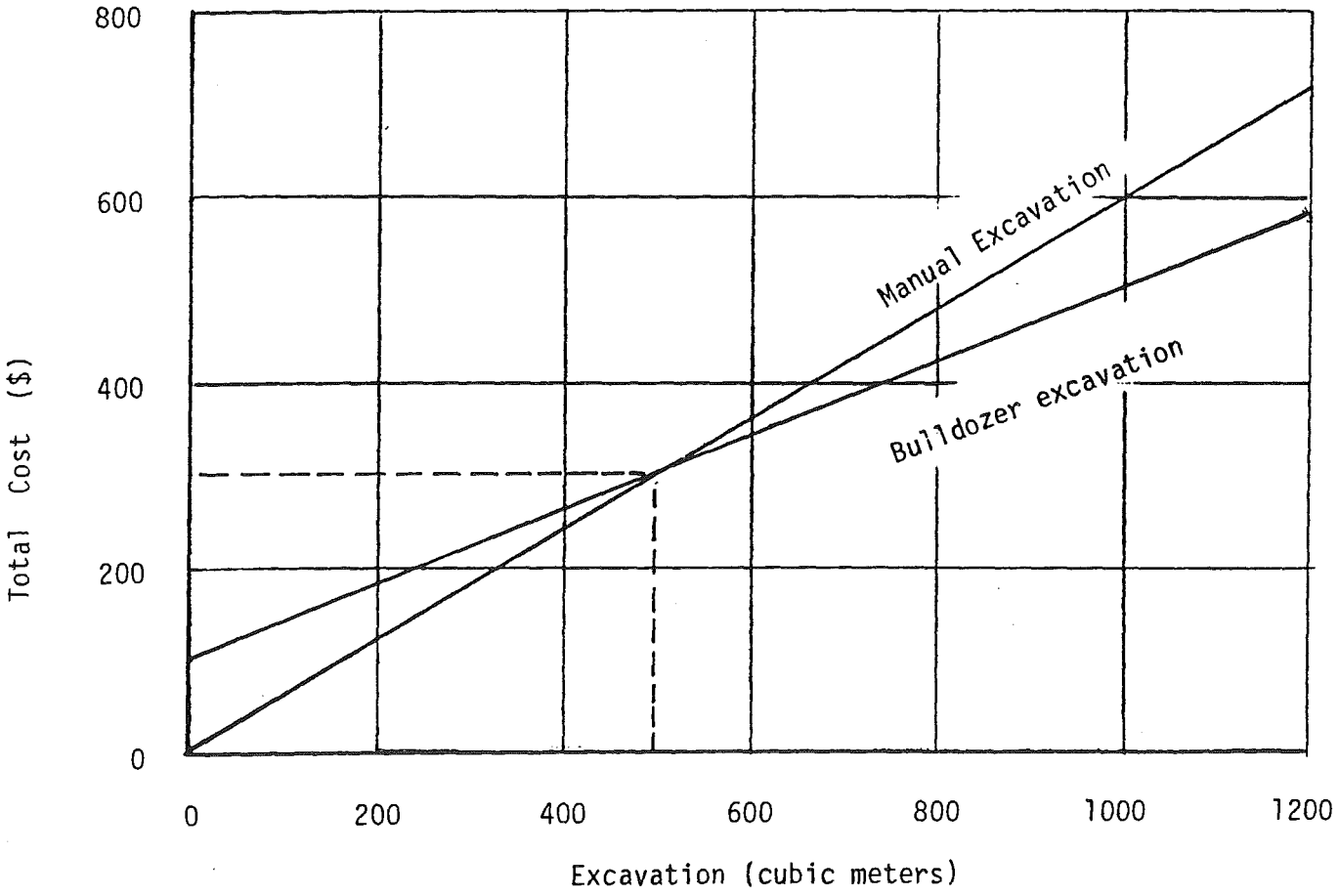


Figure 1.1 Breakeven Example for Excavation.

manual method, and F' and V' are the corresponding values for the bulldozer method. Since all values are known except N, we can solve for N using the formula N = (F'-F)/(V-V')

$$N = \frac{100 - 0}{0.6-0.4.} = 500$$

1.5 Minimum Cost Analyses

A similar, but different, problem is the determination of **the point of minimum total cost.** Instead of balancing two methods with different fixed and variable costs, the aim is to bring the sum of two costs to a minimum. We will assume a clearing crew of 20 men is clearing road right-of-way and the following facts are available:

1. Men are paid at the rate of $0.40 per hour.
2. Time is measured from the time of leaving camp to the time of return.
3. Total walking time per man is increasing at the rate of 15 minutes per day.
4. The cost to move the camp is $50.

If the camp is moved each day, no time is lost walking, but the camp cost is $50 per day. If the camp is not moved, on the second day 15 crew-minutes is lost--or $2.00. On the third day, the total walking time has increased 30 minutes, the fourth day, 45 minutes, and so on. How often should the camp be moved, assuming all other things are equal? We could derive an algebraic expression using the sum of an arithmetic series if we wanted to solve this problem a number of times, but for demonstration purposes we can

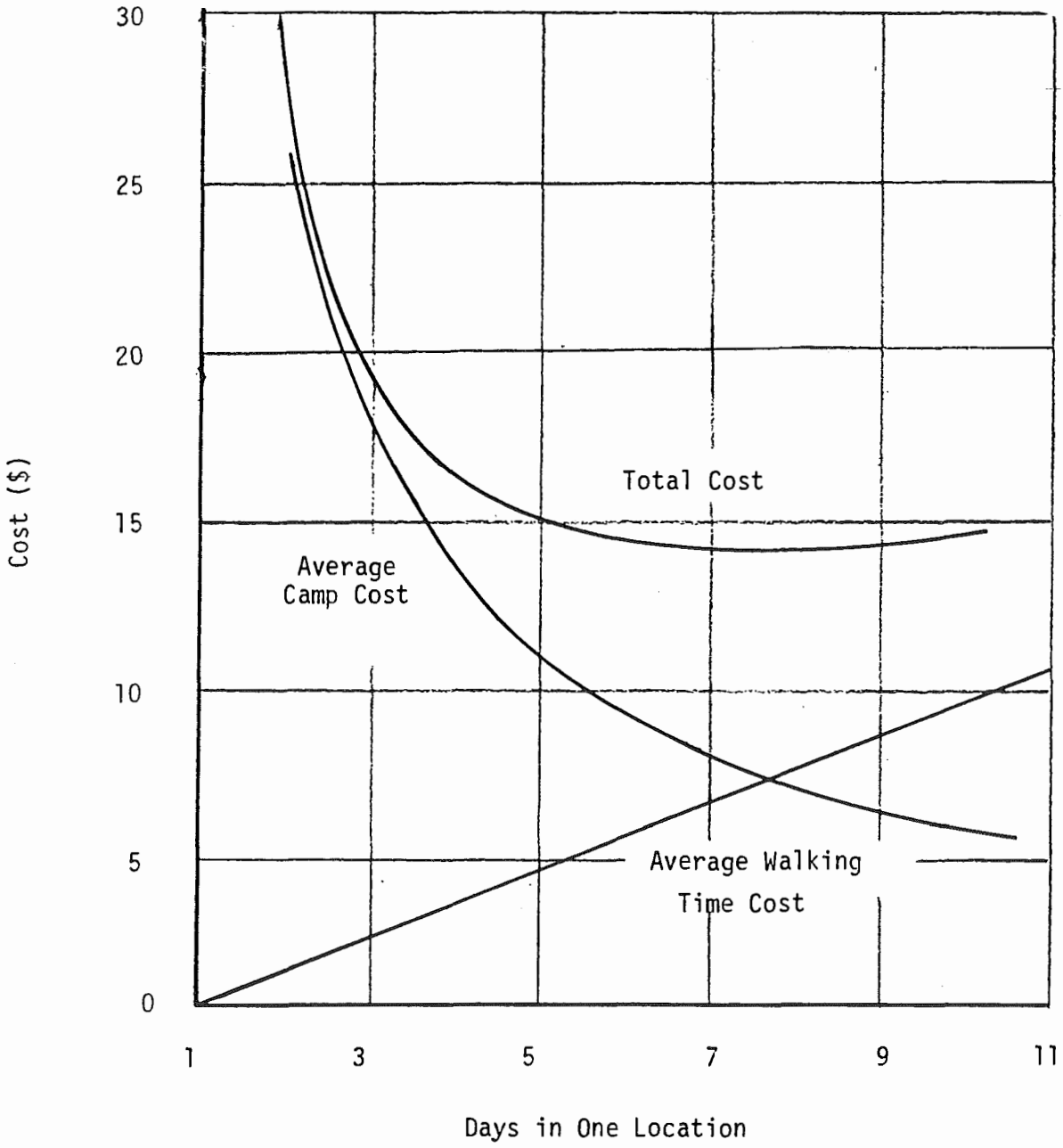
simply calculate the average total camp cost. The average total camp cost is the sum of the average daily cost of walking time plus the average daily cost of moving camp. If we moved camp each day, then average daily cost of walking time would be zero and the cost of moving camp would be $50.00. If we moved the camp every other day, the cost of walking time is $2.00 lost the second day, or an average of $1.00 per day. The average daily cost of moving camp is $50 divided by 2 or $25.00. The average total camp cost is then $26.00. If we continued this process for various numbers of days the camp remains in location, we would obtain the results in Table 1.1.

