

planning forest roads and harvesting systems

**forest logging and transport branch
forest industries division
forestry department**

**FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome 1977**

First printing 1977
Second printing 1979

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ISBN 92-5-100407-2

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FOREWORD

The Forest Logging and Transport Branch of the Forestry Department, FAO, has prepared a series of manuals and documents on specific problems related to logging, transport and forest road construction. The latest in this series is the present document "Planning Forest Roads and Harvesting Systems".

This manual is based on the work of Mr. J.A. McNally, Logging Engineer, Canada, in collaboration with the Forest Logging and Transport Branch.

The objective of this publication is to present in a comprehensive form the trends in the development of new logging techniques and their impact on the planning of forest operations.

Especially, the questions of layout of forest roads in relation to mechanized harvesting systems, in flat and undulating terrain, are described in detail. Cost and production formulae are presented for the different logging machinery taking into consideration the influence of the environment on the productive working hours for men and machines.

The mention of specific companies or of their products or brand names does not imply any endorsement or recommendation on the part of the Food and Agriculture Organization of the United Nations.



Surveying a forest road with a clinometer

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Conversion factors

1 inch	=	2.540 cm
1 foot	=	0.3048 m
1 yard	=	0.9144 m
1 chain	=	20.12 m
1 mile	=	1.609 km
1 sq. yd	=	0.83613 m ²
1 sq. mile	=	2.59 km ²
1 cu ft	=	0.02832 m ³
1 cu yd	=	0.765 m ³
1 cunit	=	2.8832 m ³
1 cord	=	2.55 m ³
1 gal (Imp.)	=	4.546 litres
1 pound	=	0.4536 kg

Note: \$ in Appendix I refers to Canadian \$

1. INTRODUCTION

A major forest operation is a complex enterprise. It requires that much planning be done and many decisions taken before it is set in motion. A long term management plan for the area should be developed, based on an inventory of the forest resources, topographic features, soil conditions and existing infrastructure. The plan should outline the location of the major forest road system for the area as well as the most important secondary roads and the logging system or systems proposed to be used in the harvesting.

The term "forest roads", in the context of this study, means those roads built in the forest to serve the growing and harvesting of the forest crop. Much has been published concerning the design, construction and maintenance of public highways, but little concerning forest roads and their relation to the harvesting systems which they must serve and the conditions which they should satisfy in doing so.

Forest operations may involve the harvesting of natural forests, the reforestation of logged-over areas or the afforestation of non-forest lands as well as the growing to maturity and the harvesting of these man-made forests.

The operations manager normally must choose between clear cutting and selective cutting unless restricted by governmental regulation or economic considerations. He must decide respecting the type of tools and machines to be used in cutting and transporting the logs to roadside, the size and configuration of hauling equipment to be used and therefore the standard of haul road to be constructed.

2. SCOPE

This manual seeks to provide guide lines which will help the forest manager to select the proper forest road standard and density or spacing and the logging system which will help to produce the lowest overall delivered wood cost, whether the operation is conducted in natural or man-made forests in a temperate or a tropical zone. The principles which are applicable in one region or to one logging system will apply normally in another.

The manual does not deal with roads hard surfaced with concrete or asphaltic (bituminous) compounds, nor does it deal at length with cable yarding on steep slopes. A manual dealing with such logging systems is scheduled for publication by FAO in 1977 or 1978. Maximum attention is given to those logging systems which use skidding or forwarding to move the wood from stump area to roadside since these are the most commonly used methods where grades do not exceed 50 - 60 %. Harvesting systems employing ground transportation methods to move wood to roadside are almost universally more economical than cable yarding systems where there is a choice between the two.

It also deals at some length with the method of estimating the operating cost of logging equipment because such cost values are often distorted by omission of or failure to recognize items which should be included.

3. COSTING LABOUR AND MACHINES ^{1/}

3.1 General

The cost of a forestry project, whether it be road construction, tending a plantation or harvesting wood, includes labour, machinery and materials and hand tools. The determination of the true costs of labour and machine operation should be well understood as their use

^{1/} This is largely a revision of Chapter 5 in FAO Manual "Harvesting Man-Made Forests in Developing Countries".

occurs frequently in this manual. They are discussed below. The cost of each is a function of:

- a) production per unit of time, and
- b) cost of the time unit,

expressed as a cost per unit of production, e.g., as a cost per m^3 .

Any attempt to compare logging systems with the view of selecting the most economical without considering all the factors which form part of the costs of labour and machinery may well lead to a faulty decision. For example, failure to include fringe benefits in the cost of labour or depreciation and interest allowances in machine operating costs would jeopardize the project.

3.2 Labour

The cost of labour comprises direct wages plus the cost of fringe benefits absorbed by the employer. Direct wages may be expressed as a rate per hour, day, week, month or year or as a rate per unit of production (piecework). Fringe benefits include one or more of such items as annual leave or vacation, statutory holidays, accident insurance, family allowances, medical care, schooling, housing, board, meals or food and transportation to and from work places. Some of these are given by labour laws and regulations, some by negotiated labour agreements and some given by the employer as a bonus to direct wages; not all are given in all countries. The cost may vary between 20 and 100 percent of direct labour cost. It must be determined for each situation. When expressed as a percentage of direct wages, such payments are usually much higher in developing countries, where direct wages are usually much lower, than in countries where industry is more fully established. On an operation in Colombia the cost of fringe benefits for a worker in a logging crew amounted to 60 % of his daily direct earnings of US\$ 2.25, i.e., US\$ 1.35 per day. In eastern Canadian logging operations, where wage rates per 8-hour day are around US\$ 40.00 for general labourers and US\$ 48.00 for heavy mobile equipment operators, and pieceworkers net around US\$ 65.00 per day, the cost of fringe benefits runs around 25 - 30 %, i.e., between US\$ 10.00 and US\$ 15.00 per day.

Where no machine is involved the labour cost per unit of production is expressed by the following quotient:

$$\frac{\text{Direct labour cost for period}}{\text{Units of production in period}} \times (1 + f)$$

where f = cost of fringe labour benefits expressed as a percentage of direct labour cost.

The cost of labour involved in operating a machine should be included as part of the machine operating cost.

3.3 Machines

3.3.1 General

There are a number of textbooks available describing various methods of determining the cost of operating equipment. Samset (11) has cited a short method of approximating the operating cost of a machine excluding the operator. The Caterpillar Tractor Company gives data in its performance handbook for estimating the cost of various components in a more conventional method of costing machines. The Logging Committee of the Woodlands Section of the Canadian Pulp and Paper Association recommended a method of costing logging equipment, which is, on the whole, still sound and applicable to all types of logging machines (10). It is designed to recognize and include changes in purchase prices, interest rates, fuel prices, operator rates and, in general, inflationary costs.

These methods differ from one another to various degrees and none is perfect. Some differences in the manner of treating depreciation or capital write-off, operator wages, fringe benefits, etc., are due to management policies and/or accounting practices. Other differences are due to the time unit over which the cost is distributed: the "hour" is normally used, but there are several kinds of hours and care must be taken to specify whether the term refers to shift hours, engine meter hours, or productive machine or effective hours.

Machines used in logging operations are essentially of two types: those which have a major travelling function and those which do not. The principal representative of the former type are hauling trucks and trailers. Other machines, such as crawler tractors, skidders, forwarders, feller-bunchers, loaders, processors and harvesters, may be considered as belonging to the latter type: all have work functions when not travelling. This classification is made principally for the purpose of establishing meaningful hourly operating costs. Whereas the latter type of machine may be costed on a productive machine (PMH) or effective hour basis, hauling rigs should be costed at a rate per travelling hour and a rate per standing hour. This is due to the wide difference in these latter unit time costs and the great variation in terminal times and hauling distances and speeds among hauling operations.

Machines used in logging operations should be costed on the same time unit used in expressing production. In developed countries, for machines other than trucks and trailers this is usually the productive machine hour. For less expensive machines such as power saws less detailed methods and/or a larger time unit may be used.

3.3.2 Time determination for costing purposes

While machine shift time may be broken down into a large number of items for the purpose of studying machine utilisation, reasons for down time and so on, such detail is not necessary for machine costing purposes. For tractors, skidders, loaders and such machines which do not have a major travelling function a simple service recorder is sufficient which will provide the following machine time elements:

- a) shift hours
- b) down time
- c) machine hours, divided if necessary into effective hours (PMH) and non-productive hours.

Sometimes an engine hour meter on such machines is sufficient to establish PMH when the machine is working steadily or the engine is not allowed to idle for prolonged periods.

In the case of hauling rigs, which do have a major travelling function, the time during which the machine is in use - called its in-use or machine hours - may be divided into standing hours and travelling hours. For costing purposes, a hauling rig may be considered to be in use whenever a driver is allocated to it and paid as a driver, and standing hours may be considered to equal in-use hours less travelling hours.

Determination of machine time breakdown for hauling rigs requires a more complex service recorder or tachograph, such as the Argo Kienzle TCO-14, which will provide the following data as well:

- a) distance travelled
- b) travelling time
- c) standing time
- d) beginning and end of shift.

Such recorders also usually show vehicle speeds and engine speeds (rpm), which is useful information for the hauling and maintenance supervisors.

3.3.3 Machine life

For cost estimating purposes the normal life of various types of logging machines may be taken as listed below with some regard to the comments which follow:

<u>Machine</u>	<u>Normal life in hours</u>
crawler tractors	
graders	
feller-bunchers	}
loaders	
processors	
harvesters	
forwarders	
wheeled skidders	
hauling trucks	
powersaws	
	8 000 - 12 000 (normal: 10 000) 1/
	6 000
	15 000 - 20 000 2/
	1 500

The life of mobile logging equipment depends on many factors, such as operating conditions, training of operators and mechanics, availability of replacement parts, obsolescence and, in tropical countries, on the climate. In eastern Canada, life of the larger crawler tractors (175 hp and over) often exceeds 15 000 engine meter hours with little or no increase in repair and maintenance costs during the later stages of life. In some developing countries where operators and mechanics are inadequately trained, or are imbued with a laissez-faire attitude, or where annual usage is so low that obsolescence sets in, tractor life may not exceed 8 000 hours.

Much the same comments may be made concerning graders, feller-bunchers, loaders, processors, harvesters and forwarders. As equipment manufacturers iron out the "bugs" and improve the weak points of their machines as well as servicing in the field, the life expectancy of their machines may be expected to rise. For example, the availability of a group of 50 Koehring harvesters has risen in the past few years from 65 - 70 % to 75 - 84 % and life expectancy is 20 000 engine meter hours. This is a heavy very complex articulated one-man machine which fells, delimbs, tops and bucks the tree into 2.5 m lengths, assembles the logs into an 15 m³ cradle mounted on the rear chassis, transports the wood to roadside and offloads it to truck or trailer or piles it down at roadside, all at the rate of 6 - 9 m³ per productive machine hour.

- 1/ The higher values may be allotted to the heavier and more highly priced machines, such as the Koehring Shortwood Harvester which weighs over 40 tons in unloaded condition and may be expected to be used for upwards of 20,000 hours if well maintained and obsolescence does not set in.
- 2/ In-use hours: 15 000 where hauling distances are long and the rigs spend the major part of the time travelling; 20 000 hours where hauls are so short that about 40-60 percent of round trip time is spent at terminal points (loading and unloading) and delayed for any reason - thus giving a "travelling" life of about 10 000 PMH.

3.3.4 Calculation of machine operating cost

The operating cost of a machine per unit time is the sum of several components:

- a) depreciation or capital write-off
- b) interest on average investment
- c) insurance: public liability and property damage, fire, etc.
- d) annual taxes, including cost of licensing, but not fuel taxes
- e) operating labour
- f) fuel, including fuel taxes
- g) oil and grease
- h) servicing and repairs (except tires for hauling rigs)
- i) tires for hauling trucks and trailers.

These components are discussed in some detail in Appendix H.

The form for calculating machine cost designated as Form A may be used for compiling the estimated operating cost per unit for all equipment including the operator or operators. For most machines this time unit is the PMH. For power saws and such small equipment larger time units such as the "day" may be used. For hauling trucks and trailers the time units should be the "standing hour" and the "travelling hour" for reasons given in section 3.3.1.

The operating cost, excluding the operator, per productive machine hour of those machines, including crawler tractors, which work offroad on the forest floor may be approximated with the formula

$$C = \frac{2.4A}{LE}$$

where C = operating cost in US\$ per productive machine hour excluding operator;

A = acquisition cost in US\$;

LE = life expectancy in productive machine hours, as given in section 3.3.3.

It should be noted that this formula should not be used for hauling rigs and that it should be considered as an approximation for other machines. More exact methods should be used when more precise values are needed. It is, however, a useful tool when making quick comparisons.

3.3.5 Units of machine engine power

The measuring units for power (symbol P) as recommended by International Standard Organization in the SI system (Système International d'Unités) are watts (W), instead of horsepower (hp). However, as the potential users of this manual may be more familiar with hp than with W , and machine specifications still usually are in hp , the unit horsepower as used in U.S.A. and Canada is used throughout in this manual:

$$1 \text{ North American } hp = 33\,000 \text{ ft-lb/min} = 746 \text{ watts}$$

Gross horsepower is the flywheel horsepower of an engine operating with fuel system, water pump, lubricating oil pump and air cleaner only, at SAE standard conditions (J816a) of air temperature and barometric pressure. This is the standard method of calibrating engines in North America and allows engines to be compared on the same basis. Gross horse power is the normal engine hp quoted in North America and is the hp on which fuel consumption is calculated.

Net horsepower is the flywheel hp when the engine is operating with fan, alternator or generator, air compressor (if used) muffler and exhaust system and other optional accessories as well as those listed in the preceding paragraph. Net hp varies, therefore, according to the accessories attached to the engine - normally being between 85 % and 95 % of gross hp .

FORM A
MACHINE OPERATING COST ESTIMATE

Machine: Description _____
Gross hp _____ Delivered Cost _____
Life in Years _____ Hours (days): per year _____ life _____
Fuel: Type _____ Price per litre _____
Tires: Size _____ Type _____ Number _____
Cost of replacement set _____
Operator: Rate per hour (day) _____ Fringe benefits _____ %

<u>Cost Component</u>		<u>Cost per hour (day)</u>
(a) Depreciation	= <u>delivered cost x .90</u> life in hours	_____
(b) Interest	= <u>delivered cost x .60 x interest rate</u> average hours per year	_____
(c) Insurance	= <u>delivered cost x .60 x .03</u> average hours per year	_____
(d) Taxes	= <u>annual tax amount</u> average hours per year	_____
(e) Operating Labour	= <u>labour cost per period x (1 + f)</u> machine hours in period	_____
	where f = cost of labour fringe benefits expressed as % of direct labour cost.	
		Sub-Total 1/
(f) Fuel	= <u>GHP x X x CL</u> where GHP = gross engine horsepower; CL = fuel cost per litre in dollars X = .12 for diesel fuel, .175 for gasoline	_____
(g) Oils and greases	= <u>GHP x X</u> 100 where X = .20 for tractors, skidders, front end loaders and trucks; X = .30 for feller-bunchers and knuckle boom loaders; X = .50 for processors, harvesters and forwarders.	_____
(h) Servicing and Repairs (*)	= <u>Delivered Cost</u> life in hours **	_____
	* include tires except for hauling rigs; ** use lifetime travelling hours in case of hauling rigs.	
(i) Tires for hauling rigs	= .0006 x CST where CST = cost of set of replacement tires.	_____
		Total 2/

1/ This represents the cost per standing hour of a hauling rig.

2/ This represents the cost per travelling hour of a hauling rig, and cost per productive machine or effective hour for other machines.

Countries on the metric system of measurements use the DIN horsepower to rate engines determined according to the Deutsche Normen Standard (DIN 6770), which specifies different air temperatures and barometric pressures than the SAE J816a standards, and different engine accessories as well. The following equivalents may be used:

$$1 \text{ metric hp} = 736 \text{ watts}$$

$$\text{so that } 1 \text{ North American hp} = 1.014 \text{ metric hp.}$$

4. THE STRUCTURAL PARTS OF A ROAD

Forest roads, like major hard-surfaced highways, are engineering structures. All consist of two parts: the subgrade and the pavement. Some terms commonly used for various parts of the structure are shown in Figure 1 (5).