TABLE 1.1 Average daily total camp cost as the sum of the cost of walking time plus the cost of moving camp.

Days camp remained in location	Average daily cost of walking time	Average daily cost of moving camp	Average total camp cost
1	0.00	50.00	50.00
2	1.00	25.00	26.00
3	2.00	16.67	18.67
4	3.00	12.50	15.50
5	4.00	10.00	14.00
6	5.00	8.33	13.33
7	6.00	7.14	13.14
8	7.00	6.25	13.25
9	8.00	5.56	13.56
10	9.00	5.00	14.00

We see the average daily cost of walking time increasing linearly and the average cost of moving camp decreasing as the number of days the camp remains in one

Figure 1.2 Costs for Camp Location Problem



location increases. The minimum cost is obtained for leaving the camp in the same location 7 days. This minimum cost point should only be used as a guideline, as all other things are rarely equal. An important output of the analysis is the sensitivity of the total cost to deviations from the minimum cost point. In this example, note the total cost changes slowly between 5 and 10 days. Often, other considerations which may be difficult to quantify will affect the decision. In the following section where we discuss balancing road costs against skidding costs, a higher road density than would result from the minimum total cost is sometimes selected if excess road construction capacity is available. The is to reduce the risk of disrupting skidding production because of poor weather or equipment availability. Due to the usually flat nature of the total cost curve, the increase in total cost is often small over a considerable range of road densities.

2. UNIT COSTS AND COST EQUATIONS

2.1 Introduction

The use of break-even and minimum-cost-point formulas requires the collection of unit costs. Unit costs can be divided into subunits, each of which measures the cost of a certain part of the total. A typical unit cost formula might be

$$X = a + b + c$$

where X is the cost per unit volume such as dollars per cubic meter and the subunits a,b,c will deal with distance, volume, area, or weight. Careful selection of the subunits to express the factors controlling costs is the key to success in all cost studies.

2.2 Example of Cost Equations

Let us suppose the cost of logging from felling to loading on trucks is being investigated. If X is the cost per cubic meter of wood loaded on the truck, we could represent the total cost per unit as

$$X = A + B + Q + L$$

where A would be the cost per unit of felling, B the cost of bucking, Q the cost of skidding, and L the cost of loading.

To determine the cost per subunit for felling, bucking, skidding, and loading, the factors which determine production and cost must be specified. Functional forms for

production in road construction and logging are discussed in Sections 4 and 5. Examples for felling and skidding follow.

For felling, tree diameter may be an important explanatory variable. For example for a given felling method, the time required to fell the tree might be expressed as

$$T = a + b\ D^2$$

where T is the time to fell the tree, b is the felling time required per cm of diameter, D is the tree diameter and a represents the felling time not explained by tree diameter---such as for walking between trees. The production rate is equal to the tree volume divided by the time per tree. The unit cost of felling is equal to the cost per hour of the felling operation divided by the hourly production or

$$A = C/P = C/(V/T) = C\ (a + b\ D^2)/V$$

where C is the cost per hour for the felling method being used, P is the production per hour, V is the volume per tree, and T is the time per tree. The hourly cost of operation is referred to as the machine rate and is the combined cost of labor and equipment required for production. (Machine rates are discussed in the Section 3.)

Example:

Determine the felling unit cost for a 60 cm tree if the cost per hour of a man with power saw is $5.00, the tree volume

is 3 cubic meters, and the time to fell the tree is 3 minutes plus 0.005 times the square of the diameter.

$$T = 3 + .005\ (60)(60) = 21\ min = .35\ hr$$

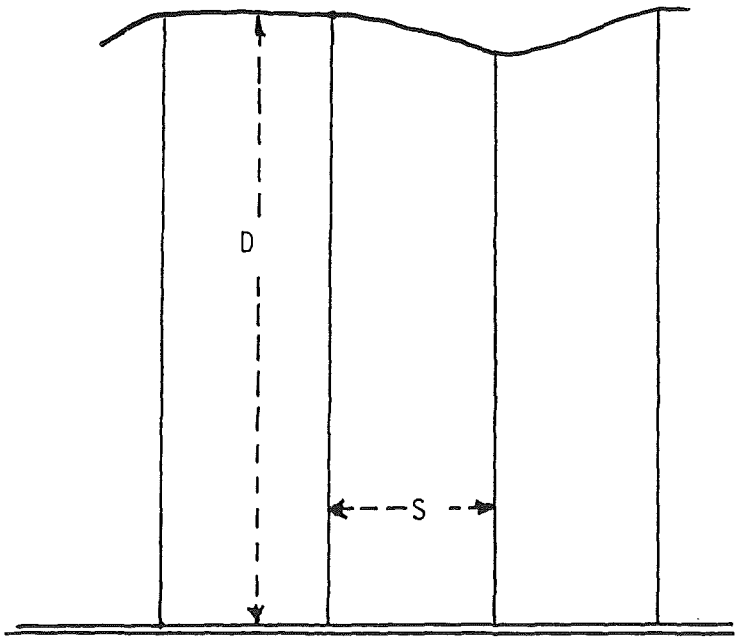
$$P = V/T = 3.0/.35 = 8.57\ m^3/hr$$

$$A = C/P = 5.00/8.57 = \$0.58/m^3$$

In skidding, for example, if logs were being skidded directly to a road (Figure 2.1), then the distance skidded is an important item and the stump to truck unit cost might be written as

$$X = A + B + F + C(D/2) + L$$

where the skidding subunit P has been replaced by symbol F representing fixed costs of skidding such as hooking, unhooking and decking and C(D/2) represents that part of the skidding costs that varies with distance. C is the cost of skidding a unit distance such as one meter and D/2 represents the average skidding distance in similar units. It is important to note that the average skidding cost occurs at the average skidding distance only when the skidding cost, C, is constant with respect to distance. If C varies with distance as, for example, with animal skidding where the animal can become increasingly tired with distance, the average skidding cost does not occur at the average skidding distance and substantial errors in unit cost calculations can occur if the average skidding distance is used.



D = Length of Spur Road
S = Spacing between Spur Roads

Figure 2.1 Nomenclature for 2-way skidding to continuous landings along spur roads.

If logs were being skidded to a series of secondary roads (Figure 2.1) running into a primary road, then the expression C(D/2) would be replaced by the expression C(S/4) and the cost of truck haul on the feeder roads would appear as a separate item. In the expression C(S/4), the symbol S represents the spacing of the secondary roads and the distance S/4 is the average skidding distance if skidding could take place in both directions. Therefore, the expression C(S/4) would define the variable skidding cost in terms of spacing of the secondary roads.

A formula for the cost of logs on trucks at the primary road under these circumstances would be

$$X = A + B + F + C(S/4) + L + H(D/2)$$

where D/2 is the average hauling distance along the secondary road and H is the variable cost of hauling per unit distance.

The formula can be extended still further to include the cost of the secondary road system by defining the road construction cost per meter R, and the volume per square meter, V. Then, the formula becomes

$$X = A + B + F + C(S/4) + L + H(D/2) + R/(VS).$$

2.3 Applications of Cost Equations

In the preceding equation, we have a situation where as the spacing between skidding roads increases, skidding unit

costs increase, while road unit costs decrease. With the total cost equation, we can look at the cost tradeoffs between skidding distance and road spacing. Calculus can be used to derive the formula for road spacing which minimizes costs as follows:

$$dX/dS = C/4 - R/(VS^2) = 0$$

or

$$S = (4R/CV)^{.5}$$

An alternative method is to compare total costs for various road spacings. The total cost method has become less laborious with the use of programmable calculators and microcomputers and provides information on the sensitivity of total unit cost to road spacing without having to evaluate the derivative of the cost function.

Example:

Given the following table of unit costs, what is the effect of alternative spur road spacings on total cost of wood delivered to the main road, if 50 m^3 per hectare is being cut and the average length of the spur road is 2 km. The cost of spur roads includes landings.

TABLE 2.1 Table of costs by activity for the road spacing example.

Activity	Unit	Cost	
Felling	$/m^3	0.50	
Bucking	$/m^3	0.20	
Skidding	$/m^3	2.00	(fixed cost)
Skidding	$/m^3/km	2.50	(variable cost)
Loading	$/m^3	0.80	
Hauling	$/m^3/km	0.15	
Roads	$/km	2000	

$$X = A + B + F + C(S/4) + L + H(D/2) + R/(VS)$$

$$X = 0.50 + 0.20 + 2.00 + C(S/4) + 0.80 + .15\ (1) + R/(VS)$$

Since only the skidding costs and spur road costs are affected by the road spacing, the total unit cost can be expressed as

$$X = 3.65 + C(S/4) + R/(VS).$$

To evaluate different road spacings, we vary the spur road spacing S and calculate the total unit costs (Table 2.2). It is important to use dimensionally consistent units. That is, if the left side of the equation is in $/m^3$, the right side of the equation must be in $/m^3$. This is most easily done if all volumes, costs and distances are expressed in meters; such as volume cut per m^2, skidding cost per m^3 per meter, and road cost per meter. For example, the total cost for a spur road spacing of 200 meters is 3.65 + (2.5/1000)(200/4) + (2000/1000)/[(50/10000)(200)] or $5.78 per m^3.

TABLE 2.2 Total unit cost as a function of road spacing.

Spur Road Spacing, m	Total Unit Cost, $/m^3$
200	5.78
400	4.90
600	4.69
800	4.65
1000	4.68
1200	4.73
1400	4.81
1600	4.90
1800	5.00
2000	5.10

The road spacing which minimized total cost could be interpolated from the table or calculated from the formula

$$S = (4R/CV)^{.5}$$

$$S = \frac{4 \times 2000/1000}{(2.5/1000)(50/10000)}$$

$$S = 800 \text{ m.}$$

When costs have been collected in a form which permits unit costs to be developed from them, not only is it possible to accurately predict costs, under given conditions, it is also possible to adjust conditions so that minimum cost can be achieved. Too often, recorded costs are only "experience figures" and, in the form in which they are usually made available, can be used to predict costs only under conditions that closely conform to those existing where and when the recorded costs were collected. This is not true of unit costs, which can be fitted into the framework of many different logging situations and can be made to tell the story of the future as well as that of the past.

A wide range of cost control formulas can be derived. Typical problems include:

1. The economic location of roads and landings. -- The calculation of the optimal spacing between spur roads and landings subject to one-way skidding, two-way skidding,

skidding on slopes, linear and nonlinear skidding cost functions.

2. The economic service standard for roads. -- The comparison of the benefits of lower haul costs and road maintenance costs as a function of increased capital expenditures. The calculation of the optimal length of swing roads as a function of the tributary volume.

3. The economic selection of equipment for road systems fixed by topography or other factors. -- The identification of the breakeven points between alternative skidding methods which have different fixed and variable operating costs.

4. The economic spacing of roads which will be served by two types of skidding machines. -- For example, machines used to skid sawtimber and to relog for fuelwood.

5. The economic spacing of roads which will be reused in future time periods.

Another important application of unit costs is in choosing between alternative logging systems.

Example:

A forest manager is developing an area and is trying to decide between two harvesting plans. He has two choices of skidding systems, two choices of road standards, and two choices of trucks. He can buck the bigger logs into smaller

logs on the landing. Assume that bucking in the field does not affect log quality or yield.

The manager's staff has developed the relevant unit costs, which are summarized in Table 2.3 and Table 2.4. What should he do?

TABLE 2.3. Unit costs for options of using small equipment and large equipment.

	Small Equipment $/m3	Large Equipment $/m3
Fall, buck	0.70	0.50
Skid	1.70	2.55
Load	1.00	0.80
Transport	*	*
Unload	0.40	0.30
Process	-	0.05

* See Table 2.4 for transport costs as a function of road standard. Wood for large system could be bucked on landing for $0.15/m3 and loaded on small trucks.

TABLE 2.4. Unit costs for road and transport options using small and large equipment.

	Small Equipment $/m3	Large Equipment $/m3
Road		
High Std	1.30	1.30
Low Std	1.00	1.00
Transport		
High Std	3.50	3.00
Low Std	4.00	3.40

These choices can be viewed as a network (Figure 2.2). You can verify that the least cost path is obtained by using the smaller skidding equipment and trucks and constructing the higher standard road. The total unit cost will be $8.20 per m^3. A key point is the ease at which these problems can be analyzed, once the unit costs have been derived. In turn, the derivation of the unit costs is facilitated by having machine rates available.

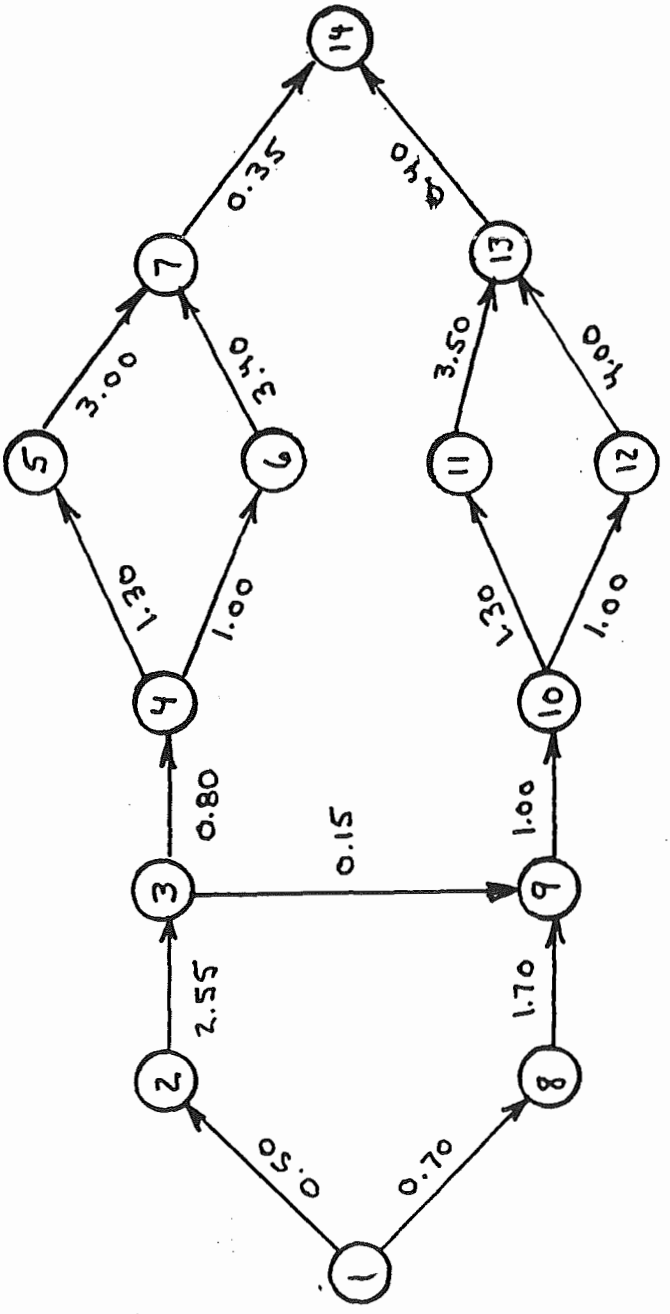


Figure 2.2 Network Diagram for Equipment Choice.

3. CALCULATION OF MACHINE RATES

3.1 Introduction

The unit cost of logging or road construction is essentially derived by dividing cost by production. In its simplest case, if you rented a tractor with operator for $60 per hour--including all fuel and other costs--and you excavated 100 cubic meters per hour, your unit cost for excavation would be $0.60 per cubic yard. The cost of the tractor with operator is called the machine rate. In cases where the machine and the elements of production are not rented, a calculation of the owning and operating costs is necessary to derive the machine rate. The objective in developing a machine rate should be to arrive at a figure that, as nearly as possible, represents the cost the work done under the operating conditions encountered and the accounting system in force. Most manufacturers of machinery supply data for the cost of owning and operating their equipment and that will serve as the basis of machine rates. However, such data usually need modification to meet specific conditions of operation, and many owners of equipment will prefer to prepare their own rates.

3.2 Classification of Costs

The machine rate is usually, but not always, divided into fixed costs, operating costs, and labor costs. For certain cash flow analyses, only items which represent a

cash flow are included. Certain fixed costs, including depreciation and sometimes interest charges, are omitted if they do not represent a cash payment. In this paper, all fixed costs discussed below are included. For some analyses, labor costs are not included in the machine rate. Instead, fixed and variable costs are calculated. Labor costs are then added separately. This is sometimes done in situations where the labor associated with the equipment works a different number of hours from the equipment. In this paper, labor is included in the calculation of the machine rate.

3.2.1. Fixed Costs

Fixed costs are those which can be predetermined as accumulating with the passage of time, rather than with the rate of work. They do not stop when the work stops and must be spread over the hours of work during the year. Commonly included in fixed costs are equipment depreciation, interest on investment, taxes, storage, and insurance.

3.2.2 Operating Costs

Operating costs vary directly with the rate of work. They include the costs of fuel, lubricants, tires, equipment maintenance and repairs.

3.2.3 Labor Costs.

Labor costs, logically are those costs associated with employing labor and include direct wages, food contributions, transport, and social costs, including payments for health and retirement. The cost of supervision may also be spread over the labor costs.