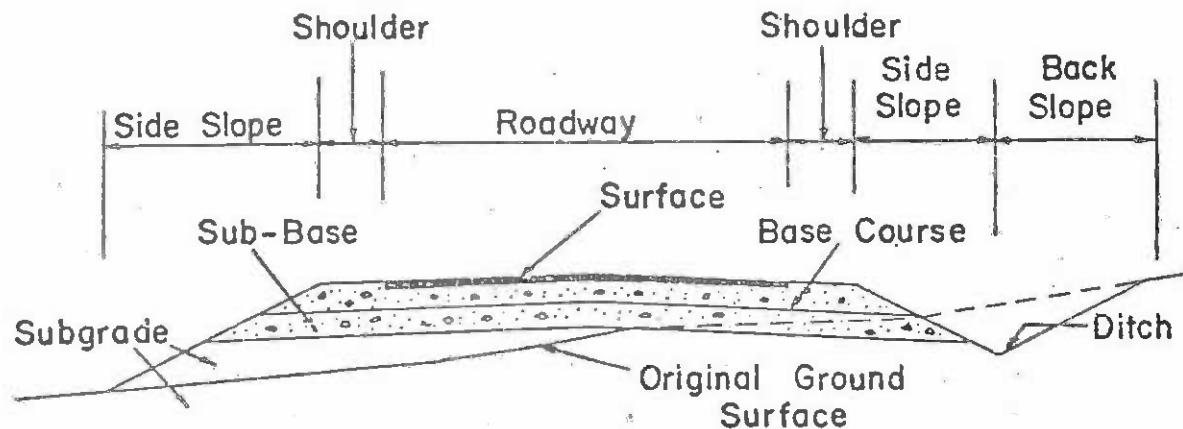


Figure 1 - Typical Road Cross Section

The subgrade consists of soil that occurs naturally at or near the right-of-way. In cut sections, the inner half normally consists of undisturbed soil, the outer part of soil carried, pushed or bulldozed from the "cut" side of the road and compacted. In fill sections, the subgrade is built up with soil bulldozed or otherwise transported from cuts or borrow pits.

The term "pavement" is commonly used to designate the concrete or asphalt layer of a hard-surfaced road. However, from an engineering viewpoint it consists of all the material placed on the road above the subgrade. On a properly engineered road it consists of three layers: the surface course, the base course and the sub-base. Ideally the layers should increase in load-supporting quality from the bottom up; this usually is the situation in high quality public roads built for severe traffic density and long life. However, in many forest roads, a single layer of pit-run gravel may serve for all three courses. On some long term or heavy duty forest roads in Eastern Canada, the pavement, defined as the engineering term, consists of a coarse-crushed gravel (up to 5-6 cm in diameter) base course and a surface course of fine-crushed material (up to 1-2 cm in diameter).

5. SOME GENERAL ROAD CONSIDERATIONS

Most countries specify by law and regulation the maximum gross vehicle loads which may be hauled over the public road system. These restrictions vary according to the load bearing standard to which the road has been constructed, the load capacity of the bridges over which the road passes and the time of year in countries with severe rainy seasons or frost penetration in winter. Maximum legal loads are usually based on tire width (as marked on the tire by the manufacturer), gross axle weights at road contact point and the number and spacing of axles under the vehicle. Some countries disregard axle weights and spacings and base their regulations solely on number of axles and gross vehicle weight.

Most public roads also restrict, except by special limited-time permits, overall dimensions - length, width and height - of the vehicle whether it be a single truck or a combination rig and whether it be loaded or empty. In many countries there are also regulations concerning such items as braking capacity - the ability to control the loaded vehicle on downgrades and/or bring it to a stop within stipulated distances under prescribed road and traction conditions (6).

On the other hand, privately owned roads - and forest roads normally fall within this category - are governed by no such regulations unless restricted by special legislation to protect others with right to use such roads. Vehicles and/or loads are often wider and longer and axle loads much greater than permitted on public roads. In practice on forest roads, gross axle and vehicle loads sometimes exceed not only rated road capacity, but design or rated capacity of tires, axles, drive line or other components of the vehicle. For example, 5-axled semi-trailer rigs are normally allowed to carry gross loads of 32 000 - 36 000 kg on the best public roads but often gross 50 000 - 55 000 kg on private forest roads regardless of road category. While forest roads are not bound by highway weight regulations, every effort should be made to distribute the load to the best advantage among the axles. This matter is referred to in Section C-4 of Appendix C as well.

6. FOREST ROAD CLASSIFICATION

6.1 Classification System

Forest roads may be classified in a variety of ways. The U.S. Forest Service, for example, has devised the forest road classification system given in Appendix A. It is based on maintenance of average running speed. The hauling cost table is worth inspection for several reasons:

- a) it develops hauling costs as a standing cost per unit volume plus a travelling cost per unit volume per unit hauling distance, e.g., a standing cost per cord (or per m³) to cover loading, unloading and delay time, plus a travelling cost per cord/mile (or per m³/km);
- b) it shows that the travelling cost per cord/mile (or per m³/km) decreases in almost inverse proportion to travel speed, thus supporting the method of costing hauling rigs by the hour;
- c) it shows the cost advantage of using tandem-axle over single-axle hauling equipment.

The FAO manual dealing with "Logging and Log Transport in Tropical High Forests" (1) classifies roads into two broad categories: access roads and feeder roads.

This manual uses the classification given in FAO manual on "Harvesting Man-Made Forests in Developing Countries" (2):



Formation of main forest road in hilly terrain

- a) haul roads
 - i) primary or main roads
 - ii) secondary roads
 - iii) feeder roads
- b) strip roads (skidding or forwarding trails)
- c) access roads.

This classification does not, however, give the specifications to which the roads have been or are to be built. The terms indicate only a comparative standard and their relative position in the road network. To permit proper specifications to be drawn up, more information is needed: gross vehicle and axle loads, overall load width, axle type and spacing, planned travel speeds, traffic density and seasonal availability.

Paterson (3) in a study of forest roads in eastern Canada proposed that forest roads, for design purposes, be described according to:

- a) single axle load, or the equivalent obtained by converting tandem or triple axle loads to design single axle loads using Table 33 in Appendix B;
- b) traffic density - the maximum number of design single axle load passes over the road in a 24-hour day during its planned life;
- c) speed - the sustained speed below which the loaded vehicle should not have to drop for reasons other than traffic congestion affected by geometric considerations, such as width, crown, sight distances, etc;
- d) seasonal availability - the period of the year when the road is to be used under normal circumstances;
- e) anticipated life in years.

6.2 Haul Roads

Haul roads are those which form the transportation network over which the logged material is hauled from secondary, or occasionally primary, landings to the mill or to the shipping point if it is disposed of unprocessed. Primary landings are those points in the stump area at which the prepared logs are first assembled or left in place. Secondary landings are those roadside points to which the logs are yarded, skidded or forwarded from the stump area. Normally primary landings lie within 20 m and secondary landings within 400 m of the stump.

The haul road system comprises all classes of haul roads from the main road nearest the mill or shipping point to the feeder roads lying farthest away and forming the fingers of the network. Normally feeder roads lead into secondary roads and secondary roads into main roads. The haul road network may be privately owned or use part of the public highway system and be subject to its regulations. If privately owned, it may or may not be government regulated with respect to vehicle dimensions, gross and axle weights, travel speeds, safety practices, and so on.

It should be common practice to build or to upgrade all haul roads to the standard required to carry fully loaded hauling rigs using them at planned traffic density. However, there are exceptional circumstances when this should not be done; for example, when the soil has a very low bearing capacity, the road is short, wood volume is low, road building materials are scarce and it is obviously more economical to haul part loads (and probably top load to other vehicles at a road of higher standard) than to upgrade the road.

In temperate countries with winter frost penetration, hauling over low bearing soils is often delayed till winter when road building costs are less and full loads can be hauled. When this is done, both optimum feeder road spacings and skidding or forwarding distances become less, resulting normally in a substantial logging cost reduction. The bearing capacity of frozen soil is about 8 - 10 times the normal summer value, depending on the depth of frost penetration. In tropical countries, the hauling programme normally calls for the more critical areas to be hauled during the dry season.

If a public road system is to be used as part of the main haul road and its standard is low, and no plans exist for upgrading it, hauling equipment should not be designed for roads of higher standard, nor should the remainder of the road network be built to greater load carrying capacity.

Main or primary haul roads, where travel speeds are high and traffic is dense, should be sufficiently wide for two hauling rigs (one loaded, the other light) to meet safely at any point without reducing speed, particularly if sight distances are less than desirable. The optimum lane width of such a two-lane road is overall vehicle or load width plus 1.2 m (3); thus the design width of road will depend on the maximum vehicle or load width adopted for the operation. The maximum legal load width, for example, is 8 feet (2.44 m) on most U.S. highways and 8.5 feet (2.59 m) on most Canadian public roads. It was 2.5 m in Sweden in 1969 but was expected to be increased to 2.65 m. Where public roads are not involved, load width for raw forest products may be as much as 3, 3.5 and, in the Pacific Northwest, as much as 4.5 m, necessitating a wider design standard for the road.

In some cases where forest road widths do not meet the required standard, the log bunks are "hinged" on the traffic side (when meeting another vehicle) and swung in for the return trip light to reduce vehicle width and facilitate meeting loaded rigs.

In natural forests in temperate regions, where the rotation period may be between 50 and 100 years, feeder roads are usually temporary structures to be abandoned when logging has been completed.

In plantations, on the other hand, feeder roads should be designed and built as permanent roads capable of carrying the expected gross haul vehicle weights. They are single-lane roads, often with little or no shoulder and sometimes without ditches. Vehicles meet at turn-out points constructed at appropriate intervals. Traffic density is light and/or periods of use are usually brief.

Secondary haul roads are intermediate in width between feeder and main roads, and shoulders are usually narrower than on main roads. Vehicles can meet, but loaded rigs have priority; hauling rigs returning light and other vehicles are expected to move over to the shoulder and, if necessary, stop to allow the loaded rig to pass safely at normal speed.

Haul road design is referred to more fully in Appendix C.

6.3 Feeder Roads

Feeder roads are located in the logging area. They form the extreme or outer ends of the haul road network. They serve to provide worker access to the immediate logging area and to reduce the skidding or forwarding distance. They are strictly temporary roads and normally are abandoned when the area has been logged. They are therefore built to the lowest possible standard commensurate with the purposes which they must serve. On solid ground they are often merely narrow single-lane bulldozed roads with minimum ditches or other drainage facilities and gravelled only where necessary. In soft-low-bearing ground, their use for hauling may have to be restricted to dry weather or frozen ground conditions. Maintenance normally receives little consideration.

Feeder roads should be so located, i.e., spaced, that their construction cost per unit volume of harvested wood served by the road will equal the travelling portion of the skidding or forwarding cost, expressed on the same basis, such as cost per m^3 . This is

called the optimum feeder road spacing or density. Its value depends on several factors: feeder road cost; skidder or forwarder payload, travelling speed and operating cost; stand density or volume harvested per unit area, and factors to compensate for delays and additional travelling due to winding trails, feeder roads and so on. Optimum feeder road spacing is covered more fully in Appendix D.

When skidding or forwarding is done manually or with animals, the same principles of optimum feeder road spacing apply in theory. In practice, however, skidding or forwarding distances, and therefore feeder road spacing, are dictated more by tendency of men and animals to become unduly tired on long carrying or skidding distances. For this reason men usually do not move wood more than 50 - 60 m and animals twice this distance.

6.4 Strip Roads

Strip roads are the skidding or forwarding trails leading from roadside landings back to the stump area. On flat and undulating terrain they normally use the undisturbed forest floor and do not need to be cleared or bulldozed for mechanical skidding or forwarding. In tropical forests crawler tractors with their penetrating capability are often used to clear the skidder trails and to concentrate the logs for the faster and more economical 130 - 180 hp wheeled skidders. The new 300 hp skidders are expected to be able to break through to the felled trees without crawler assistance and deliver their loads direct to roadside.

On steep terrain wheeled skidders and forwarders working on the forest floor must travel straight up and down the slope, i.e., at right angles to the contours. When there are no plateaux where the vehicle can be turned, it must back up the slope to the loading point sometimes assisted by the winch line anchored to a tree or stump, or it must travel to the top of the skidding trail by a bulldozed round-about go-back trail on a more moderate gradient. Under some conditions of firm soil and uniform slopes skidding trails may be bulldozed diagonally across the slope.

6.5 Access Roads

Access roads, in the context of this manual, may be defined as those roads leading to a forest area from labour, material supply and administrative centres. The term is purely functional and does not imply any standard or quality of road.

Some access roads may be or become primary or main haul roads, in which case they should be built to haul road standard. If an access road forms part of a low-standard system, it should be upgraded. If there are no government plans to do so, and the enterprise does not wish to carry out such work and axle loads are restricted, the remainder of the haul road network should not be constructed to a higher load carrying capacity.

7. SITING OR LOCATING FOREST ROADS

7.1 General Procedure

The operation of siting or locating forest roads for the purpose of providing access to a forest and harvesting the crop usually results from an inventory of the resources of the area and a decision to build up a forest-based industry. It should be done with the utmost care. It is essential that grades and curves be kept to a minimum and the road sited to the best advantage. Siting roads on flat and rolling terrain is normally not difficult, but hilly and mountainous terrain may present many problems.

The operation can best be done by:

- a) first reviewing the management and harvesting plan with the view of determining the areas to be served first and therefore the general direction which the roads should take;
- b) checking on road specifications required: minimum radius of curvature, maximum grades, type of hauling equipment, weight of loads to be carried, vehicle speeds, etc.;
- c) choosing a tentative road alignment in the office using stereoscopic aerial photographs and topographic maps and those geological, land classification and soil data that may be available;
- d) checking the tentative route in the field for alignment, grades and curves, soil conditions, drainage water, rock outcrop, side-cut work, stream crossings, availability of gravel and other material, and so on.

Stereoscopic aerial photographs on a scale of 1:10 000 to 1:20 000 are quite suitable for road location work. Photographs on a scale of 1:50 000, commonly used in many countries, will provide some information, but their use will entail much more field work. The preliminary field check work may be done by a crew of two or three men using steel tape (30 m), compass and clinometer, or even by one man pacing and using compass and aneroid barometer.

A photogrammetrist trained in soil identification from stereoscopic aerial photographs should be able to distinguish general soil classes if the photographic scale is large enough, but only examination in the field along the planned road site, verified if necessary by laboratory test, will ensure the engineer of the type of soil on which the road must be built.

7.2 Soil Tests in the Field

Johann Eisbacher (15) has described visual and manual methods which may be used in or near the field with care and experience. Visual methods determine the size of soil particles down to sizes which can be seen with the naked eye (a broad classification only) and the colour of the soil. Manual methods are applied to fine-grained soils to determine:

- a) dry-state stability - do lumps break apart easily when dry or do they resist pressure ?
- b) reaction of the soil, particularly silty ones, to shaking in the hand;
- c) the plasticity of a soil and its silt and clay content by kneading;
- d) the proportion of sand, silt and clay by rubbing a small sample between the fingers, sometimes under water;
- e) the clay content by cutting a moist soil sample with a knife.

Other soil classification systems have been proposed or used on the basis of grain size. For road purposes in North America, perhaps the most frequently used is the AASHO (American Association of State Highway Officials) system, which is based on the ASTM (American Society for Testing and Materials) system of classifying soil particles by size - using sieves of various sizes. This system, along with the plasticity index of the soil determined in the laboratory, furnishes the soil information required for road design.

It is doubtful, however, that most forest roads location work requires more than careful and economical field tests. It must be noted that forest roads must be built to serve the access to and the harvesting of the forest, and there is often little or no choice respecting their location.

7.3 Erosion

Forest roads should be sited to avoid or limit erosion. Erosion is normally caused by rain in wet weather and by wind in dry weather. The larger the raindrops the greater will be the rate of erosion. It may be expected to become serious when rainfall exceeds 25 mm per hour, as often happens in the tropics. Its magnitude, under a given set of conditions, depends on physical properties of the soil, gradient, length of slope and, most importantly, vegetative cover. Silty, light sandy and uncompacted soils erode more readily than heavier clay and well compacted soils.

Erosion occurs on the faces of side cuts and embankments, on the sides, bottom and outfalls of drainage ditches, and on the shoulders and surface of the roadway. Very steep slopes should be avoided, whenever possible, to reduce the area of exposed soil on both the side cut above and the embankment below the road. When constructing forest roads, side cut slopes are often left steep initially and soil slips and eroded material removed from the ditches until the angle of repose has been reached. Clay soils rich in iron or aluminum compounds harden on exposure and may be side cut with steeper faces.

7.4 Some General Principles

Forest roads should be sited, whenever possible, where the properties of the soil indicate good drainage and support qualities. Silts and clays with their high capillarity should be avoided. Unpaved ditches should have a gradient of at least 1% to produce a water flow, otherwise percolation and evaporation must be relied upon to dispose of run-off. Forest roads should avoid water courses with steep gradients which may be difficult to control during rainy or spring run-off seasons without special construction works.

Because forest roads are being opened more and more to public travel for recreation and aesthetic purposes, large cuttings and embankments should be avoided. They mar the scenery and the wounds are slow to heal. The road should therefore follow the terrain as much as specifications will permit.

7.5 Feeder Roads

Feeder roads in those areas where the wood is to be skidded or forwarded to roadside should be so located or sited or spaced that the cost of constructing the feeder road equals the travelling portion of the skidding or forwarding cost, when both costs are expressed on the same basis, e.g., in US\$/m³. This is the optimum spacing. It produces the lowest combined cost of the two operations. Optimum feeder road spacing is discussed in Appendix D.

Sometimes in tropical forests, when only a few of the more valuable species are to be removed, an inventory map is prepared showing the location of each tree to be felled. In theory the same principle of optimum feeder road spacing is applicable, but in practice feeder roads are routed to tap the areas of greatest tree concentration to reduce the skidding distance.

7.6 Sample Evaluation of Alternate Routes

Not only should forest roads be sited to serve the harvesting operation to the best advantage, but the problem of torrent control, erosion, surface water, low capacity soils (such as organic soils and silts) and so on, should be considered. For example, it may be possible to re-route the road to avoid a muskeg area without reducing its efficiency.

This problem may be illustrated by the following example:

a) Input to the problem:

- i) it will cost US\$ 3 000 more to build the road over the muskeg, but this route will save 1.5 min per round trip, resulting in a time saving per year of 60 hours, during which the rig would be standing because no additional trips could be made per shift;
- ii) the road would be used for 5 years;
- iii) hourly operating cost of the hauling rig would be US\$ 20.00 while travelling and US\$ 8.00 while standing;
- iv) there would be no difference in road maintenance cost;
- v) the enterprise pays income tax at the rate of 40 % of net income;
- vi) money is worth 10 %.

b) The question is - which road should be built ?

c) The answer to the problem may be developed as follows:

- i) annual savings realised hauling via the muskeg road:

- hauling - 60 hrs x (US\$ 20 - US\$ 8)	=	US\$ 720
- road maintenance	=	Nil
Total		US\$ 720
- ii) It would appear that the road should be built over the muskeg since US\$ 600 of the capital cost of building the road would be recovered each year, leaving US\$ 120 as profit. However, the time value of money should be considered. The present value of the after-tax income or cash flow for the 5 years would have to be calculated as in (1) or (2) below:

(1) gross annual saving	US\$ 720	
less depreciation (3 000 + 5)	600	
Taxable income		120
less income tax at 40 %	48	
After-tax income		72
plus depreciation	600	
Annual cash flow		US\$ 672

(2) Annual cash flow	
= (600 x .40) + (720 x .60)	= US\$ 672
- d) The present worth of a cash flow of US\$ 672 per year for 5 years at 10 %
= 672 x 3.791 = US\$ 2 550

where 3.791 is the present value factor used to determine the present value of a series of 5 annual payments.

It is evident that the road should be constructed around the muskeg, because the present value of the savings to be realised over 5 years (US\$ 2 550) if the road is built over the muskeg is less than the extra cost of the road (US\$ 3 000).

8. FOREST ROAD CONSTRUCTION

8.1 General Considerations

Forest roads may be built for a variety of purposes of which the most significant is harvesting the forest crop. As such, they are essentially heavy duty haul roads and should be built for this work. Such functions as recreation and wildlife management are secondary. The road standard should be as uniform as can be justified economically throughout the network, but not better than the transport capacity dictates. While the standard may be reduced for the secondary and particularly for the feeder roads, the load-bearing capacity of these roads should not be lowered. This may mean limiting some feeder road hauling to the winter frost or to the dry season. It is fundamental that the transport capacity of a haul road is determined by its weakest section.

Road construction methods vary little throughout the world, the major difference being in the proportionate use of manpower and machines for forming and ditching the road. The alignment of access, primary and most secondary roads should be staked, the degree of staking related to the importance of the road and the difficulty of the terrain. The right-of-way boundaries should be marked. It is also normal practice - and sometimes required by law - to salvage all merchantable wood from the right-of-way before clearing and forming is begun, particularly when bulldozers are being used. Regulations may also require that all trees and shrubbery on the right-of-way be burned or otherwise removed or destroyed along the more permanent roadways for aesthetic or fire prevention reasons or to facilitate the logging process.

Rock drilling and blasting may have to be done, surfacing material may have to be crushed or blasted and crushed, and subgrades in low-lying areas or soils with strong capillarity may have to be stabilised.

8.2 Costs General

Road construction methods and costs vary little throughout the world. The cost of the labour extensive work involved when bulldozers, graders and other heavy equipment are used seems to be largely offset by labour cost when this work is done with manpower in some developing countries where unemployment is high and low-cost manpower is plentiful. When construction is mechanised, the cost of equipment normally amounts to 75 - 80 % of the total cost, labour 10 - 15 % and material 5 - 10 %.

Examples of road construction costs in tropical forests in West Africa, prepared by Estève and Lepitre in 1972, are given in FAO publication "Logging and Log Transport in Tropical High Forest" (1). They referred to roads in gently rolling terrain in Ivory Coast and to easy, average and difficult terrain in Gabon. For 1977 the total costs, excluding supervision and overhead, are given in Table 1.

The haul road specifications adopted by one large pulp and paper company in eastern Canada are shown in metric measurements in Table 2. Feeder roads are not included on the sheet as they are narrow short-term roads built as cheaply as possible, some only for winter hauling over frozen ground. Average construction costs for a number of these primary, secondary and access roads (sometimes used for hauling also) are shown in Table 3. The operating costs of tractors and other machines used in developing these costs include depreciation, interest and labour fringe benefits.

TABLE 1

TOTAL DIRECT COST (EXCLUDING
SUPERVISION AND OVERHEAD) IN US\$ PER KM OF
FOREST ROADS: WEST AFRICA

Type of Road	Access Roads	Primary Roads	Secondary roads Gravelled	Secondary roads Non-gravelled	Skidding Trails
Roadway width including shoulders	10-12 m	8 m	6 m	6 m	4.5 m
Ivory Coast	6 100	3 700	2 200	1 800	520
Gabon:					
(1) easy terrain	12 600	8 800	5 600	4 100	750
(2) average terrain	14 500	9 900	7 100	5 600	1 450
(3) difficult terrain	16 500	12 600	8 600	7 200	1 900

For purposes of cost control during construction and future estimating, road construction labour and machine time and costs are often broken down into and accumulated by their several elements: staking alignment, clearing right-of-way, forming and grading the road including normal ditching, culverts, bridges, rock drilling and blasting, crushing gravel or rock, graveling, stabilising the subgrade and miscellaneous work. Sometimes two or more of these elements may be grouped.

TABLE 2
FOREST ROAD SPECIFICATIONS USED BY ONE LARGE PULP AND PAPER
COMPANY IN EASTERN CANADA

Characteristics	Main Haul Road Standards	Secondary Haul Road Standards	Limit Access Road Standards
<u>Operating Data</u>			
Estimated years of useful life	10	2	20
Estimated quantity hauled yearly ³ m ³	300 000	60 000	N/A
Availability - months per year	10	10	12
Load capacity	70 ton	70 ton	70 ton
Maximum speed	80 km	55 km	80 km
Average speed	70 km	50 km	70 km
Culvert type - wood, steel or concrete	Steel or Concrete	Wood	Steel or Concrete
<u>Width</u>			
Cleared right-of-way	30 m	25 m	30 m
Centre line ditch to centre line ditch	10.6 m	8.7 m	9.4 m
Outer edge of shoulder to outer edge of shoulder	9.7 m	7.9 m	8.5 m
Travelling surface	7.3 m	6.1 m	6.7 m
<u>Alignment</u>			
Maximum grade - loaded	8 %	9 %	8 %
- light	9 %	10 %	8 %
Maximum horizontal degree of curve	8°00'	12°00'	12°00'
Minimum visibility distance	170 m	110 m	170 m
<u>Slopes</u>			
Height of crown	15 cm	13 cm	14 cm
Superelevation - banking	Yes	Yes	Yes
Ditches - rock sub-base	Yes	Yes	Yes
gravel sub-base	Yes	Yes	Yes
sand sub-base	Yes	No	Yes
clay sub-base	Yes	Yes	Yes
<u>Soil</u>			
State road bed - rock gravel sand or clay ²	-	-	-
Minimum depth of gravel surface over			
rock sub-base	15 cm	10 cm	15 cm
gravel sub-base	15 cm	10 cm	15 cm
sand sub-base	30 cm	25 cm	25 cm
clay sub-base	30 cm	25 cm	25 cm
<u>Bridges</u>			
State type - timber or steel	-	-	-
Capacity	70 ton	70 ton	70 ton
Deck width	4.9 m	4.9 m	4.9 m

1/ Where required

2/ State more than one if applicable

Note: Haul road standards shown are for semi-trailer hauling.

TABLE 3

TYPICAL FOREST ROAD CONSTRUCTION
COSTS IN EASTERN CANADA

(Based on specifications given in Table 2)

Item	Type of Road		
	Primary Haul	Secondary Haul	Acess and Haul
	(costs in US\$/km)		
Clearing	\$ 2 000	\$ 2 000	\$ 2 000
Forming, ditching and grading	8 000	6 000	7 000
Gravelling	2 500	2 000	2 500
Culverts	1 000	500	1 000
Totals	\$ 13 500	\$ 10 500	\$ 12 500
Road width including shoulders	9.7 m	8 m	8.5 m

8.3 Staking, Felling, Forming, Clearing, Grading and Miscellaneous Work

The major work in constructing a forest road comprises clearing of the area where the road is to be built, forming and grading the roadbed, construction of drainage ditches and of culverts and bridges where required, and cleaning up the side slopes and embankments and stabilising them when necessary. It may include some rock drilling and blasting and some stabilising of the subgrade.

From an engineering viewpoint, a road consists of a surface coat, a base and a sub-base, all supported by a subgrade. In forest road construction these distinctions are seldom made. It is customary to form the road using materials found on the site and apply the depth of granular material required to carry the load. It is obvious, however, that on occasion, e.g., on low capacity soils, such material constitutes the base and sub-base as well as the surface coat.

The work of forming the road and preparing it to receive the surface coat may be done largely with manpower or with bulldozers, graders and other machines. When mechanical equipment is used, the formula below gives the approximate cost of constructing and preparing the road for gravelling, but excluding rock drilling and blasting, construction of culverts and bridges, and extraordinary work to stabilise the subgrade (1).

$$C_i = 230 + 17SL + 660 ST_i + 30 SL^2 ST_i$$

where C_i = the direct cost in US\$ per km for road standard i
(supervision and overhead excluded);

SL = the inclination in percent of the major slope (> 50 m) of the hillsides;

ST_i = the road standard values listed in Table 4.

However, as road construction costs have increased since 1972, the formula needs to be adjusted for 1977 and would read as follows:

$$C_i = 370 + 27 \text{ SL} + 1050 \text{ ST}_i + 48 \text{ SL} \cdot \text{ST}_i$$

The formula was developed for use in developing countries for roads of standards and widths including shoulders shown in Tables 1 and 4.

TABLE 4
VALUES OF ST_i FOR USE IN THE ABOVE FORMULAE

<u>Description of Road</u>	<u>Road width including shoulders</u>	<u>Value of ST_i</u>
Access roads and primary haul roads	10 - 12 m	3
Secondary roads	8 - 10 m	2
Feeder roads	5 - 7 m	1
Skidding trails	3.5 - 4.5 m	0



Mechanized drilling to speed up road construction in rocky mountainous terrain

Although the formula was developed for conditions in developing countries, it may be used in developed countries as well. It should be noted that the formula is considered to produce approximate results only, that it should not be applied to ridge roads, and that roads are sometimes built narrower on steep terrain or with wider shoulders on low bearing soils.

The approximate productivity ratios, purchase prices and hourly operating costs (excluding operator) of crawler tractors of various horsepowers, when equipped with bulldozer, protective canopy and towing winch are shown in a chart in Appendix E.

8.4 Ditches

The estimated maximum water flow and the characteristics of the subgrade soil will determine ditch dimensions. For access and primary roads in terrain with good drainage characteristics a V-ditch extending 30 - 40 cm below the shoulder will usually suffice. In flat terrain, where drainage is poor and water must be disposed of by percolation or evaporation, a trapezoidal ditch 30 - 50 cm deep and 40 - 60 cm wide should be provided unless the water can be drained off to drain or borrow pits or other depressions. Secondary roads usually are built with smaller ditches unless deeper ditches are needed to drain sub-surface water from the subgrade. Feeder roads are only ditched where free water is a real problem.

Ditches on side slopes are usually of the V-type and constructed with angledozer or grader, so that eroded soil from the slope above may be removed with a grader and hauled away or disposed of over the embankment.

Ditches of forest roads should have a gradient of at least 1 % for acceptable water flow. When the grade line exceeds 5 %, erosion may present a problem. On side cut roads, water should be led at short intervals through culverts with a 5 % gradient and guided down the embankment via pipes or lined ditches. It may be advisable to build a well or catch box at the inner end of such culverts. Where both sides of the road on a hill are ditched, it is usually possible to drain the water away on one side or the other onto the right-of-way or into the forest.