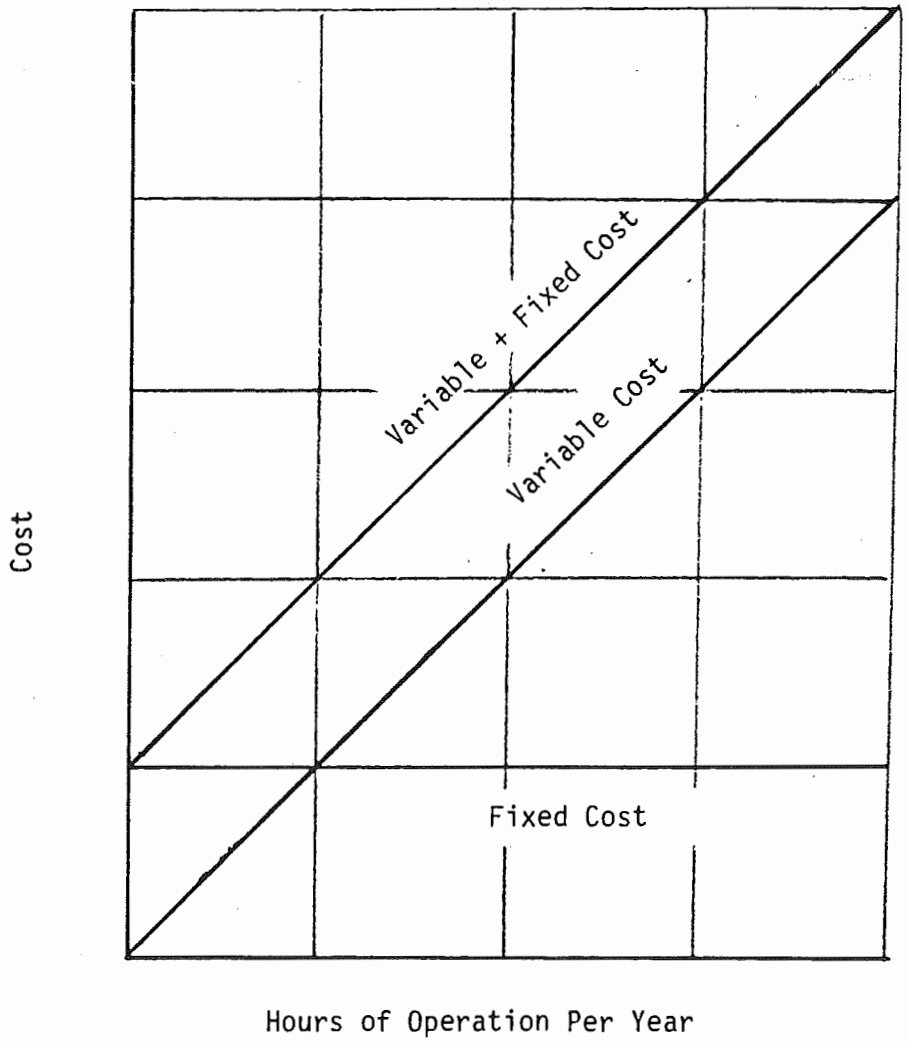


Figure 3.1 Equipment Cost Model.

The machine rate is the sum of the fixed plus operating plus labor costs. The division of costs in these classifications is arbitrary, although accounting rules use a rigid classification. The key point is to separate the costs in a way that makes the most sense in explaining the cost of operating the men and equipment. For example, if a major determinant of equipment salvage value is the rate of obsolescence such as in the computer industry, the depreciation cost is largely dependent on the passage of time, not the hours worked. For a truck, tractor, or power saw, a major determinant may be the actual hours of equipment use. The tractor's life could be viewed as the sand in an hour glass which is only permitted to drop during the hours the equipment is working.

3.3 Definitions

3.3.1 Purchase Price (P)

This is defined as the actual equipment purchase cost including the standard attachments, optional attachments, sales taxes, and delivery costs. The most common pricing policies are the factory and delivered price. The factory price applies if the buyer takes title to the equipment at the factory and is responsible for shipment. The delivered price applies if the buyer takes title of the equipment at a specific delivery point. The delivered price usually includes freight, packing, and insurance and the buyer takes title of the equipment at this point. Miscellaneous costs

for installation or adaptation of the equipment to the logging system should be included in the initial investment cost. Special attachments may sometimes have a separate machine rate, if their lives differ from the main equipment and form an important part of the equipment cost.

3.3.2. Economic Life (N)

This is the period over which the equipment can operate at an acceptable operating cost and productivity. The economic life is generally measured in terms of years, hours, or in the case of trucks and trailers in terms of kilometers. It depends upon a myriad of factors, including physical deterioration, technological obsolescence or changing economic conditions. Physical deterioration can arise from such factors as corrosion, chemical decomposition, or by wear and tear due to abrasion, shock and impact. These may result from normal and proper usage, abusive and improper usage, age, inadequate or lack of maintenance, or severe environmental conditions. Changing economic conditions such as fuel prices, tax investment incentives, and the rate of interest can also affect the economic life of equipment. Examples of ownership periods for some types of skidding and road construction equipment, based upon application and operating conditions, are shown in Table 3.1. Since the lives are given in terms of operating hours, the life in years is obtained by working backwards by defining the number of working days per year and the estimated number of working hours per day. For

Table 3.1.a -- Guide for selecting ownership period based on application and operating conditions.

	ZONE A	ZONE B	ZONE C
WHEEL TRACTOR SCRAPERS	Level or favorable hauls on good haul roads. No impact. Easy-loading materials.	Varying loading and haul road conditions. Long and short hauls. Adverse and favorable grades. Some impact. Typical road-building use on a variety of jobs.	High impact condition, such as loading ripped rock. Overloading. Continuous high total resistance conditions. Rough haul roads.
Small	12,000 Hr	10,000 Hr	8,000 Hr
Large	16,000 Hr	12,000 Hr	8,000 Hr
OFF HIGHWAY TRUCKS & TRACTORS	Mine and quarry use with properly matched loading equipment. Well maintained haul roads. Also construction use under above conditions.	Varying loading and haul road conditions. Typical road-building use on a variety of jobs.	Consistently poor haul road contitions. Extreme overloading. Oversized loading equipment.
	25,000 Hr	20,000 Hr	15,000 Hr
WHEEL TRACTORS & COMPACTORS	Light utility work. Stockpile work. Pulling compactors. Dozing loose fill. No impact.	Production dozing, pushloading in clays, sands, silts, loose gravels. Shovel clean-up. Compactor use.	Production dozing in rock. Push-loading in rocky, bouldering borrow pits. High impact conditions.
	15,000 Hr	12,000 Hr	8,000 Hr
WHEEL LOADERS	Intermittent truck loading from stockpile, hopper charging on firm, smooth surfaces. Free flowing, low density materials. Utility work in governmental and industrial applications. Light snowplowing. 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 bucket. Hopper charging in low to medium rolling resistance. Loading from bank in good digging. Load and carry on poor surfaces and slight adverse grades.	Loading shot rock (large loaders). Handling high density materials with counterweighted machine. Steady loading from very tight banks. Continuous work on rough or very soft surfaces. Load and carry in hard digging; travel longer distances on poor surfaces with adverse grades.
Small	12,000 Hr	10,000 Hr	8,000 Hr
Large	15,000 Hr	12,000 Hr	10,000 Hr
TRACK-TYPE LOADERS	Intermittent truck loading from stockpile. Minimum traveling, turning. Free flowing, low density materials with standard bucket. No impact.	Bank excavation, intermittent ripping, basement digging of natural bed clays, sands, silts, gravels. Some traveling. Steady full throttle operation.	Loading shot rock, cobbles, glacial till, caliche. Steel mill work. High density materials in standard bucket. 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

Table 3.1.a -- Guide for selecting ownership period based on application and operating conditions.

	ZONE A	ZONE B	ZONE C
TRACK-TYPE TRACTORS	Pulling scrapers, most agricultural drawbar, stockpile, coalpile and landfill work. No impact. Intermittent full throttle operation.	Production dozing in clays, sands, gravels. Pushloading scrapers, borrow pit ripping, most land-clearing and skidding applications. Medium impact conditions.	Heavy rock ripping. Tandem ripping. Pushloading and dozing in hard rock. Work on rock surfaces. Continuous high impact conditions.
Small	12,000 Hr	10,000 Hr	8,000 Hr
Large	22,000 Hr	18,000 Hr	15,000 Hr
MOTORGRADERS	Light road maintenance. Finishing. Plant and road mix work. Light snowplowing. Large amounts of traveling.	Haul road maintenance. Road construction, ditching. Loose fill spreading. Landforming, land-leveling. Summer road maintenance with medium to heavy winter snow removal. Elevating grader use.	Maintenance of hard pack roads with embedded rock. Heavy fill spreading. Ripping-scarifying of asphalt or concrete. Continuous high load factor. High impact.
	20,000 Hr	15,000 Hr	12,000 Hr
EXCAVATORS	Shallow depth utility construction where excavator sets pipe and digs only 3 or 4 hours/shift. Free flowing, low density material and little or no impact. Most scrap handling arrangements.	Mass excavation or trenching where machine digs all the time in natural bed clay soils. Some traveling and steady, full throttle operation. Most log loading applications.	Continuous trenching or truck loading in rock or shot rock soils. Large amount of travel over rough ground. Machine continuously working on rock floor with constant high load factor and high impact.
	12,000 Hr	10,000 Hr	8,000 Hr
WHEEL SKIDDERS	Intermittent skidding for short distances, no decking. Good underfoot 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 underfloor conditions: wet floor, steep slopes and numerous stumps.
	12,000 Hr	10,000 Hr	8,000 Hr

Adapted from Caterpillar Performance Handbook.

equipment that works very few hours per day, the derived equipment lives may be very long and local conditions should be checked for the reasonableness of the estimate.

3.3.3 Salvage Value (S)

This is defined as the price that equipment can be sold for at the time of its disposal. Used equipment rates vary widely throughout the world. However, in any given used equipment market, factors which have the greatest effect on resale or trade-in value are the number of hours on the machine at the time of resale or trade-in, the type of jobs and operating conditions under which it worked, and the physical condition of the machine. Whatever the variables, however, the decline in value is greater in the first year than the second, greater the second year than the third, etc. The shorter the work life of the machine, the higher the percentage of value lost in a year. In agricultural tractors for example, as a general rule 40 to 50 percent of the value of the machine will be lost in the first quarter of the machine's life and by the halfway point of lifetime, 70 to 75 percent of the value will be lost. The salvage value is often estimated as 10 to 20 percent of the initial purchase price.

3.4 Fixed Costs

3.4.1 Depreciation

The objective of the depreciation charge is to recognize the decline of value of the machine as it is

working at a specific task. This may differ from the accountant's depreciation schedule--which is chosen to maximize profit though the advantages of various types of tax laws and follows accounting convention. A common example of this difference is seen where equipment is still working many years after it was "written off" or has zero "book value."

Depreciation schedules vary from the simplest approach, which is a straight line decline in value in the absence of alternative information, to more sophisticated techniques which recognize the changing rate of value loss over time. The formula for the annual depreciation charge using the assumption of straight line decline in value is

$$D = (P' - S)/N$$

where P' is the initial purchase price less the cost of tires, wire rope, or other parts which are subjected to the greatest wear and can be easily replaced without effect upon the general mechanical condition of the machine.

3.4.2 Interest

Interest is the cost of using funds over a period of time. Investment funds may be borrowed or taken from savings or equity. If borrowed, the interest rate is established by the lender and varies by locale and lending institution. If the money comes from savings, then opportunity cost or the rate this money would earn if invested elsewhere is used as the interest rate. The accounting practice of private firms may ignore interest on equipment on the ground that interest

is a part of profits and, therefore, not a proper charge against operating equipment. Although this is sound from the point of view of the business as a whole, the exclusion of such charges may lead to the development of unrealistic comparative rates between machines of low and high initial cost. This may lead, in turn, to erroneous decisions in the selection of equipment.

Interest can be calculated by using one of two methods. The first method is to multiply the interest rate by the actual value of the remaining life of the equipment. The second simpler method is to multiply the interest rate by the average annual investment.

For straight-line depreciation, the average annual investment, AAI, is calculated as

$$AAI = (P-S)(N+1)/(2N) + S.$$

Sometimes a factor of 0.6 times the delivered cost is used as an approximation of the average annual investment.

3.4.3 Taxes

Many equipment owners must pay property taxes or some type of usage tax on equipment. Taxes, like interest, can be calculated by either using the estimated tax rate multiplied by the actual value of the equipment or multiplying the tax rate by the average annual investment.

3.4.4 Insurance

Most private equipment owners will have one or more insurance policies against damage, fire, and other

destructive events. Public owners and some large owners may be self-insured. It could be argued, however, that the cost of insurance is a real cost that reflects the risk to all owners and some allowance for destructive events should be allowed. Not anticipating the risk of destructive events is similar to not recognizing the risk of fire or insect damage in planning the returns from managing a forest. Insurance is handled in the same way as interest and taxes.

3.4.5 Storage and Protection

Costs for equipment storage and off-duty protection are fixed costs, largely independent of the hours of use. Costs of storage and protection must be spread over the total hours of equipment use.

3.5 Operating Costs

Operating costs, unlike fixed costs, change in proportion to hours of operation or use. They depend upon a variety of factors, many of which are, to some extent, under the control of the operator or equipment owner.

3.5.1 Maintenance and Repair

These include everything from simple maintenance to the periodic overhaul of engine, transmission, clutch, brakes and other major equipment components, for which wear primarily occurs proportional to use. Operator use or abuse of equipment, the severity of the working conditions, maintenance and repair policies, and the basic equipment design and quality all affect maintenance and repair costs.

The cost of periodically overhauling major components may be estimated from the owner's manual and the local cost of parts and labor, or by getting advice from the manufacturer. Another owner's experience with similar equipment and cost records under typical working conditions are valuable sources. If experienced owners or cost records are not available, the hourly maintenance and repair cost can be estimated as a percentage of hourly depreciation (Table 3.2).

Table 3.2. Maintenance and repair rates as a percentage of the hourly depreciation for selected equipment.

Machine	Percentage Rate
Crawler tractor	100
Agricultural tractor	100
Rubber-tired skidder with cable chokers	50
Rubber-tired skidder with grapple	60
Loader with cable grapple	30
Loader with hydraulic grapple	50
Power saw	100
Feller-buncher	50

3.5.2 Fuel

The fuel consumption rate for a piece of equipment depends on the engine size, load factor, the condition of the equipment, operator's habit, environmental conditions, and the basic design of equipment.

To determine the hourly fuel cost, the total fuel cost is divided by the productive time of the equipment. If fuel consumption records are not available, the following formula

can be used to estimate liters of fuel used per machine hour,

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

where LMPH is the liters used per machine hour, K is the kg of fuel used per brake hp/hour, GHP is the gross engine horsepower at governed engine rpm, LF is the load factor in percent, and KPL is the weight of fuel in kg/liter. Typical values are given in Table 3.3. The load factor is the ratio of the average horsepower used to gross horsepower available at the flywheel.

Table 3.3. Weights, fuel consumption rates, and load factors for diesel and gasoline engines.

Engine	Weight (KPL) kg/liter	Fuel Consumption (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

3.5.3 Lubricants

These include engine oil, transmission oil, final drive oil, grease and filters. The consumption rate varies with the type of equipment, environmental working condition (temperature), the design of the equipment and the level of maintenance. If you lack actual data, the lubricant consumption in liters per hour for skidders, tractors, and front-end loaders could be estimated as

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

These formulas include normal oil changes and no leaks. They should be increased 25 percent when operating in heavy dust, deep mud, or water. In machines with complex and high pressure hydraulic systems, such as forwarders, processors, and harvesters, the consumption of hydraulic fluids can be much greater. Another rule of thumb is that the cost of lubricants and grease costs 5 to 10 percent of the cost of fuel.

3.5.4 Tires

Due to their shorter life, tires are considered an operating cost. Tire cost is greatly affected by the operator's habits, vehicle speed, surface conditions, wheel position, loadings, relative amount of time spent on curves, and grades. For off-highway equipment, if local experience is not available, the following categories for tire life based upon tire failure mode could be used as guidelines with tire life given in Table 3.4.

In Zone A, almost all tires wear through to tread from abrasion before failure. In Zone B, most tires wear out--but some fail prematurely from rock cuts, rips, and non-repairable punctures. In Zone C, few if any tires wear through the tread before failure due to cuts.

Table 3.4. Guidelines for tire life for off-highway equipment.

Equipment	Tire Life, hours		
	Zone A	Zone B	Zone C
Motor graders	8000	4500	2500
Wheel scrapers	4000	2250	1000
Wheel loaders	4500	2000	750
Skidders	5000	3000	1500
Trucks	5000	3000	1500

3.6 Labor Costs

Labor costs include direct and indirect payments such as taxes, insurance payments, food, housing subsidy, etc. Labor costs need to be carefully considered when calculating machine rates, since the hours the labor works often differs from the hours the associated equipment works. What is important is that the user define his convention and then uses it consistently. For example, in felling, the power saw rarely works more than 4 hours per day, even though the cutter may work 6 or more hours and may be paid for 8 hours, including travel. If felling production rates are based upon a six-hour working day, with two hours of travel, the machine rate for an operator with power saw should consider 4 hours of actual power saw use and eight hours of labor for six hours of production.

3.7 Variable Effort Cycles

The concept that men or equipment work at constant rates is an abstraction that facilitates measurements,

record keeping, payments and analysis. However, there are some work cycles which require such variable effort that it is more useful to construct machine rates for parts of the cycle. One important case is the calculation of the machine rate for a truck. When a log truck is waiting to be loaded, is being loaded, and is being unloaded, its fuel consumption, tire wear, and other running costs are not being incurred. For the standing truck, a different machine is often constructed using only the fixed cost and the labor cost for this part of the cycle. Part or all of the truck depreciation may be included.

If a single machine rate were used to estimate the unit cost for truck transport and this value were converted to a ton-km cost or $/m^3/km$ cost without removing the "fixed" cost of loading and unloading, then the "variable" cost of transport would be overestimated and could lead to erroneous results, when choosing between road standards or haul routes.

3.8 Animal Rates

The calculation of the animal rate is similar to the machine rate, but the types of costs differ and merit additional discussion.

3.8.1 Ownership Cost

The ownership cost includes the investment cost of the animal or team, harness, yoke, cart, logging chains and any

other investments with a life more than one year. Other ownership costs include the upkeep of the animals.

The purchase price of the animal may include spare animals if the working conditions require that the animal receive rest more than overnight, such as every other day. To allow for the possibility of permanent injury, the animal purchase price may be increased to include extra animals, if the period for animal training is long. In other cases, accidents can be allowed for in the insurance premium. The salvage cost for the animal has the same definition as for a machine but in the case of the animal, the salvage value is often determined by its selling value for meat. Average annual investment, interest on investment, and any taxes or licenses are treated the same as for machines. To find the total ownership costs for the animals, the ownership costs for the animal, cart, harness, and miscellaneous investments can be calculated separately and the hourly costs added together since they usually have unequal length lives.