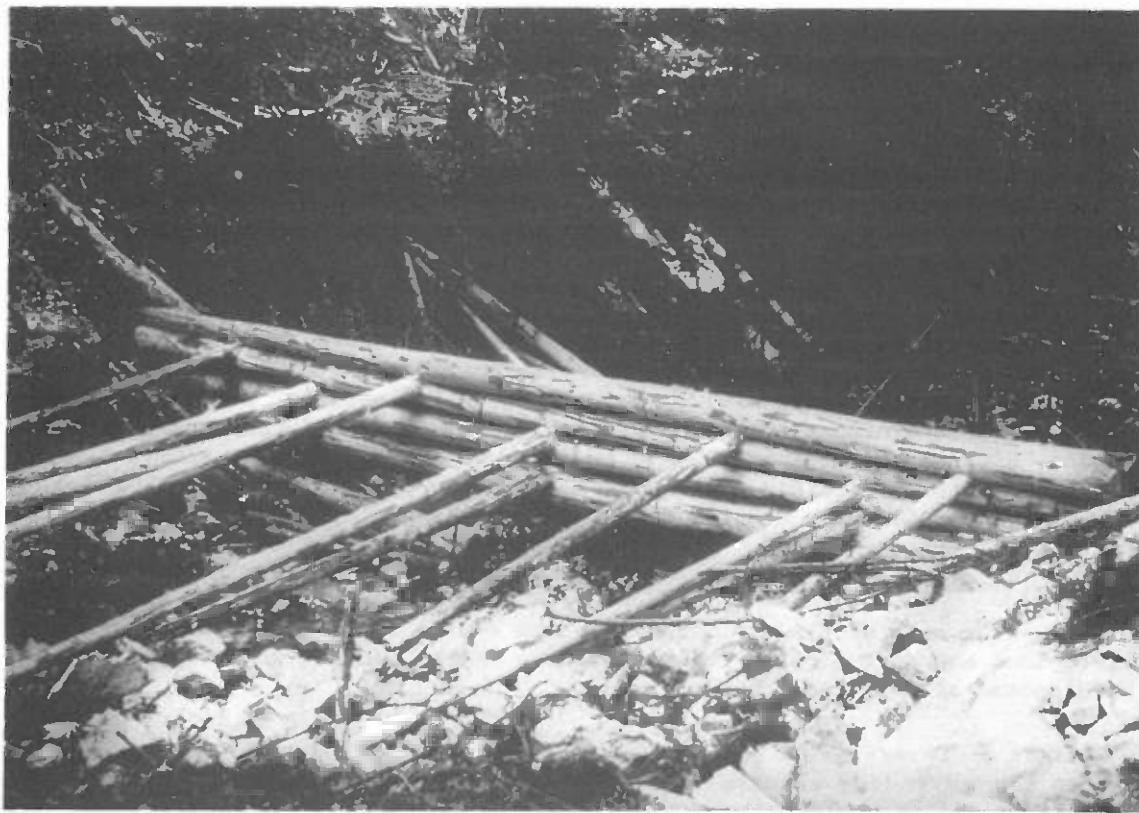
8.5 Stabilisation of Slopes

Stabilisation of long side-cut and embankment slopes to prevent or limit erosion of fine sand, silt and other easily eroded soils may be accomplished in a variety of ways:

- a) unbroken horizontal benches or shelves may be constructed at intervals along the slope to interrupt the flow of water;
- b) turf may be placed or brushwood staked down in unbroken horizontal lines at intervals of 1 - 2 m along the face of the slope;
- c) the slopes may be seeded, possibly fertilised, and covered with hay, straw or mulch to further the growth of vegetation.

Erosion on side-cut slopes may be reduced by digging cut-off ditches beyond the top of the slope, sufficiently far away that water percolating into the soil from the ditch will not contribute to a land slide.

When soils on long side slopes tend to slide or roll down the slope, revetments may be constructed immediately beyond the ditch to catch and hold the rolling stones and finer material and eventually stabilise the slope. These usually consist of open cribwork built of round peeled logs either untreated or treated with one of the wood preservatives which may be applied in the field.



Timber crib revetment under construction to prevent embankment erosion

On more permanent forest roads creosoted squared timber or precast concrete may be used in place of round logs. Embankments subject to landsliding may have to be stabilised with piles driven near the top of the embankment.

8.6 Subgrade Stabilisation

The major problem in forest road siting and construction in flat and rolling terrain is finding soils with good drainage characteristics and load bearing qualities and avoiding organic soils (swamps and muskeg) and soils with high capillarity.

Free water in the subgrade of a road may cause problems through upward capillary movement toward the road surface. Table 5 shows the maximum capillarity for various types of soils and gives an indication of the rate at which the action takes place. The table shows that the maximum height to which capillary water will rise is in inverse proportion to soil grain size, and that rate of rise is low in coarse soils, increases as soil particles decrease in size but again drops for the finest soils.

A high water table under a road may be lowered by providing deep ditches, either open or gravel-filled and sealed (see Figure 2), extending well down into the water table. The sealed type of ditch is expensive and usually can be afforded only on permanent high capacity roads. The water will seep horizontally into the ditches, approximately at the rates shown in Table 6, and eventually lower the water table.

TABLE 5

CAPILLARITY OF VARIOUS SOILS (18)

Soil Name	Particle size in mm	Capillary Rise in cm	
		Maximum	In first 24 hours
Medium to fine gravel	5 - 2	2 - 3	2 - 3
Very coarse sand	2 - 1	5 - 6	5
Coarse sand	1.0 - 0.5	5 - 15	11
Medium sand	0.5 - 0.25	13 - 50	21
Fine sand	0.25 - 0.10	40 - 100	38
Very fine sand	0.10 - 0.05	100 - 150	53
Coarse silt	0.05 - 0.02	150 - 200	110
Medium silt	0.02 - 0.01	150 - 550	48
Fine silt	0.01 - 0.005	400 - 1 000	28
Clay	0.005 - 0.002	1 700	14
Colloid	0.002	7 000	5

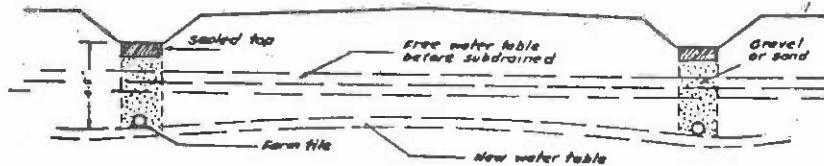


Figure 2 - Drainage for lowering subsoil water table (18).

TABLE 6

RATE OF FREE WATER FLOW HORIZONTALLY IN SOILS (18)

Type of Soil	Particle size in mm	Rate of Flow per Year in cm
Silt	0.01 - 0.2	15 - 50
Medium sand	0.2 - 0.5	75
Coarse sand	0.5 - 1.0	400
Gravel		1 000

When a subgrade is composed of fine sand, silt or clay - all soils with medium to high capillarity - a layer of coarse sand or gravel of a thickness equal to twice the maximum capillary rise of the soil being hauled in as shown in Table 5, will interrupt the upward capillary movement of water and improve the load bearing capacity of the road (see Figure 3).

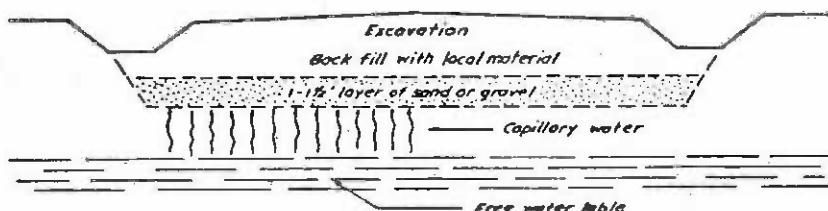


Figure 3 - Insulation layer between subsoil water table and subgrade containing soil with high capillary capacity (18).

Water seeping downslope and across under a road over an impervious soil layer may be cut off with a deep ditch or ditch and drain as shown in Figure 4.

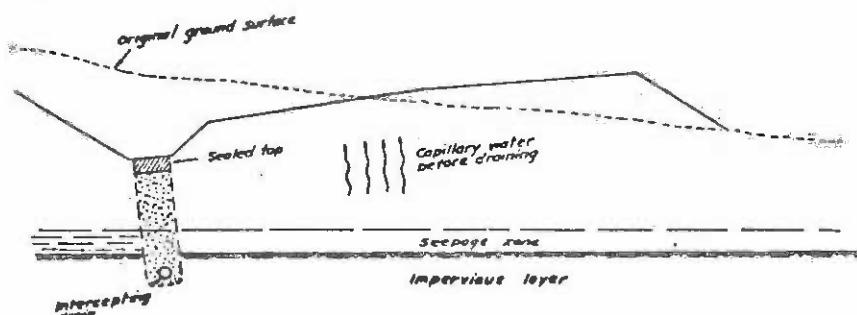


Figure 4 - Drainage of subsoil seepage water (18).

Road construction in deep low-load-bearing soils requires that the subgrade be stabilised before further construction proceeds. For forest roads this is often done by clearing and levelling the soil and corduroying with small trees growing on or near the right-of-way. In tropical forests it is customary to use two layers of logs, averaging around 10 cm in diameter and being the width of the road in length. The lower layer is laid lengthwise on the road, the upper one crosswise. Logs larger than 10 cm are split with an axe. Where trees are cut with an axe and carried and placed by hand, production averages around 20 m² per man-day.

In some northern temperate forests where swamps, muskeg and other very low-bearing soils are encountered, the corduroying is often effected by felling some of the trees standing on the right-of-way lengthwise of and the remainder across the roadbed without resorting to bulldozing the site.

Instead of using corduroy on cleared and levelled subsoil, non-woven fabric, pervious to water, may be procured in rolls and spread to stabilise the subgrade. The main purpose of the fabric is to prevent the fines in the subsoil from rising and mixing with the granular material on top and to prevent the latter from working downward to weaken the load carrying capacity. The material may be purchased in a variety of widths and roll lengths, will not rot in the ground and is highly resistant to wear and tear. It is reported that about 1 500 m² of the fabric may be placed on the road per man-hour.

The material may be obtained with various physical characteristics pertaining to breaking strength, tear strength, stretch, etc. These dictate the price. Among the manufacturers are:

- a) Rhone-Poulenc - Textile, Paris, France;
- b) Chemie Linz AG, Austria;

c) Celanese Corporation, New York City, U.S.A.

The fabric called BIDIM (made by Rhone-Poulenc - Textile), with a breaking strength of 70 kg and a breaking stretch of 50 - 70 %, sold in Canada for US\$ 1.34/m² in 1974.

Many trials have been made to find an additive which, when mixed with soil, would stabilise it and improve its capacity to support loads. Among these are bitumens, portland cement and hydrated lime. A strong bitumen - stabilised soil can be produced only from a soil which was of high quality, i.e., granular, before the bitumen was added. It is therefore of small concern to forest road builders. Likewise, the soils that are most amenable to portland cement stabilisation are the granular ones with a mixture of particle sizes from fine sand (0.10 mm) up to gravel (around 5 mm in diameter). Again these represent already good load-bearing soils and do not require stabilisation. The finer the soil the more cement is required, the harder the mixing becomes and the less beneficial are the results.

On the other hand, lime, usually in hydrated form, may be mixed with clayey and other fine grained soils to stabilise them. Many clay soils in the tropics contain oxides of silica and/or alumina, such as those in the upper Amazon Basin. Lime, when mixed intimately with such soils through pulverisation, forms calcium silicates and/or aluminates, which tend to cement the soil particles together. The resulting mixture must be compacted. It should be allowed to rest for 4 - 6 months and covered with granular surfacing material. Appendix F contains the case histories of two lime stabilisation projects carried out in eastern Canada in 1966 and reported on in late 1968.

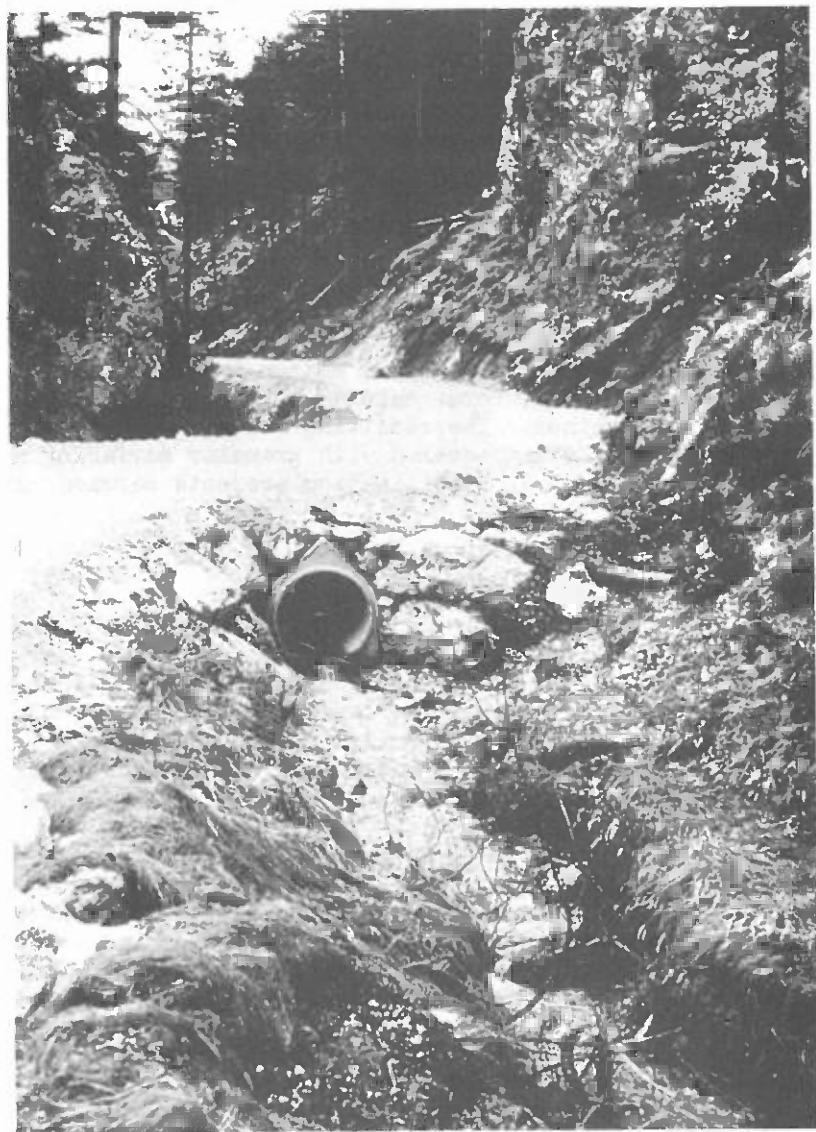
8.7 Culverts

Surface water in the road ditches should be led under and away from the roadway by means of culverts sited at appropriate intervals - the steeper the ditch and the greater the flow of water, the more closely they should be spaced. In steep terrain with long slopes they may need to be spaced 15 - 20 m apart, in flat and rolling terrain probably 100 - 150 m depending on the absorption qualities of the soil; in sand and gravel soils few culverts will be needed. Natural streams should be drained under the road without altering the flow route more than necessary.

Anticipated culvert life should have an important bearing on the type of material and the care used in constructing it. Feeder roads to be used one season only, whether in temperate or tropical forest zones, normally require culverts only where there is an abundance of surface water or a stream to be drained across the road. Sometimes unmerchantable trees and brush pushed into gullies or depressions and covered with soil will serve the purpose. Roads to be used more than one season should be ditched and culverted.

On secondary roads which will not become permanent, culverts may be made of local round timber, untreated if road life is not expected to exceed 5 - 7 years. In some industrialized countries where wage rates are high, it has become more economical to use galvanised corrugated culverts on secondary roads and remove them for use elsewhere when logging has been completed. On permanent roads, concrete, galvanised corrugated steel or preservative-treated wood should be used, because of the high maintenance and replacement cost of untreated wood culverts. It is a question of comparing costs of culverts installed using each of the available materials.

The proper size of culverts to be used depends on several factors, such as topography, soil, forest cover, size of watershed, frequency and magnitude of sudden rain storms and, not least, culvert spacing. It is, for example, well known that runoff from cut-over or burned-over land is heavier and more severe than from forested land. Several formulae have been devised in different parts of the world for calculating the maximum flow of water which may be expected for various conditions, but these cannot have universal application. The most satisfactory results can probably be obtained by looking for high water marks, examining local meteorological records (if there are any) and consulting local inhabitants. One



Pre-cast concrete culvert for natural water flow

forestry company in eastern Canada uses a maximum run-off flow of 80 ft³/sec per square mile (approximately 0.88 m³/sec per km²) for high rolling to steep forest land and 60 - 70 ft³/sec for low lands (18), but stresses that these values may not apply elsewhere and should be used only with great discretion.

The approximate cost of galvanised corrugated round steel culvert material of the commonly used thickness and bought in 20-foot (6.1 m) lengths - but procurable in other lengths as well - f.o.b. fabricating plant in eastern Canada is given in Table 7. The price of concrete culverts in short sections runs about the same at the plant, but the higher transportation costs due to greater weight make it a less attractive material under most circumstances. The cost of such material at the culvert site would have to be examined for each situation. Locally treated local timber, preferably squared, would probably be the cheapest culvert material in many places, but installation costs would be much greater.