Animal support costs which do not vary directly with hours worked include pasture rental, food supplements, medicine, vaccinations, veterinarian services, shoes, ferrier services and any after-hours care such as feeding, washing or guarding. It could be argued that food and care requirements are related to hours worked and some part of these costs could be included in operating costs. Pasture area can be estimated by dividing the animal consumption

rate by the forage production rate. Food supplements, medicine, vaccination, and veterinarian schedules can be obtained from local sources such as agricultural extension agents.

3.8.2 Operating Costs

Operating costs include repair and maintenance costs for harnesses, carts, and miscellaneous equipment.

3.8.3 Labor Costs

The labor cost in the animal rate is for the animal driver. For full year operations 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.

3.9 Examples

The Appendix has examples of machine rates for a power saw, a tractor, a truck and a team of oxen. The examples show the flexibility in format to meet alternative needs.

4. ESTIMATING ROAD CONSTRUCTION UNIT COSTS

4.1 Introduction

The unit cost of road construction in dollars per kilometer is the sum of the subunit costs of the road construction activities. Road construction unit costs are estimated by dividing the machine rates by the production rates for the various activities involved in the road construction activity. The various road construction activities considered here are surveying, clearing and grubbing, excavation, surfacing, and drainage.

4.2 Surveying

Surveying and staking costs vary considerably, depending on type and size of the job, access, terrain, and job location. One method of estimating production is to estimate the number of stakes which can be set per hour and the number of stakes which must be set per kilometer. For example, assume about 15 stakes can be set per hour with a two-man crew with the preliminary survey line already in place. A typical five-point section consists of two reference stakes, two slope stakes, and one final centerline stake.

The surveying production rate in km per hour is equal to the number of stakes the crew sets per hour, divided by the number of stakes required per km.

Example:

A survey crew is setting 300 stakes per km at a rate of 15 stakes per hour. The cost of a survey crew including transport is $10 per hour.

$$P = 15/300 = .05 \text{ km/hr}$$

$$UC = 10/.05 = \$200/km$$

4.3 Clearing and Piling

The clearing and piling cost can be calculated by estimating the number of hectares of right-of-way to be cleared and piled per kilometer of road. The clearing and piling production rate in hours per km is the hectares per hour which can be cleared and piled per hour divided by the number of hectares per km to be cleared and piled. Clearing can be accomplished in a number of ways, including men with axes or power saws. Merchantable logs may be removed by skidder or tractor and the remainder piled by tractor for burning or decay. Felling rates and skidding rates for logging can be used for determining the cost of the removal of merchantable logs.

On gentle terrain, if a wide right-of-way is being cleared to permit sunlight to dry the road surface after frequent rains, the project might be estimated as a land clearing project. A method for estimating the total time per hectare required to clear, grub, and pile with a tractor and shearing blade on gentle terrain is shown below.

4.3.1 Mechanized Clearing

The clearing time will depend upon the size of the tractor and the number and size of the trees. The clearing time, Tc, in machine hours per hectare is

$$Tc = (X/60)(AB + M_1N_1 + M_2N2 + M_3N_3 + M_4N_4 + DF/30) .$$

Where X is the hardwood density factor, A is the vine density factor, B is the base time per hectare, M is the minutes per tree in each diameter range, N is the number of trees per hectare in each diameter range, D is the sum of the diameters of all trees per hectare larger than 180 cm, and F is the minutes per 30 cm of diameter to cut trees with diameters greater than 180 cm.

Table 4.1. Production factors for felling with Rome KG blade.

Tractor GHP	Factors	Diameter Range, cm				
		30-60	60-90	90-120	120-180	>180
	B	M_1	M_2	M_3	M_4	F
140	100	0.8	4.0	9.0	-	-
200	62	0.5	1.8	3.6	11	3.6
335	45	0.2	1.3	2.2	6	1.8
460	39	0.1	0.4	1.3	3	1.0

X = 1.3 if the percentage of hardwoods >75 and X = 0.7 if percentage of hardwood is < 25, X=1 otherwise.

A = 2.0 if number of trees/ha > 1500 and A= 0.7 if number of trees/ha < 1000, A=1.0 otherwise. Increase value of A by 1.0 if there are heavy vines.

For hectares which must be cleared and where stumps must be removed (grubbed), multiply the total time for clearing by a factor of 1.25.

4.3.2 Mechanized Piling

To compute piling time, when a rake or an angled shearing blade is used, an equation to calculate the piling time per hectare, Tp, is

$$Tp = (1/60)(B + M_1N_1 + M_2N2 + M_3N_3 + M_4N_4 + DF/30)$$

where the variables are defined as above. Table 4.2. shows the coefficients for piling when stumps have not been removed.

Table 4.2. Production factors for piling in windrows.

Tractor GHP	Factors	Diameter Range, cm				
		30-60	60-90	90-120	120-180	>180
	B	M_1	M_2	M_3	M_4	F
140	185	0.6	1.2	5.0	-	-
200	135	0.4	0.7	2.7	5.4	-
335	111	0.1	0.5	1.8	3.6	0.9
460	97	0.08	0.1	1.2	2.1	0.3

When piling includes piling of stumps, increase the total piling time by 25 percent.

Example:

Five hectares per km of right-of-way are being cleared for a road (extra width is being used to help the road dry after rains). Of the five hectares, 1.2 hectares per km will need to have the stumps removed. Tractor machine rate is $80 per hour. All material will be piled for burning. Work is being done by a 335 HP bulldozer. The average number of trees per hectare is in the following table.

TABLE 4.3 Data for clearing, grubbing and piling example.

Number of trees < 30 cm	Diameter Range, cm 30-60 N_1	60-90 N_2	90-120 N_3	120-180 N_4	>180 D
1100	35	6	6	4	60

Note: Less than 1 tree >180 cm per hectare.

$$Tc = (X/60)(AB + M_1N_1 + M_2N2 + M_3N_3 + M_4N_4 + DF/30)$$

$$Tc = (1/60)[(1)(45)+(.2)(35)+(1.3)(6) +(2.2)(6)+(6)(4)+(60)(1.8)/30] = 1.68 \text{ hr/ha}$$

$$Tp = (1/60)(B + M_1N_1 + M_2N2 + M_3N_3 + M_4N_4 + DF)$$

$$Tp = (1/60)[111+(.1)(35)+(.5)(6)+(1.8)(6) +(3.6)(4)+(.9)(60)/30] = 2.41 \text{ hr/ha}$$

$$\text{Total tractor time/km} = 5(1.68+2.41) + 1.2(.25)(1.68+2.41)$$

$$= 21.7 \text{ hr/km}$$

$$P = 1/21.7 = .046 \text{ km/hr}$$

$$UC = 80 \times 21.7 = \$ 1736/\text{km}$$

4.4 Earthwork

The earthwork cost is calculated by estimating the number of cubic meters of common material and rock which must be moved to construct the road. The earthwork production rate is calculated as the cubic meters per hour which can be excavated and placed divided by the number of cubic meters per km to be excavated.

Local road construction superintendents can often directly estimate the number of meters per hour that their equipment can build road just by looking at the topography. The engineer's method is to estimate the number of cubic

meters to be excavated. Formulas and tables for calculating earthwork quantities as a function of sideslope, road width, cut and fill slope ratios are available, as are production rates for common bulldozers and hydraulic excavators.

For example, a 6.0 meter subgrade on a 30 percent slope with a 1.5:1 fill slope and 0.5:1 cut slope with a one foot ditch and a 20 percent shrinkage factor would be approximately 2100 bank cubic meters per km for a balanced section.

An average production rate in common material from an equipment performance handbook might be 150 bank cubic meters per hour for a 300 hp power shift tractor with ripper. The tractor cost is $80/hr. The rate of excavation would be

$$P = (150\ m^3/hr)/(2100\ m^3/km) = .07\ km/hr$$

$$UC = 80/.07 = \$1143/km$$

If the earthwork is not being placed or sidecast within 50 meters of the cut, the production rate for pushing the material to the placement location must be made. Scrapers or excavators and dump trucks may be used.

Excavation rates in rock vary with the size of job, hardness of rock and other local conditions. Often there is a local market price for blasting. Estimates of blasting production can be made by knowing the size of equipment and the type of job. For example, a 10 cm track-mounted drill and 25 cubic meter per minute air-compressor may prepare 40

cubic meters per hour for small, shallow blasts and 140 cm per hour for larger, deeper blasts including quarry development to produce rock surfacing. A major cost will be explosives. For example, 0.8 kg of explosive such as Tovex may be used per cubic meter of rock at a cost of approximately $2 per kg.