When bulldozers and other heavy equipment are being used to form and ditch the road, excavating for placement of culverts, backfilling after placement and digging drainage ditches to lead water away from the culvert outlet, are normally done mechanically. A course of coarse sand or gravel around 10 cm deep should be placed to form a smooth bed for a round pipe-arch, or arch culvert, the material should be left loose so that the corrugations will sink into the bed. The bed should have a steady gradient of 3 - 5 % and support the culvert piping throughout its length. The backfilled soil should be compacted by 6-inch layers as it is placed to provide side support for the culvert walls. This may easily be done with a hand-held vibratory compactor. The depth of soil placed over the culvert should depend on the thickness of culvert material used, characteristics of the soil, and vehicle axle loads and travel speeds. Recommended practice is to cover the culvert with good load carrying material compacted to a depth equal to the diameter of the pipe.

Slowly running water in culverts, designed too small and/or placed too close to the top of the ground, particularly in exposed places, tends to freeze and eventually block during winter weather in northern zones. This may be remedied by increasing the culvert gradient, using a bottomless wood culvert or insulating the intake end with softwood branches as the cold weather season approaches. Culverts sited on too low a gradient tend to become blocked with debris and/or stones and coarse sand. This may be counteracted by building a well or catch pit at the culvert entrance, and small abutments to protect against erosion and guide the water into the culvert.

Large concrete or galvanised corrugated steel culverts may be used singly or severally in place of small bridges. They are permanent, are normally cheaper to construct (depending on the cost of material) and require little or no maintenance. When used in groups, they should be placed far enough apart to allow compactors to be used between them, either hand-held or mobile or both. Using compactors may mean using coffer-dams to divert the water from the work area. Such culverts should not be used, however, where the stream carries large debris which might bridge the opening and cause it to become blocked.

8.8 Gravelling

The depth of surfacing material which should be placed on a forest road depends on the characteristics of the soil on which the road is constructed, the loads (axle loads and spacing) which are to be hauled over it, traffic density, and, to some extent, travel speed and the season of the year when the hauling is to take place. Some forest roads require little or no gravel, others on silt or clay may need a depth of up to 50 - 60 cm. The cost varies considerably, depending on whether the material has to be crushed or screened and the distance it has to be hauled.

Table 8 shows a comparison between 1972 gravelling costs with pitrun gravel given in FAO publication "Logging and Log Transport in Tropical High Forests" (1) and typical 1977 forest road gravelling costs in eastern Canada.

TABLE 7

APPROXIMATE COST OF GALVANISED CORRUGATED ROUND STEEL CULVERTS
BOUGHT IN 20-FEET (6.1 m) LENGTHS IN EASTERN CANADA

Approximate Diameter in cm	Thickness		Approximate Cost F.O.B. Fabricating Plant		
	U.S. Standard Gauge	in mm	per m of length		Joint Collar each
			Joint	Collar	each
30	16	1.59	\$ 2.40	\$ 2.50	
41	16	1.59	3.30	3.30	
61	14	1.98	5.00	5.00	
91	14	1.98	7.25	7.00	
122	12	2.78	12.50	12.00	

TABLE 8

SOME COMPARATIVE GRAVELLING COSTS

(costs expressed in US\$/m³ or US\$ per m³/km)

Item	Cost in FAO: "Logging and Log Transport in Tropical High Forest" 1972 1/	Typical Costs in eastern Canada (1977) 2/
Natural gravel at pit	\$ 0.10 - 0.40	-
Loading		
(a) small quantities	\$ 0.65 - 1.30	-
(b) large quantities	\$ 0.15 - 0.25	\$ 0.60
Transportation	\$ 1.00/m ³ plus \$ 0.05 per m ³ /km	\$ 0.40/m ³ plus \$ 0.075 per m ³ /km
Grading and rolling	\$ 0.35 - 0.40	\$ 0.50 3/

1/ These costs which involve machines should be increased around 50 % to bring them to 1977 values.

2/ Converted from government-set gravel hauling rates.

3/ No rolling or compacting is included.



Gravel being loaded on to truck for graveling main forest roads
in a small forest operation company

In eastern Canada in the mid-sixties, the crushing, loading and hauling and dumping of pit gravel was being contracted at the rate of US\$ 2 500 per mile (US\$ 1 550 per km) under the following conditions:

- a) the contractor supplied all labour and machinery;
- b) average hauling distance was 4 - 5 km;
- c) road width gravelled equalled 7.3 m;
- d) depth of material spread was 20 cm;
- e) the material was not spread or compacted.

A present contract price would probably be double the above figure, i.e., around US\$ 3 000 per km.

If the natural or pit run gravel is too coarse and has to be crushed before being placed on the road, the cost in stockpile at the crusher or loaded on trucks will be between US\$ 2.00 and US\$ 3.00 per m³ depending on the size of material produced. If loaded direct from crusher, the loading cost in Table 8 may be disregarded. Some operators use pre-crushers to produce coarse material (up to 7 - 10 cm in diameter) for the sub-base and base course and a conventional crusher to produce the finer material for the surface course. If surfacing material has to be produced from rock by drilling, blasting and crushing, the cost in stockpile at the quarry will be US\$ 5.00 - US\$ 6.00 per m³.



Motor grader reshaping a main forest road during road maintenance

9. FOREST ROAD MAINTENANCE

Road maintenance consists normally of removing irregularities from the surface of the road, but maintenance also includes other operations which are performed at irregular intervals: destroying shrubbery on the right-of-way to improve sight distances, cleaning ditches, applying dust abatement agents and regravelling. In northern zones, road maintenance costs also include snow removal, sanding or salting icy roads, etc. Snow removal is usually done with a truck fitted with a one-way plough and grading blade when long distances are involved or with motor graders. Most logging operations use the latter because the slower motor grader, with its longer wheel base, leaves a smoother less undulating surface so that high hauling speeds may be maintained.

The cost of maintenance depends on many factors: standard of construction, gross vehicle weights, traffic density, travel speeds and climatic conditions and so on. Consequently, it is difficult to estimate. FAO publication "Logging and Log Transport in Tropical High Forests" gives annual costs of US\$ 50 - 100/km plus 1 - 2 % of construction cost as of 1972 depending on weather conditions and standard of construction, but present day costs are much higher. In very hilly country annual maintenance costs may approach 10 % of construction costs until the road has become well stabilised. The maintenance cost of a corduroyed main road in Colombia is around US\$ 1 000 /km per year, i.e., 5 % of the cost of constructing the road.

Sometimes major roads are constructed to a relatively low standard and improved from time to time with the cost of such work being charged to maintenance, thus distorting both cost amounts.

Gravelled haul roads on a logging operation where travel is heavy, speeds are high and hauling rigs return empty, rapidly develop surface irregularities or wash boarding. This phenomenon is said to be due to the action on the road surface of the rapidly revolving driven tires of unloaded vehicles as they alternately hit the road surface and rebound clear. While these irregularities can be removed with shovels, picks and rakes, it is customary to use tractor-drawn drags of various types or self-propelled blade graders. Motor graders can

also re-shape the road, retrieve loose gravel from the shoulders and shallow ditches, and spread it evenly over the road. Motor graders sometimes also haul a drag behind as it moves along the road.

Dust is a problem on heavily travelled untreated gravel roads in dry weather. It has been estimated that annual loss in surfacing material may reach as much as 300 tonnes per km. The loss on one busy untreated haul road in eastern Canada was reported to vary between 100 m³ and 200 m³/km/year. A number of substances are used widely as a dust palliative, the most common of which is calcium chloride applied either in solution or in solid form at rates of 0.25 - 1.5 kg/m² depending on the soil. Dust abatement provides safer driving conditions and usually enables higher travel speeds to be maintained: it also creates cleaner atmospheric conditions for the vehicle, but the salt causes more rapid rusting of exposed metal parts. A summary of experience in the pulp and paper industry in eastern Canada in the 1960's with calcium chloride as a dust palliative may be found in Appendix G.

Maintenance costs will normally be considerably greater on primary or main haul roads than on secondary roads, probably by a factor of 2 to 1. These costs at present (1977), all-inclusive, year round and averaged over a period of years, will probably be around US\$ 800 and US\$ 400 per km respectively. The cost of maintaining access roads should not exceed that of secondary roads unless used as haul roads as well. Feeder roads receive very little maintenance.

10. HARVESTING SYSTEMS

10.1 General Considerations

Planning a forest harvesting system is a complex undertaking. Many factors must be considered: the physical characteristics of the terrain, the forest stand, the climate, the forest management and silvicultural plans, the product, labour, logging equipment and the method of measuring production. Most of the factors will be known in an on-going operation; in a new operation being planned all must be considered.

10.1.1 Terrain

Topography and soil exert a major influence on road construction costs and extraction methods. Roads sited on steep slopes require deep side cuts and expose much soil to erosion. Both construction and maintenance costs are increased. On flatter ground, fine silt and clay sub-soils have to be stabilised because of problems with water capillarity in these soils, and organic soils either have to be removed or corduroyed and covered with gravel hauled at a cost of US\$ 1.50 - 2.00 per m³ plus US\$ 0.08 - 0.10 per m³/km.

Steepness and roughness of slopes and the traction characteristics of the soil and ground cover determine if skidders, forwarders and other logging machines can be used. Normally, given good traction conditions, some skidders and forwarders can work on down grades up to 50 % or even 60 % under exceptionally good conditions. They can work on up-grades to around 20 - 25 %, but payloads, particularly with skidders, must be drastically reduced.

Table 9 shows the minor transportation methods practicable in temperate zone forests under various ground conditions. The table should apply equally well in tropical forests, but the methods listed in the table can be used much less widely because of poor soil conditions, larger tree size, lower stand density (or volume harvested per ha) and severe underbrush.

In many low jungle forests of the tropical zone where silt and clay soils predominate, harvested trees are often large - up to 150 cm in diameter - and harvested volume per ha may be as low as 5 - 10 m³, ground skidding is rapidly becoming the standard method of moving the wood to roadside - or sometimes riverside - either in tree length or short log form. However, the deep ruts made by the wheeled skidders in these high capillarity soils (with low traction coefficient) by the slowly spinning lug-type tires trying to overcome the frictional drag of the payload and the rolling resistance of the machine present a serious problem.

In many tropical countries wheeled skidding can be carried on only during the dry season of 4 - 6 months, and even during that season has to be interrupted, when it showers, for periods of from 2 - 3 hours to 2 - 3 days to give the ground a chance to dry. Water collecting in the wheel ruts only serves to soften the soil and cause the ruts to become even deeper with each passage of the skidder. Wheeled skidders develop a ground pressure of 1.1 - 1.4 kg/cm² depending on tire width.

Standard crawler tractors, on the other hand, develop a ground pressure of 0.5 - 0.7 kg/cm² and therefore perform much better on silt and clay soils. Not only do they have much better traction characteristics but also greater penetration capability - i.e., greater ability to clear trails to the felled trees - than even the 185 hp wheeled skidders and possibly the new 300 hp recently put on the market. New low ground pressure (LGP) crawlers with longer tracks and wider track shoes, which are now available in small and medium size models, reduce ground pressure to \pm 50 % of that of standard machines. They should increase the ground skidding possibilities in soft soils very considerably.

Along some tropical rivers where the ground is relatively flat and smooth, logs, even up to 125 - 150 cm in diameter, are cut in 3 m lengths, "roll ways" are cleared and the logs are rolled to river bank manually for distances up to 1.5 - 2 km.

On one operation in Colombia where ground bearing capacity is 0.2 kg/cm², manual forwarding and cable yarding of short wood are the standard methods of moving the wood to roadside. Even the lightest wide-tracked skidding machines available can work on the forest floor only with great difficulty and main skidding trails have to be corduroyed.

10.1.2 Forest stand

The volume of wood being harvested per ha affects the optimum spacing or density per ha of the feeder roads: the less wood harvested per ha the wider should be the spacing or the lower the density. This is discussed in Appendix D. In tropical zones where normal practice is to "cream" the forest, taking out only a few of the more valuable species and logging as low as 5 - 10 m³/ha, and where roads are expensive to build, optimum road spacing may, by the spacing formula, be several km apart.

In temperate zone forests and in plantations, regardless of their geographical location, stands of small trees (up to 20 cm dbh) may be economically handled as short wood by the cut-bunch-forward method. If the logs are to be forwarded, or loaded and unloaded, manually, the logs must be small enough or short enough to be man handled by one or two men. The appropriate weight would depend on several climatic and human factors: temperature, altitude, body weight, nutrition, etc. It would probably be around 30 - 40 kg per man. If the logs are to be loaded and offloaded mechanically with grapples or clamps, the logs should be not less than 2.5 m in length.

Larger trees are best ground skidded to roadside if topography and ground conditions permit. The branches and tops may be removed in the stump area or at roadside with axe or power saw or with mechanical delimiters or delimiter-buckers, either those which handle one tree at a time or the recently developed multi-tree flail delimiter.

10.1.3 Climatic conditions

High ambient temperatures and relative humidity, such as prevail in certain seasons of the year in tropical countries, have an important effect on the ability of a forest worker to perform heavy physical work steadily. Table 10 shows the productivity reductions which may be expected and the time allowances which should be made under such conditions, using a temperature of 26°C and a relative humidity of 90% as base values.

TABLE 10

TIME CONSUMPTION ALLOWANCE OR REDUCTION OF PRODUCTIVITY IN HEAVY FORESTRY WORK IN TROPICAL COUNTRIES DUE TO HEAT STRESS

Temperature in Celsius	Relative Humidity	Allowance in 1/ Time Consumption	Reduction in 2/ Productivity
26	90 %	0 %	0 %
28	90 %	10 %	10 %
29.5	90 %	25 %	20 %
31.5	90 %	55 %	35 %
33.5	90 %	185 %	65 %
33	70 %	45 %	30 %
35	70 %	100 %	50 %
37	70 %	550 %	85 %

1/ These allowances are in addition to the rest periods normally taken when ambient temperature is 26°C and relative humidity is 90 %.

2/ Productivity is in inverse ratio to the time required to perform the task.

The table shows that frequency and duration of rest periods increase rapidly as either ambient temperature or relative humidity rises and indicates that heavy work should be avoided during the hottest part of the day.

On the other hand, the machine operator seated in a comfortable air-conditioned cab may work at full productivity during such hot weather - an excellent argument for mechanising certain phases of the harvesting operation.

Tests on forestry workers on piecework cutting and skidding operations in eastern Canada, i.e., doing heavy physical labour, show that normal resting time amounted to 10 % of the workday when the mean ambient workday temperature was -12°C, but increased in summer and decreased in winter, as shown in Table 11.

The forest floor is an unpleasant work area for a man on foot when it is raining. Production is slowed down or stopped. In tropical countries with a pronounced rainy season and considerable precipitation during the remainder of the year, this is a serious problem. Machine use is curtailed; depreciation and interest costs rise; overhead costs go up - all adding to the costs of the harvested wood.

In temperate zones snow may also disrupt harvesting operations, but while it brings immediate problems, they are in most cases more than offset by its long term benefits.

TABLE 11 1/

MEAN TOTAL RESTING TIME DURING WORKDAY
IN HEAVY TEMPERATE FORESTRY WORK

Mean Workday Temperature in °C	Mean Total Resting Time as Percentage of Total Workday Time
-40°	5 %
-30°	7 %
-20°	8 %
-10°	10 %
0	12 %
+10°	14 %
+20°	16 %
+30°	18 %

1/ Based on studies made in eastern Canada (19).

As altitude increases physical working capacity diminishes due to the decreasing amount of oxygen in the air. The effect becomes noticeable at an altitude of 1 200 m, reaches 15 % at 2 300 m and around 30 % at 4 000 m. Nature has endowed many peoples who live constantly at high altitude with greater lung capacity, more blood and a higher percentage of red corpuscles than corresponding lowland peoples. While the latter may become acclimatized to high altitude work, they never reach the efficiency of the highland worker.

10.1.4 Management and silviculture

The forest management plan may place restrictions on the type of logging. It may call for selective logging and natural regeneration or clear cutting and reforestation by artificial means, as in mature pine plantations. Selective logging is the standard system in tropical forests, due in most part to the large number of species for which no commercial use has been found. This brings about a continuous degradation of the forest as the valuable species removed are seldom replaced with seedlings of valuable species. Tropical forests being harvested for pulpwood are normally clear cut, except possibly for a few species with high silica or latex content, and planted with better pulpwood species, principally eucalyptus, cypress or pine.

Regulations may contain restrictions respecting erosion on certain soils and limit or even prevent ground skidding on steep slopes.

There may be regulations concerning the disposal of brush, tops and other logging debris. Some logging systems call for the full trees to be taken to roadside or even to the final landing, but some silviculturists maintain that the nutrients which they contain should not be removed from the forest.

Some management plans call for clear cutting in strips or patches, not only for fire protection purposes but for restocking the cut-over areas by natural seeding from the uncut stands; some demand that seed trees be left and that planting be done where natural seeding has not been successful.

10.1.5 Length or type of product

Choice of a harvesting system may be affected by the length or type of product required at the mill or final landing. There may be a strong demand for a standard uniform log length, not only because of mill requirement, but because it is most efficient for long distance transportation or because it permits some of the very productive processing machines to be used.

If logs are to be manually handled, short wood must be produced. Producing short wood manually in the stump area requires more labour than any other system, but it is a simple logging method and allows the material to be handled in "bulk" from the stump area on to the final landing. It is a suitable method for regions of high unemployment and low wage rates; it is readily adapted to piecework rates but it is heavy work requiring 4 000 calories per day or more for good production.

If chips must be delivered to the mill, consideration must be given to chipping tree length or complete trees at roadside.

10.1.6 Labour

Planning a harvesting system requires that major consideration be given to the labour situation: availability, experience, aptitudes, attitude toward work and training, body weight, general health and nutrition, the work day, wage rates and fringe benefits, motivating influences and so on.

Workers with no previous forestry training or experience with normal logging tools and equipment will probably require 2 years to become fully proficient. Much will depend on worker absenteeism and turnover and on the intensity of training and supervision in the work area. They should be able to increase their productivity by 50 % during the second year. In eastern Canada inexperienced forwarder operators required 1 000 hours of work to become fully proficient in manipulating the knuckle boom loader on the machine.

Worker capacity for hard physical labour depends on body weight among other things. Most logging productivity time data have been prepared in countries where the logging industry has been well developed and forest worker weight averages around 70 kg. If average worker weight in the region where it is intended to use such data is less than 70 kg, a time allowance should be made by applying the factor:

$$\frac{70}{\text{average body weight in kg}}$$

This would not apply to machine operators.

The lethargy so often found among workers in hot climates is often put down to laziness, but may be due essentially to an improper and/or insufficient diet. Workers doing hard physical forestry work need an intake of at least 4 000 K cal per day. If they do not get it, they cannot perform at full efficiency. Poor nutrition may contribute to high absenteeism and labour turnover. In cases where poor nutrition may be a factor, plans should be considered for improving nutrition of the workers in some manner.

The geographical relationship between the work area and the labour source must also be considered. Woods workers have traditionally come from rural areas, are familiar with the forest, do not mind living at a logging camp and possess a working knowledge of hand tools at least. However, the present day migration from rural to urban areas has damaged that concept. The feeling of the worker toward family and village has a bearing on absenteeism. In developed countries labour turnover and, to a great degree, absenteeism

have been stabilised wherever it has been possible to run "commuter camps", i.e., woods operations where the workers live at home and travel to and from work each day either by private automobile or autobus. This may be done for distances up to 50 km if the roads are of sufficiently high standard. In warm climates it may be possible to establish forest villages near the work area at reasonable cost, which would serve as a base or focal point for improving nutrition, health and general well-being and for reducing absenteeism and labour turnover.

Wage rates and the cost of fringe benefits must be considered. In Canada, the cost of the latter amounts to 30 % or more of direct wages in major forest enterprises; in developing countries it may reach or surpass 100 %.

The best means of motivating workers to increase productivity should be considered. In developed countries this has taken different forms. The most common - and very effective - means has been monetary: work payment at a price per unit of production (i.e., piecework), or payment by daily or weekly wage for a specified production plus a bonus for excess production. These methods should not be expected to lower or raise the cost per unit of wood. The emphasis should be on higher manday production with the objective of reducing fringe benefit and other indirect costs.

Wage rates have a tremendous influence on the choice of logging system. Labour intensive systems, such as the cut-bunch-forward method in small and medium wood, especially where wage rates are low and piecework is acceptable, is a very promising method. Some experts claim that, even in those countries where wages are high, the method, which produces short wood in the stump area in the length required at the mill and handles it in "bulk" with forwarders from that point on, is the most economical method. This is exemplified in Sweden where 85 - 90 % of the harvested wood is produced in this manner. The problem in some countries is to find the workers who are willing to struggle in the brush and debris on the forest floor and perform the hard physical labour required to fell, delimb, buck, assemble and bunch the wood.

10.1.7 Mechanical equipment

When mechanical logging equipment is being considered, the simplicity of the machine, the availability of service and replacement parts from the distributor and its ability to perform adequately on the terrain in the logging area, are probably the most important points to be considered. Its production rate may be quite satisfactory but if it cannot be kept in working order for a minimum of 70 % of scheduled working time it should not be acquired. This may not be the fault of the machine. There are known instances of machines sitting idle for as long as six months because of import restrictions and "red tape". Some of the most complex logging machines in use at the present time on multiple-shift work have, however, over 80 % availability.

Some one-man machines with heated and air-conditioned cabs can be double shifted year round without loss of production during the hours of darkness. Both feller-bunchers and forwarders, both of which work on the forest floor, fall into this category. Mechanical forwarders, by offloading at roadside direct to truck or trailer, eliminate the additional log loading operation which must be a separate operation when skidding and other forwarding means are used. It is a common saying that another US\$ 0.50 - 0.60/m³ is added to the cost of wood every time it is put down and picked up again.

In some tropical countries normal machine life is considered to be 4 - 6 years, regardless of the small number of hours the machine may be used per year. Consider a machine costing US\$ 100 000, a normal machine life of 10 000 hours and an interest rate of 10 %. If the machine were used only 1 000 hours per year for 5 years in a tropical zone instead of the normal 2 000 hours elsewhere, comparative depreciation and interest costs per machine hour would be as follows:

Annual usage in hours	<u>2 000</u>	<u>1 000</u>
Cost per machine hour:		
depreciation	US\$ 10.00	US\$ 20.00
interest	3.00	6.00
Total	<u>US\$ 13.00</u>	<u>US\$ 26.00</u>

In such a situation, manual methods must be given serious consideration, especially when wage rates are low.

10.1.8 Measuring wood production

The method of measuring wood production may affect the cost of harvesting and should be considered in this respect. Logs are usually measured or scaled for one or more reasons:

- (a) to pay pieceworkers and/or contractors;
- (b) to pay government dues;
- (c) for production control purposes.

Production may be measured by counting or scaling each log, weighing and sampling, measuring in bulk (piles), etc. It may be carried out in the stump area, at roadside or at final landing.

A logging operation should be considered as a continuous process. Stopping the flow generally adds to the cost of the product. If this must be done solely to allow the wood to be measured, an unnecessary expense is incurred. Economical measurement methods should therefore be devised with the appropriate authorities, which will satisfy all who may be concerned. The matter is discussed at greater length in FAO publication: "Harvesting Man-Made Forests in Developing Countries".

10.2 Harvesting Systems Classification

There are several different methods of classifying harvesting systems. They may be classified according to the state of the tree or the length of log in which the wood being harvested is transported from stump area to roadside:

- (a) the full tree system, in which the complete tree is transported to roadside;
- (b) the tree length system;
- (c) the short wood system, in which the trees are debranched, topped and bucked into two or more logs in the stump area.

Further classification may be made according to the method used to move the wood to roadside:

- (a) ground skidding with animals or mechanical equipment;
- (b) forwarding with manpower, with animals or machines pulling sledges or wheeled trailers, or with self-loading mechanical forwarders;
- (c) cable yarding with one or more of several systems.

From the secondary landing at roadside the wood is usually transported by truck or combination rig to a final landing at mill, river or railroad.

Figure 5 may be considered as a general flow chart of the several harvesting systems in use in various parts of the world today.

There are, as a rule, several tools or machines which may be used to perform any one of the phases or parts into which a harvesting system or operation may be divided. For example, felling may be done with axe, bow saw, crosscut saw, power saw (motor chain saw) or one of several types of mobile machines; ground skidding with animals, choker skidder, grapple skidder, bunk jaw skidder, feller-skidder, etc.; delimiting with axe, power saw, or mechanical knife type or flail type delimeter and so on. It is the choosing of the machines and methods that will best fit the operating conditions, as spelled out earlier in this chapter, and the organising of labour and machine elements into a smooth-running economical whole that is the harvesting manager's major task. Each sub-operation is usually affected by the preceding phase and may influence the one that follows; each should flow smoothly into the next.

It is a virtual impossibility to give the actual productivity and cost or to evaluate the potential of every conceivable combination of labour and logging machines. All that can be done in a short manual is to provide data regarding each machine or operational phase which will allow them to be fitted together into a whole and permit an estimated cost of wood to be developed with that particular system. For example, as the feller-buncher fits into all three primary or main harvesting systems, data regarding its productivity and cost will be given once only.

The manual, while it deals with most of the methods or systems in the chart, does not cover cable yarding or long distance transport beyond the final landing as defined above. River driving, barging and rail hauling are considered to be beyond the scope of this manual.

10.2.1 The full tree harvesting system

Full tree harvesting systems are those which deliver complete trees to roadside. They are being carried onto an ever-increasing degree in developed countries due to the overall high man-day productivity of the system and a desire to reduce manual labour to a minimum in the adverse working conditions in the stump area.

The trees may be felled manually or mechanically, skidded or forwarded to roadside, processed there to tree lengths or short wood or loaded and transported to mill as complete trees. Manual felling is considered to be cheaper, and more desirable than mechanical felling, unless the trees are to be bunched in order to facilitate the next phase of the operation. They may also be felled mechanically with feller-bunchers or with feller-forwarders in which case they are stored on the machine and transported to roadside when a complete load has been collected. The various ramifications of the full tree system are illustrated in Figure 6.

In several parts of North America, complete hardwood trees, growing in a mixture of species, are being felled, bunched, grapple skidded to roadside and chipped with a portable chipper at that point. The chips are conveyed pneumatically into a covered truck or van and hauled direct to pulp mill. The system has been extended on occasion to pine species in southern U.S.A. with up to 20 percent of full tree chips being cooked with clean chips from debarked wood. Its general extension to major operations in coniferous forests at this stage of manufacturing techniques may hinge on development of satisfactory means to segregate and separate bark from wood chips.