4.5 Finish Grading

Finish grading of the subgrade can be estimated by determining the number of passes a grader must make for a certain width of subgrade and the speed of the grader. This number can be converted to the number of hours per hectare of subgrade. For example, a 120 hp grader may require about 10 hours of productive machine time without delays per hectare of subgrade or 0.1 hectares per hour. Similarly, the rate of pulling ditches per kilometer can be estimated. The production rate for final grading of a 6.0 meter subgrade would then be,

$$P = (0.1 \text{ ha/hr})/(0.6 \text{ ha/km}) = .17 \text{ km/hr.}$$

If the grader cost is $20/hr, the unit cost of grading is

$$UC = 20/.17 = \$118/\text{km.}$$

4.6 Surfacing

Surfacing costs are a function of the type of surfacing material, the quantity of surfacing material per square meter, and the length of haul. Local information is the best guide in constructing surfacing costs, due to the wide range of conditions that can be encountered.

Natural gravel from streams may require only loading with front-end loaders directly to dump trucks, transporting, spreading, and may or may not be compacted.

Laterite may be ripped by crawler tractor, loaded by front-end loader, transported, spread and grid-rolled with a sheeps-foot roller to produce a sealed running surface.

Rock may have to be blasted, loaded into crushers(s), stockpiled, reloaded, transported, spread, and compacted.

The costs for each of these operations can be developed by estimating the equipment production rates and machine rates. For example, a relatively complex surfacing operation requires developing a 20,000 cubic meter solid rock source (26,400 cubic meters in the road prism) to surface 26.4 km of road. The operation will include shooting and crushing, loading, transporting, and spreading rock as follows:

To open up rock source use data from clearing and common excavation:

(a) To clear and excavate rock:

Equipment	Machine hours	Machine Rate	Cost
Tractor	27	72.00	1944.00

Cost per cubic meter solid rock = $0.10

(b) To drill and blast at a production rate of 140 cubic meters per hour:

Equipment	Machine hours	Machine Rate	Cost
Drills	1.0	60.00	60.00
Compressor	1.0	55.00	55.00
Explosives	0.8 kg x $2.0/kg x 140 m^3		224.00
			339.00

Cost per cubic meter solid rock = $2.42

(c) To crush 225 tons per hour (2.6 tons/solid cubic meter):

Equipment	Machine hours	Machine Rate	Cost
tractor	0.5	72.00	36.00
loader	1.0	90.00	90.00
crusher	1.0	90.00	90.00
stacker	1.0	15.00	15.00
generator	1.0	20.00	20.00
			251.00

Cost per cubic meter solid rock = $2.90

(d) To load, transport, spread 20,000 cubic meters of rock:

1 truck x 3 loads/hr x 20 tons/load x m^3/2.6 ton
= 23 m^3/hr

If 4 trucks are used:

Equipment	Machine hours	Machine Rate	Cost
4 trucks	872	50.00	43,600
loader	218	90.00	19,600
tractor	218	72.00	15,700
grader	20	60.00	1,200
			80,100

Cost per cubic meter solid rock = $4.01

The total unit cost per cubic meter of rock spread on the road is as follows.

Activity	$/cu m solid	$/cu m prism	$/km
Develop pit	0.10	0.08	80
Drill and blast	2.42	1.83	1830
Crush	2.90	2.20	2200
Load, transport, and spread	4.01	3.03	3030
	9.43	7.14	7140

Equipment balancing plays an important role in obtaining the minimum cost per cubic meter for surfacing. In some areas, market prices for various types of surfacing may be standard and tradeoffs between aggregate cost, aggregate quality, and hauling distance will have to be evaluated. Since surfacing is often expensive, a surveying crew is sometimes added to stake and monitor the surfacing operation.

4.7 Drainage

Drainage costs vary widely with the type of drainage being installed. The costs of drainage dips (water bars), culverts, and bridges are often expressed as a cost per lineal foot, which can then be easily applied in road estimating. Local values for cost per lineal foot for culverts and different types of bridges are generally available. If not, constructed costs can be found by using time study data. An example is given below:

A 45-cm culvert, 10 meters long, is being installed. Experience indicates that a small backhoe and operator, and two laborers can install 3 culverts per day. The culvert crew uses a flat-bed truck to transport themselves and the pipe each day.

To install 3 culverts:

Equipment	Machine hours	Machine Rate	Cost
backhoe	6	50.00	360.00
truck	9	12.00	108.00
Pipe cost	30 meters x $15/meter		450.00
			918.00

Cost per lineal meter of culvert = $30.60 per meter

Alternatively, the cost could be stated as $306 per culvert or if there were an average of 4 culverts per km, then $1224 per km.

5. ESTIMATING LOGGING UNIT COSTS

5.1 Introduction

Logging unit costs are estimated by dividing machine rates by the production rates for the various logging activities. Logging components considered here are felling, bucking, skidding, loading, and transport.

5.2 Felling and Bucking

The major variables in felling and bucking are the tree diameter and the number of bucking cuts after felling. An example of the time to fell and buck a tree is

$$T = a + b\ D^2 + c\ B$$

where T is the time per tree in minutes, b is the minutes per unit diameter and the D is the diameter, c is the time per bucking cut and B is the number of bucking cuts. The coefficient a is the time per tree that is not related to diameter such as walking between trees or preparing to cut. Sometimes terrain and brush are taken into account by using equations of the form

$$T' = (1+f)\ T$$

where f is an adjustment factor for terrain or brush. The production rate, P is in cubic meters per hour and can be expressed as

$$P = V/T$$

where V is the volume per tree and T is the time per tree. The unit cost of felling is

$$UC = C/P$$

where C is the machine rate for felling and bucking and P is the production rate.

Example:

A power saw and operator cost $5.00 per hour and the time to fall and buck a tree is

$$T = 4.0 + .005\ D^2 + 2.0\ B.$$

For a tree with volume 6 m^3, dbh of 80 cm and 1 bucking cut:

$$T = 4.0 + .005\ (80)(80) + 2.0\ (1) = 38.0 \text{ min} = 0.63 \text{ hr}$$

$$P = V/T = 6/0.63 = 9.5\ m^3 \text{ per hr}$$

$$UC = 5/9.5 = \$0.52 \text{ per } m^3$$

For a tree with volume 1.25 m^3, dbh of 40 cm and 1 bucking cut:9

$$T = 4.0 + .005\ (40)(40) + 2.0\ (1) = 14.0 \text{ min} = 0.23 \text{ hr}$$

$$P = V/T = 1.25/.23 = 5.4\ m^3 \text{ per hr}$$

$$UC = 5/5.4 = \$0.93 \text{ per } m^3$$

5.3 Skidding

Skidding production is estimated by dividing the volume per load by the minutes per roundtrip. The roundtrip time, T, is composed of travel unloaded, hooking, travel loaded, and unhooking.

$$T = a\,N + b_1\,x_1 + b_2\,x_2$$

where a is the combined time for hooking and unhooking per log, b_1 is the minutes per meter for unloaded travel, b_2 is the minutes per meter for loaded travel, x_1 is the distance from the landing to load pickup point and x_2 is the distance from the load pickup point to the landing. If the outhaul distance and inhaul distance are the same, the roundtrip time can be expressed as

$$T = a\,N + b\,x$$

where b is the minutes per roundtrip distance and x is the one-way distance. The coefficient b is calculated as

$$b = \frac{v_1 + v_2}{v_1\,v_2}$$

where v_1 is the travel speed unloaded and v_2 is the travel speed loaded.

Example:

A skidder is bringing in 3 logs with a volume of 4 m^3. The unloaded velocity is 200 meters per minute and the loaded velocity is 100 meters per minute. The hook time is 1.5 minutes per log and the unhook and decking time is 1.1 minutes per log. The skidding distance is 300 m. The machine rate for the skidder and crew is $40 per hour.

$$T = (2.6)(3) + 300/200 + 300/100 = 12.3 \text{ min} = .21 \text{ hr}$$

$$P = 4/.21 = 19.5 \text{ m}^3 \text{ per hour}$$

$$UC = 40/19.5 = \$2.05 \text{ per m}^3$$

alternatively,

$$b = (200 + 100)/[(200)(100)] = .015 \text{ min/m}$$

$$T = (2.6)(3) + .015\ (300) = 12.3 \text{ min.}$$

The cost of hooking, unhooking and decking is

$$UCF = (C/60)(aN)/V$$

$$UCF = (40/60)(3)(2.6)/4 = \$1.30 \text{ per m}^3$$

The cost per cubic meter of wood per unit distance (measured one-way), UCV, is

$$UCV = (C/60)(b)/V$$

$$UCV = (40/60)(.015)/4 = \$0.0025/\text{m}^3/\text{m}.$$

At a skidding distance of 300 meters

$$UC = UCF + UCV = 1.3 + (.0025)(300) = \$2.05 \text{ per m}^3$$

The same method can be used to estimate the skidding costs with agricultural tractors and trailers, animals, or with cable systems.

Let's try another example, this time with oxen.

A team of oxen brings in one log with a volume of 0.8 m^3. The unloaded velocity is 30 meters per minute and the loaded velocity is 30 meters per minute. The hook time is 2.0 minutes and the unhooking and watering time is 5

minutes. The skidding distance is 100 meters. The rate for the oxen and driver is $3.00 per hour.

$$T = (7) + 100/30 + 100/30 = 13.7 \text{ min} = .23 \text{ hr}$$

$$P = .8/.23 = 3.48 \text{ m}^3 \text{ per hour}$$

$$UC = 3/3.48 = \$0.86 \text{ per m}^3$$

5.4 Loading

Loading production is estimated by dividing the volume per cycle by the minutes per cycle.