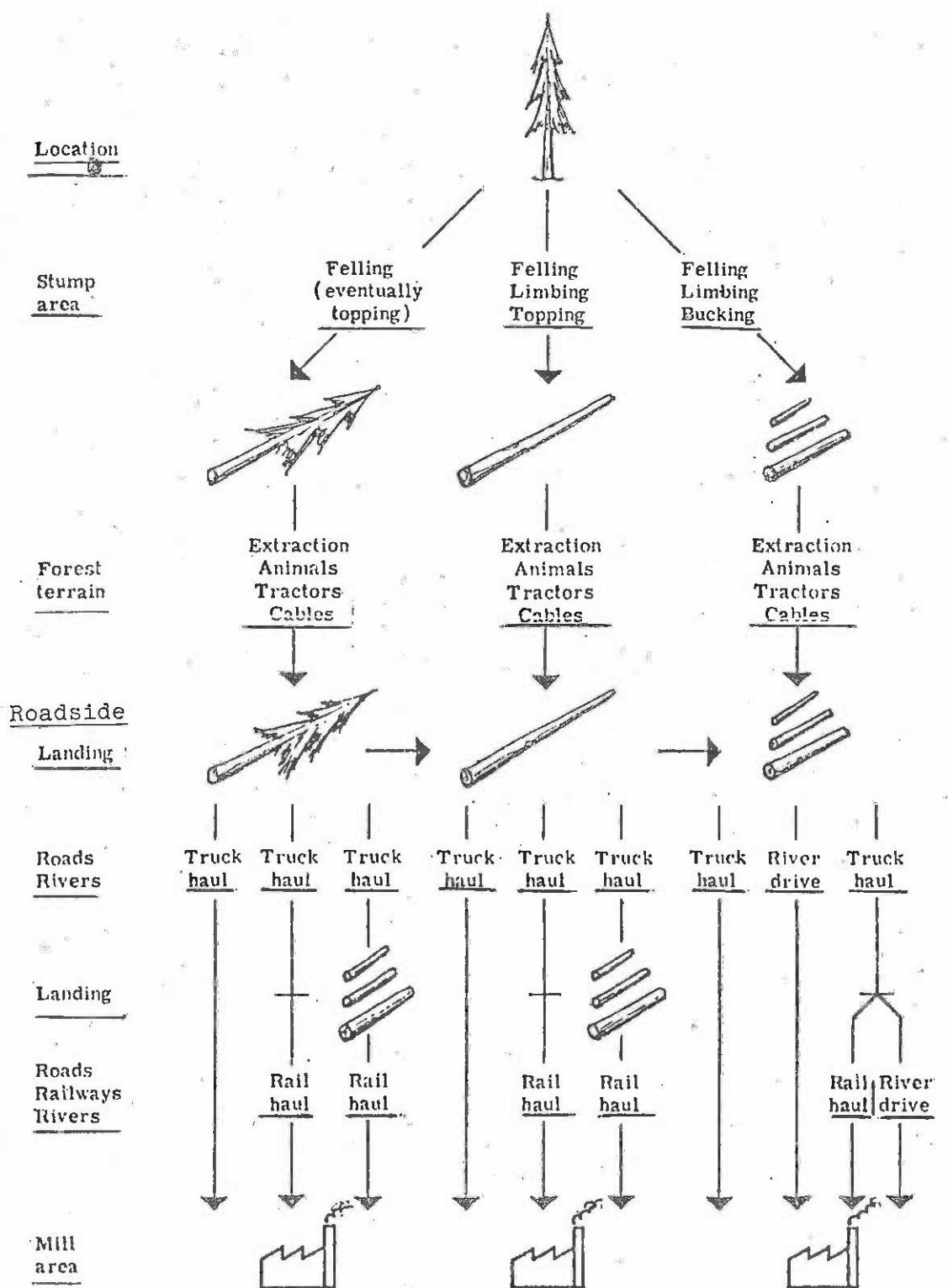


Figure 5 - Main logging systems

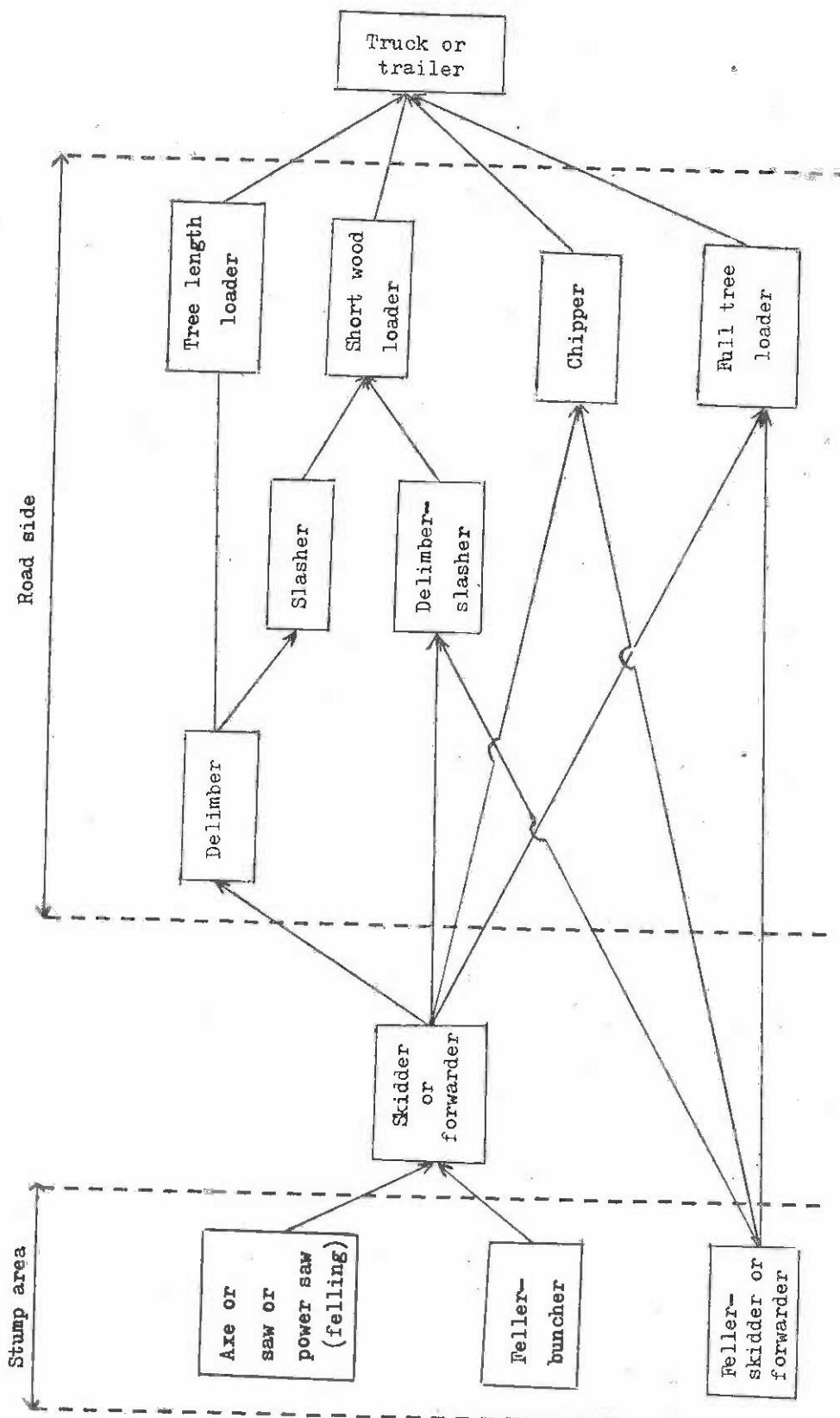


Figure 6. Flow chart for full tree harvesting system

The full tree system has some advantages over the other two:

- (a) removes branches and tops from the forest to reduce fire hazard and leave the area clear for planting;
- (b) concentrates many operations at a central point, permitting bulk operations — a particular advantage when trees are small;
- (c) has possibility of transporting branches and tops to the mill for use as fuel or in manufacture.

The system has, however, some disadvantages:

- (a) the accumulation of branches, etc. at roadside may clutter the operating area;
- (b) removal of branches, etc. to roadside will remove both seed cones and nutrients from the forest area;
- (c) because branches and tops comprise around 30-40 percent by weight of complete coniferous trees, the smaller skidder or forwarder load will reduce optimum feeder road spacing and increase road cost.

10.2.2 The tree length harvesting system

Tree length harvesting systems are those which deliver delimbed and topped tree stems to roadside, i.e. only the merchantable part of the tree. The trees may be felled by one of the several methods mentioned in the section on full tree logging and delimbed in the stump area manually or with a delimiting machine, or they may be felled and delimbed with a single machine working in the stump area. The tree stems may be skidded or forwarded to roadside, bucked into short wood or loaded on semi-trailer rigs in full lengths. The various system ramifications available are illustrated in Figure 7.

The tree length system may be applied almost universally, wherever ground minor transportation systems can be used. It is particularly applicable in coniferous forests, in both temperate and tropical countries. In plantations it may be applied in thinning operations with care and in the final cut. In tropical high forests, it is the standard logging method, unless short logs have to be made because the skidder cannot drag the entire stem.

In mountainous countries in some parts of Europe, on slopes too steep for machines to work, the tree lengths may be sluiced down hill top first, and processed further at roadside.

The system has some advantages:

- (a) no problem with branches and debris accumulating at roadside;
- (b) no loss of nutrients in the forest area;
- (c) higher man day productivity and wider choice of final product than with the short wood system;
- (d) wider feeder road spacing, and therefore lower road cost per m^3 , than with the full tree system.

10.2.3 The short wood harvesting system

In short wood harvesting systems all the work of converting the tree to the form in which it will be delivered to the mill is done in the stump area. From that point the wood is forwarded (unless animal skidded) to roadside and piled down or loaded on truck or trailer. The system is illustrated in its several modifications in Figure 8.

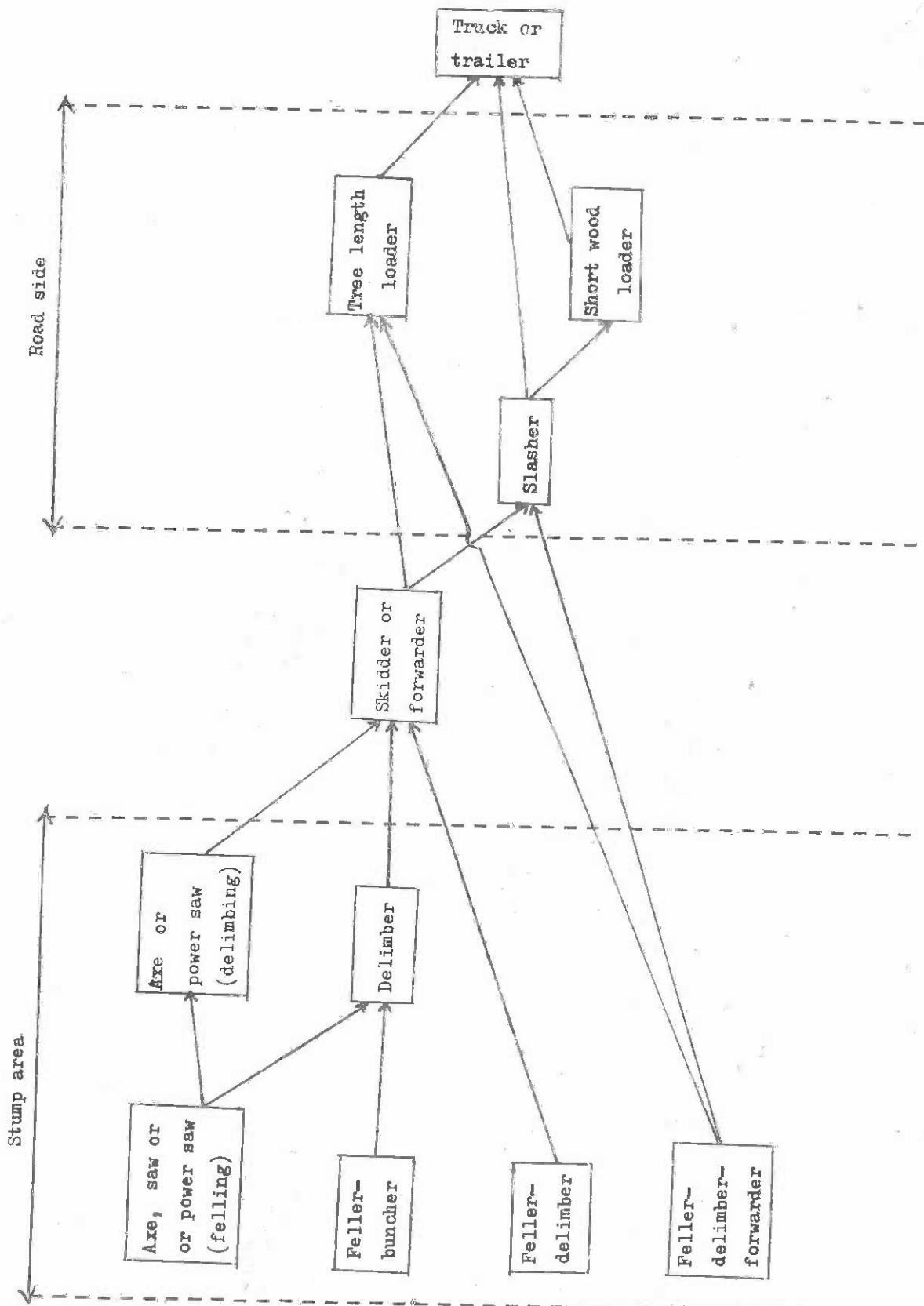


Figure 7 - Flow chart for tree length harvesting system.

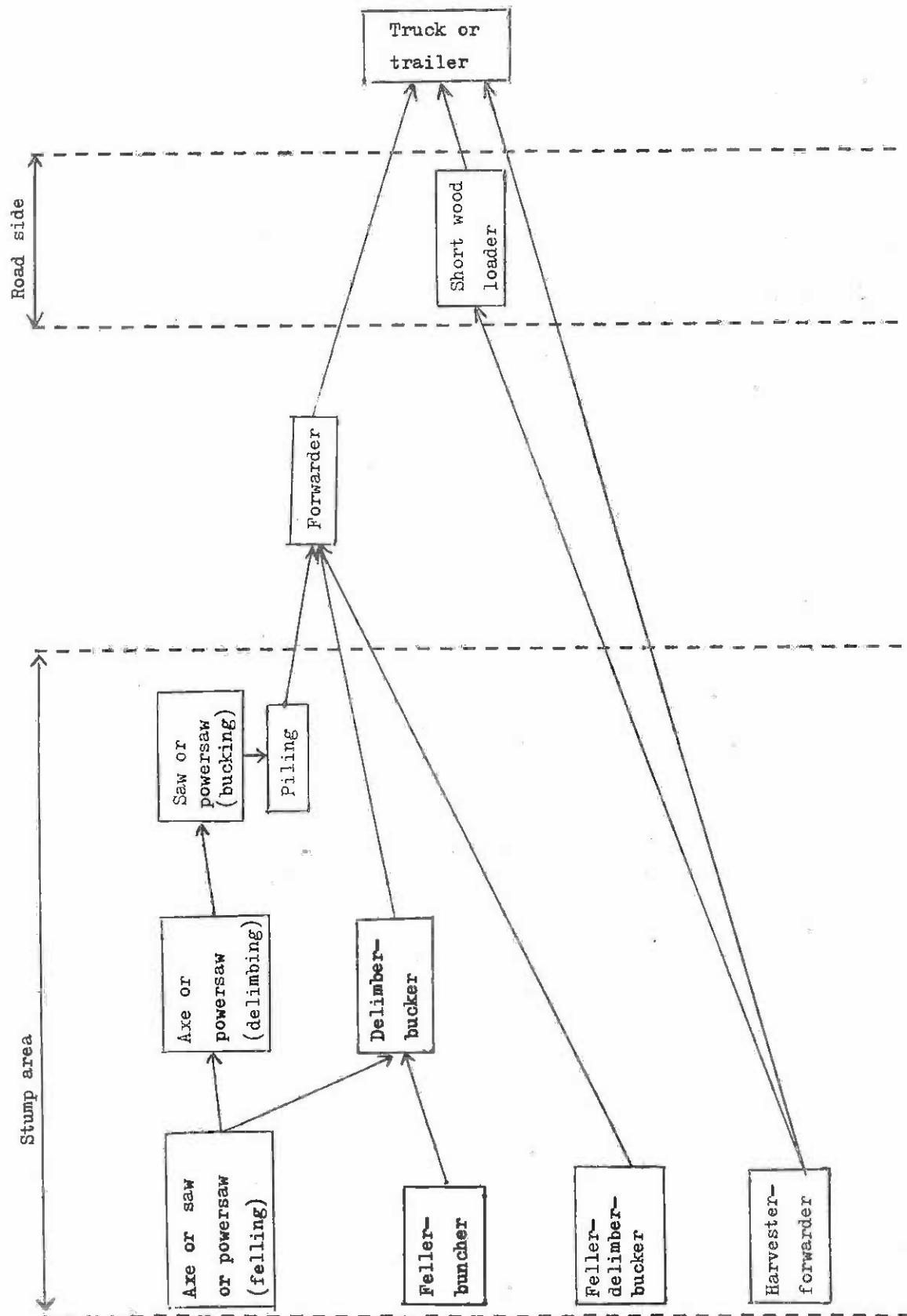


Figure 8 - Flow chart for short wood harvesting system

The short wood system has been practised for generations and is still being used widely. For example, about 85-90 percent of harvesting operations in Sweden are conducted in this manner. Much of the wood in eastern Canada - about 40 percent of the wood produced in Quebec Province - particularly in small operations and/or rough terrain is still being produced by this method - much of it felled, delimbed, topped and bucked with light power saws. (The axe is rarely used nowadays.) It is a very labour intensive system unless multifunction machines are used.

In some tropical forests the axe and/or crosscut saw is still used for felling, because either the trees are too large for easily-carried power saws or the workers have not been trained in their use or because of poor saw repair service in isolated logging areas. It requires $2\frac{1}{2}$ days to fell a tree 150 cm in diameter with an axe but only $3\frac{1}{2}$ hours with a 9-feet (275 cm) crosscut saw. The axe is still being used in a few operations for "bucking" - even in the case of very large trees.

The main advantages of the system in its older form are its simplicity and its low capital requirement. Its main disadvantage is the great amount of manual work required to produce the short wood. In its newest form - production with short wood harvesters - it is labour extensive but requires large capital outlays.

11. SOME JOB TIME ADJUSTMENT FACTORS

11.1 Manual Workers

When forest workers perform heavy physical labour or work on the forest floor, it may be necessary to make certain job time adjustments, generally to compensate for differences between current conditions and those pertinent to the region where the basic data were obtained. This is particularly true for tropical countries, but some adjustments may apply to all countries. The adjustments, made to basic productive times per m³ as set down in felling, dellimbing, bucking and piling tables, relate to general rest time; slope, underbrush and snow depth; temperature and humidity; altitude, body weight and general health, and level of nutrition in the region.

The magnitude of the recommended time adjustments is given below:

- (a) general: + 10% of basic productive time to cover normal rest time;
- (b) slope, ground roughness, underbrush and snow: + 10% of basic productive time + 2% of basic productive time for each increase of 0.5 in the walking quotient, which may be defined as the ratio of time, when putting out the same physical effort, required to walk in both directions around a representative square 25 m on each side in the logging area to the time required to walk 200 m on a level road (20);
- (c) altitude: + 10% for each 1 000 m increase in altitude beyond 1 000 m.
- (d) body weight (when average body weight is less than 70 kg): a factor equal to
$$+ \left(\frac{70}{\text{average body weight in kg}} - 1 \right);$$
- (e) general health and nutrition in the region: a judgment factor based on observation and study.
- (f) ambient temperature and relative humidity: percentages as read from Table 12 and applied to basic productive time per unit of production.

In applying time adjustment percentage, it should be noted that a time adjustment of, for example, + 50%, reduced production per unit time by only 33%.

TABLE 12
TIME ADJUSTMENT PERCENTAGE ALLOWANCES (1)
TO COMPENSATE FOR AMBIENT TEMPERATURE AND
RELATIVE HUMIDITY

Mean work day temperature in °C	Relative humidity			
	< 70%	70%	80%	90%
+ 35°	+ 50%	+ 100%	+ 200%	+ 300%
+ 34°	+ 30%	+ 70%	+ 120%	+ 200%
+ 33°	+ 20%	+ 45%	+ 75%	+ 125%
+ 32°	+ 15%	+ 30%	+ 50%	+ 75%
+ 31°	+ 10%	+ 20%	+ 30%	+ 50%
+ 30°	+ 8%	+ 10%	+ 20%	+ 30%
+ 20°	+ 6%	+ 8%	+ 10%	+ 15%
0°	+ 2%	Disregard relative humidity		
- 10°	0%			
- 20°	- 2%			
- 30°	- 3%			
- 40°	- 5%			

Note (1) interpolate for intermediate values.