The time per log for loading single logs is often as simple as

$$T = a$$

where a is the time per cycle.

Example:

A truck is being loaded by hydraulic knuckleboom loader, which is loading 1.0 m^3 logs individually at an average rate of 2 logs per minute. To prepare for loading the trucks, however, the loader spends 30 minutes per hour in sorting logs. The cost of the loader is $40/hr. What is the loading production rate and cost?

When the loader is actually loading logs, the production rate is

$$P = (1.0)/.5 = 2.0 \text{ m}^3/\text{min} = 120 \text{ m}^3/\text{hr}$$

but the loading production per machine hour is 60 m^3.

The cost of log sorting can either be shown as a reduced effective rate of log loading or as a separate unit cost of the total logging unit cost. Of course, if the loader operator was just trying to keep busy, a superior alternative might be to shut down the loader between trucks. If the sorting cost is included in the loading cost the unit cost of loading is then

$$UC = 40/60 = \$0.67 \text{ per } m^3$$

5.5 Truck Transport

The method of estimating truck production depends upon the purpose of the analysis. If truck production is being calculated for the purpose of determining the number of trucks needed for truck haul, then the average truck load is divided by the total roundtrip time, including unloaded travel time, loading time, loaded travel time, and unloading time. The calculation is similar to that for skidding with the roundtrip travel time, T, expressed as

$$T = a + b_1 x_1 + b_2 x_2$$

where a is the combined time in hours for loading and unloading, b_1 is the hours per km for unloaded travel, b_2 is the hours per km for loaded travel, x_1 is the distance from the landing to load pickup point and x_2 is the distance from the load pickup point to the landing. If the outhaul distance and inhaul distance are the same, the roundtrip time can be expressed as

$$T = a + b x$$

where b is the hours per roundtrip km and x is the one-way distance. The coefficient b is calculated as

$$b = \frac{v_1 + v_2}{v_1 v_2}$$

where v_1 is the travel speed unloaded and v_2 is the travel speed loaded.

Example:

A 22-ton truck carries an average of 30 m^3 per trip. The haul route is 35 km. The unloaded travels 40 km per hour and the loaded travels 25 km per hour. The combined waiting and loading time is 30 min per load and the combined waiting and unloading time is 20 min per load. What is the production per hour? The cost per truck standing hour is $20 and the cost per truck running hour is $30.

$$T = (30+20)/60 + 35/40 + 35/25 = 3.11 \text{ hrs}$$

$$P = 30/3.11 = 9.65 \ m^3/hr$$

The "fixed" unit cost of truck standby for loading and unloading is:

UFC = ($20/hr)(30+20 min)/60 min/hr/30 m^3 = $0.56 per m^3

The "variable" unit cost of truck travel is:

UVC = ($30/hr)(35/40 hr + 35/25 hr)/30 m^3 = $2.28 per m^3

or expressed on a ton-km basis:

UVC = ($30/hr)(35/40 hr + 35/25 hr)/22 t/35 km = $.089 t-km

The total unit cost of truck haul is:

UC = UFC + UVC = 0.56 + 2.28 = $2.84 per m^3

A P P E N D I C E S

MACHINE OPERATING COST ESTIMATE [1/]

Machine:	Description - McCulloch Pro Mac 650 Power saw			
	Motor cc	60	Delivered Cost	400
	Life in hours	1000	Hours per year	1000
Fuel:	Type	Gas	Price per liter	0.56
Oper:	Rate per day	5.50	Social Costs	43.2 %

Cost Component		Cost per hour
(a) Depreciation	$= \frac{\text{delivered cost} \times .9}{\text{life in hours}}$	0.36
(b) Interest @ 10%	$= \frac{\text{delivered cost} \times .6 \times \text{rate}}{\text{average hours per year}}$	0.03
(c) Insurance	$= \frac{\text{delivered cost} \times .6 \times .03}{\text{average hours per year}}$	0.01
(d) Taxes	$= \frac{\text{annual tax amount}}{\text{average hours per year}}$	--
(e) Labor [2/]	$= \frac{\text{labor cost per year} \times (1+f)}{\text{average hours per year}}$	1.89
	where f = social costs of labor as decimal	
	Sub-Total	2.29
(f) Fuel	= 0.86 l/hr x .95 x CL + 0.86 l/hr x .05 x CO	0.70
	where CL = cost of gas, CO = cost of oil	
(g) Lub oil for bar and chain	= Fuel cons/2.5 x CO	0.45
(h) Servicing and repairs	= 1.0 x depreciation	0.36
(i) Chain, bar, and sprocket		0.67
(j) Other		0.22
	Total [3/]	4.69

1/ All costs are in US$.
2/ Labor based on 240 days per year.
3/ Add 0.04 if standby saw is purchased.

MACHINE OPERATING COST ESTIMATE 1/

Machine:	Description - CAT D-6D PS			2/
	Gross hp	140	Delivered Cost	142,000
	Life in hours	10,000	Hours per year	1000
Fuel:	Type	Diesel	Price per liter	0.44
Oper:	Rate per day	12.00	Social Costs	43.2 %
Help:	Rate per day	5.00	Social Costs	43.2 %

Cost Component		Cost per hour
(a) Depreciation	$= \frac{\text{delivered cost} \times .9}{\text{life in hours}}$	12.78
(b) Interest @ 10%	$= \frac{\text{delivered cost} \times .6 \times \text{rate}}{\text{average hours per year}}$	8.52
(c) Insurance @ 3%	$= \frac{\text{delivered cost} \times .6 \times \text{rate}}{\text{average hours per year}}$	2.56
(d) Taxes @ 2%	$= \frac{\text{delivered cost} \times .6 \times \text{rate}}{\text{average hours per year}}$	1.70
(e) Labor	$= \frac{\text{labor cost per year} \times (1+f)}{\text{average hours per year}}$ 3/	5.84
	where f = social costs of labor as decimal	
	Sub-Total	31.40
(f) Fuel	= .20 x GHP x LF x CL	6.65
	where GHP = gross engine horsepower CL = fuel cost per liter LF = load factor (.54)	
(g) Oil and grease	= 0.10 x fuel cost	0.67
(h) Servicing and repairs	= 1.0 x depreciation	12.78
(i) Other (cable, misc)	=	5.00
	Total	56.50

1/ All costs are in US$
2/ With blade, ROPS, winch, integral arch
3/ Labor based upon 240 days per year

MACHINE OPERATING COST ESTIMATE [1/]

Description - Pair of oxen for skidding

	Gross hp	--	Delivered Cost	2,000
	Life in years	5	Days per year	125
Labor	Rate per day	7.00	Social Costs	43.2 %

Cost Component		Cost per day [2/]
(a) Depreciation	= delivered cost x .65 / life in days	2.08
(b) Interest @ 10%	= delivered cost x .6 x rate / average days per year	0.96
(c) Taxes	= annual tax amount / average days per year	--
(d) Pasture	= pasture rental for year / average days per year	1.10
(e) Food supplements		1.36
(f) Medicine and veterinary services		0.27
(g) Driver	= labor cost per year x (1+f) / average days per year [3/]	9.62
	where f = social costs of labor as decimal	
(h) After-hours feeding and care		2.62
(i) Other (harness and chain)		1.00
	Total	19.01

1/ All costs are in US$
2/ Oxen sold for meat after 5 years
3/ Driver works with two pair of oxen, 250 day year

MACHINE OPERATING COST ESTIMATE 1/

Machine:	Description -- Ford 8000 LTN				
	Gross hp	200	Delivered Cost		55,000
	Life in hrs	15,000	Hrs per year		1500
Fuel:	Type	Diesel	Price per liter		.26
Tires:	Size 10 x 22	Type Radial		Number	10
Labor:	Rate per day	12.00	Social Costs		43.2 %

Cost Component		Cost per hr
(a) Depreciation =	$\frac{\text{delivered cost x .9 - tires}}{\text{life in hrs}}$	3.07
(b) Interest @ 10% =	$\frac{\text{delivered cost x .6 x rate}}{\text{average hrs per year}}$	2.20
(c) Insurance @ 3% =	$\frac{\text{delivered cost x .6 x rate}}{\text{average hrs per year}}$	0.66
(d) Taxes @ 2% =	$\frac{\text{delivered cost x .6 x rate}}{\text{average hrs per year}}$	0.44
(e) Labor =	$\frac{\text{labor cost per year x (1+f)}}{\text{average hrs per year}}$	3.30 2/
where f = social costs of labor as decimal		
	Standing Cost Sub-Total	9.67
(f) Fuel =	.12 x GHP x CL	6.24
where CL = cost per liter for fuel		
(g) Oil and grease = 0.10 x fuel cost		0.62
(h) Servicing and repairs = 1.5 x depreciation		4.61
(i) Tires =	$1.2 \times \frac{\text{replacement cost}}{1500 \text{ hrs}}$	2.40
(j) Other (chains, tighteners)		0.20
	Traveling Cost Total	23.74

1/ All costs are in US$
2/ Labor is for 240 days plus 20% overtime.