11.2 Logging Machines and Operators Working on the Forest Floor

Logging machines work best on smooth level ground free of underbrush and snow, and maximum production occurs with fully proficient and motivated operators working in a dense stand free of wind-thrown and non-merchantable trees. These ideal conditions do not often occur in practice. When these optimum conditions are not met, some compensating time or production rate adjustments must be made.

11.2.1 Terrain

It is difficult to isolate the effect of each of the terrain factors of soil (its load bearing and traction qualities), slope, ground roughness, underbrush and snow on machine travel and production. It is therefore difficult to give these effects a numerical adjustment value to be applied to productivity measured under optimum conditions. There are limiting slope gradients, both up and down, for example, beyond which a machine cannot travel or function; the same holds true for soil, load bearing capacity, ground roughness and snow depth. The limits differ among machines.

Man is affected by the same adverse terrain conditions when moving about and working on the forest floor. The effect has been measured and expressed as the walking quotient as defined in Section 11.1. It is suggested that the same approach be used in assessing the effect on logging machines, within the limits of their ability to overcome terrain conditions and that the magnitude of the effect be expressed in the form of adjustment percentages to basic production time per unit of production, i.e., per tree, or per m³. In this context basic productive time may be taken as that made by a fully proficient operator working under optimum conditions. The suggested time adjustment percentages are given in Table 13.

Not all types of logging machines are affected to the same degree by terrain factors. While feller-bunchers, feller-forwarders and such machines are affected by them all to some degree, processors (delimber-buckers) normally are not affected, for example, by underbrush and to a much less degree by some of the other factors. Underbrush may reduce feller-buncher production by as much as 10-15% by obstructing the operator's view of his immediate work site.

TABLE 13

COMPOSITE TIME ADJUSTMENT PERCENTAGES TO COMPENSATE FOR ADVERSE TERRAIN CONDITIONS: SOIL, SLOPE, GROUND ROUGHNESS, UNDERBRUSH, BLOWDOWNS AND SNOW
(TO BE APPLIED TO BASIC PRODUCTION TIME)

Walking quotient (1)	Time adjustment Percentage (2)
1.0	0%
1.1 - 1.5	+ 10%
1.6 - 2.0	+ 25%
2.1 - 2.5	+ 45%
2.6 - 3.0	+ 70%
Above 3.0	+ 100%

Notes: (1) smooth level ground, no underbrush, no blowdowns and no snow
(2) interpolate as needed

11.2.2 Climatic factors

Climatic factors, as far as logging machines are concerned, may normally be disregarded in temperate zones. The operator is sheltered from precipitation; the cab is heated in winter, and cab windows may be opened in summer unless it is air conditioned.

As far as tropical zones are concerned, it is suggested that a general time adjustment of + 10% be applied and, if the cab is not air conditioned, that a further adjustment factor equal to 50% of the appropriate value in Table 12 be applied as well.

11.2.3 The learning curve

Operators of those logging machines working on the forest floor and required to manipulate a knuckle boom fitted with felling head or grapple require a period of time to become fully proficient. Some operators learn much more quickly than others; some do not possess the manual skills ever to become fully proficient. The learning period depends on the natural dexterity of the operator and his previous mechanical and practical logging handicap.

Most operators learn to drive the machine rather quickly - their major learning problems concern manipulation of the hydraulically powered and controlled boom to perform the function for which the machine was designed. Experience has shown that increase in proficiency, measured in production per unit time, follows the typical learning curve, steep at the bottom and flattening out at the top, and that up to 6 months may be required for an individual to attain full proficiency.

The adjustment percentages given in Table 14 applied to time per unit of production are recommended to be used for all logging machines working on the forest floor beyond roadside and fitted with a knuckle boom and felling head or grapple. The adjustment would therefore apply to feller-bunchers, feller-delimiters, feller-forwarders, bunk-jaw skidders, harvesters and processors, but not to conventional choker or grapple skidders.

TABLE 14

Work period	Learning curve Time adjustment ⁽¹⁾ Percentages
First month	+ 200%
Second "	+ 100%
Third "	+ 50%
Fourth "	+ 25%
Fifth "	+ 10%
Sixth "	+ 5%
Seventh "	Nil

Note: (1) applied to basic production time per tree or per m³.

11.2.4 Basic adjustment

A machine operator performing a repetitive job such as felling trees or feeding a processor can not work at maximum efficiency for an entire shift. He usually takes a number of brief periods for rest, smoking, checking the machine and personal time, which are included in productive machine hours. For this reason an adjustment percentage of 10% should be applied to basic productive time per unit of production to compensate for such time losses.

11.2.5 Operator dexterity and motivation

Operator motivation is an important factor in logging machine production. Manual forest workers in eastern Canada motivated by piecework rates have around 40% greater productivity than dayworkers; it is expected that tests elsewhere show the same result. In the case of machine operators, the percentage is normally much less as the machine tends to "pace" the man. It also depends to some extent on the type of machine and the automatic features built into it.

Most detailed time and production data available for logging machines and used to estimate production have been gathered by timing each function of a repetitive operation, such as the breakdown of a feller-buncher boom operation into swing empty, position and shear, and swing loaded and lower. Experience has shown that such a timing procedure motivates the operator to speed up the boom movements. In practice, however, most machine operators work on a time basis without close supervision or other motivating influences.

Some operators do not possess the natural skill and dexterity ever to reach top-flight productive ability. If they are to be employed on a long-term basis, some compensating production time allowances should be made. Since it is difficult to separate the effects of motivation and skill and dexterity, it is suggested that they be combined into a single adjustment percentage applied to basic productive time per tree or per m³. The adjustment should be considered along with that for the learning curve (see 11.2.3.) and applied only after the fourth month of work. It is suggested that an adjustment percentage of + 25% be used. In some cases it should be greater.

As an example of the effect of motivation, North American type grapple skidders operated by their owners working on a piecework basis skidded more than twice as much tree length or full tree wood as operators working on a time-pay basis.

12. SOME FORMULAE USED IN COST ESTIMATING

In developing cost data (i) for mobile machines which work on the forest floor, whether in the stump area or at roadside and (ii) for minor transportation systems, particularly those using machines rather than manpower and/or animals, a number of formulae are used in the manual. While they may not give precise values under all conditions, they are considered sufficiently accurate for the purpose.

12.1 Machine Operating Cost: Short Formula

The formula covers allowances for depreciation, interest and insurance (which are sometimes overlooked) and fringe benefits for repair labour, but excludes operating labour and fringe benefits. The short formula reads as follows:

$$C = \frac{2.4 \times A}{LE}$$

where C = cost in US\$ per productive machine hour (PMH), excluding operator;

A = acquisition cost of machine in US\$;

LE = life expectancy in PMH as given in Section 3.3.3.

More comments concerning the formula are found in Section 3.3.4.

12.2 Minor Transportation Formulae

These formulae may be used in all ground transportation systems, i.e., between stump area and roadside. In theory, they may be used in systems involving manual and animal transportation, but are more readily applied to mechanical systems. Some of the data used in the formulae are also used in the optimum feeder road spacing formula; payload in m^3 , travel speed, machine operating cost (including operator).

The production and cost formulae may be applied separately:

$$(a) \text{Production: } MTP = \frac{60 \times L}{TT + \frac{2 \times ASD}{ATS}}$$

$$(b) \text{Cost: } MTC = \frac{C + c(1 + f)}{MTP}$$

or they may be combined and applied in one exercise: $MTC = \frac{(TT + \frac{2 \times ASD}{ATS}) C + c(1 + f)}{60 \times L}$

where MTP = production in m^3/PMH

MTC = minor transportation cost in US/m^3$

TT = terminal time (loading, unloading, delays) in minutes per load

ASD = average skidding or forwarding distance in m as determined in Appendix D or as measured on the ground

ATS = average travel speed in m/min

f = cost of fringe benefits expressed as a percentage of direct wages

L = average payload in m^3

C = machine cost in US\$ per PMH (excluding operator)

c = direct wages of machine operator in US/PMH$

12.3 Truck and Trailer Operating Cost: Short Formula

The operating cost of hauling rigs, for reasons mentioned earlier in the manual, should be expressed as a cost per standing hour and a cost per travelling hour, and applied in that manner when estimating or analysing the cost of a hauling operation. A detailed form (Form A) is given in Chapter 3 and discussed at greater length in Appendix H. The following short method may be used by those who need a quick method of reaching approximate values:

<u>COST PER HOUR</u>	
<u>Truck or Truck-Trailer</u>	<u>Trailer</u>
(i) $CSH = \frac{C1}{15\ 000} + c(1 + f)$	$CSH = \frac{C2}{20\ 000}$
(ii) $CTH = CSH + \frac{2.4 \times C1}{10\ 000}$	$CTH = \frac{2.4 \times C2}{15\ 000}$

where CSH = cost in US\$ per standing hour of truck, truck-tractor or trailer
 CTH = cost in US\$ per travelling hour of truck, truck-trailer or trailer
 $C1$ = acquisition cost of truck or truck-tractor
 $C2$ = acquisition cost of trailer
 c = operator direct wages in US\$ per vehicle in-use or shift hour
 f = cost of fringe benefits expressed as a percentage of direct wages.

13. MANUAL OPERATIONS IN THE STUMP AREA

13.1 Manual Felling with Saw

The felling may be done with hand or bow saw or with power saw. To estimate production and cost, proceed as follows:

- determine or estimate average DBH or average volume of the merchantable trees in the stand (DBH is the diameter measured at breast height corresponding to the volume of the average tree in the stand; it differs little from the arithmetic average of the diameters);
- find felling production in m^3 per day (PDF) with the formula:

$$PDF = \frac{SH}{FT (1 + \sum TA)}$$

where PDF = felling production per man day in m^3

SH = work day in hours or shift hours

FT = felling time in man-hours per m^3 read from Table 15

TA = time adjustments, expressed in decimal form, as set out in Section 11.1.



Preparation of felling site by clearing underbrush with machete



Tree felling with chainsaw

(c) find felling cost per m^3 with the formula:

$$CF = \frac{c(1+f) + CS}{PDF}$$

where CF = felling cost in US\$ per m^3

f = cost of fringe benefits as a percentage of direct wages

c = direct wages per day in US\$

CS = cost in US\$ of owning and operating saw per day (applies to power saws only)

PDF = felling production per man day in m^3

TABLE 15
MANUAL FELLING TIME (1) (2)

Average DBH of stand in cm	Approximate average tree volume in m^3	Man hours per m^3 (3)	
		Bow saw	Power saw
15	0.083	0.29	0.15
20	0.205	0.20	0.10
25	0.375	0.17	0.08
30	0.60	0.16	0.07
35	0.87	0.16	0.07
40	1.17	0.16	0.06

Notes: (1) interpolate as necessary

(2) based on a study of pieceworkers

(3) apply appropriate time adjustments (see Section 11.1)

13.2 Manual Delimiting with Axe or Power Saw

Manual delimiting in the stump area may be done with axe or with power saw. The time required to delimb a tree depends on the size of the tree, how much of the tree stem bears limbs and the tool being used. For the sake of convenience three branchiness classes are used in this manual:

Class 1: more than 50% of the total tree height is clear of branches that require to be removed in the delimiting process;

Class 2: between 25% and 50% of the total tree height is clear of branches;

Class 3: less than 25% of the total tree height is clear of branches.

To estimate the production and cost of delimiting manually in the stump area, proceed as follows:

- (a) determine or estimate average DBH or average volume of the merchantable trees in the stand;
- (b) estimate by sampling or observation the average branchiness class of the stand;
- (c) find delimiting production in m^3 per man day (PDD) with the formula:

$$PDD = \frac{SH}{DT (1 + \sum TA)}$$

where PDD = delimiting production per man day in m^3

SH = shift hours or work day in hours

DT = delimiting time in man hours per m^3 , read from Table 16(a) or 16(b)

TA = time adjustments, expressed in decimal form, as set out in Section 11.1.

- (d) find delimiting cost per m^3 with the formula:

$$CD = \frac{c (1 + f) + CS}{PDD}$$

where CD = delimiting cost in US\$ per m^3

c = direct wages per day in US\$

f = cost of fringe benefits expressed as a percentage of direct wages

CS = cost of operating saw in US\$ per day

PDD = delimiting production per man day.

TABLE 16 (a)
DELIMITING IN STUMP AREA WITH AXE (1) (2)

Average DBH of stand in cm	Approximate average tree volume in m^3	Man hours per m^3 (3)		
		1	2	3
15	0.083	0.26	0.33	0.51
20	0.205	0.25	0.30	0.39
25	0.375	0.24	0.27	0.33
30	0.60	0.23	0.25	0.30
35	0.87	0.22	0.25	0.28
40	1.17	0.22	0.23	0.26

Notes: (1) interpolate as necessary

(2) based on a study of pieceworkers

(3) apply appropriate time adjustments (see Section 11.1)

TABLE 16 (b)
DELIMBING IN STUMP AREA WITH POWER SAW (1) (2)

Average DBH of stand in cm	Approximate average tree volume in m ³	Man hours per m ³ (3)			
		Branchiness class	1	2	3
15	0.083		0.21	0.29	0.43
20	0.205		0.20	0.24	0.32
25	0.375		0.19	0.21	0.26
30	0.60		0.18	0.20	0.24
35	0.87		0.17	0.19	0.22
40	1.17		0.16	0.18	0.21

Notes: (1) interpolate as necessary
 (2) based on a study of pieceworkers
 (3) apply appropriate time adjustments (see Section 11.1)

13.3 Manual Bucking with Saw

Manual bucking in the stump area may be done with hand or bow saw or with power saw. To estimate production and cost, proceed as follows:

- determine or estimate average DBH or average volume of the merchantable trees in the stand;
- find bucking production in m³ per man day (PDB) with the formula:

$$PDB = \frac{SH}{BT (1 + \sum TA)}$$

where PDB = bucking production per man day in m³;

SH = work day in hours or shift hours;

BT = bucking time in man hours per m³ read from Table 17(a) or 17(b);

TA = times adjustments, expressed in decimal form, as set out in Section 11.1.

- find bucking cost per m³ with the formula

$$CB = \frac{c (1 + f) + CS}{PDB}$$

where CB = bucking cost in US\$ per m³

c = direct wages per day in US\$

f = cost of fringe benefits as a percentage of direct wages

CS = cost in US\$ of owning and operating saw per day

PDB = bucking production per man day

TABLE 17(a)

BUCKING IN STUMP AREA WITH BOW SAW (1) (2)

Average DBH of stand in cm	Approximate average tree volume in m ³	Man hours per m ³ (3)		
		log length in m 2.44 m	3 m	5 m
15	0.083	0.94	0.82	0.58
20	0.205	0.80	0.70	0.47
25	0.375	0.77	0.67	0.42
30	0.60	0.75	0.65	0.41

Notes: (1) interpolate as necessary

(2) based on a study of pieceworkers

(3) apply appropriate time adjustments (see Section 11.1)

TABLE 17(b)

BUCKING IN STUMP AREA WITH POWER SAW (1) (2)

Average DBH of stand in cm	Approximate average tree volume in m ³	Man hours per m ³ (3)		
		log length in m 2.44 m	3 m	5 m
15	0.083	0.60	0.54	0.41
20	0.205	0.47	0.43	0.33
25	0.375	0.37	0.34	0.26
30	0.60	0.31	0.29	0.21
35	0.87	0.28	0.25	0.18
40	1.17	0.26	0.23	0.16

Notes: (1) interpolate as necessary;

(2) based on a study of pieceworkers;

(3) apply appropriate time adjustments (see Section 11.1)

If tree length wood is bucked manually at the roadside, Table 17(a) will give reasonably accurate times per m³ when the bow saw is used. If the power saw is used, Table 17(b) will also give reasonably accurate results if the trees are bucked one by one. If, on the other hand, several trees are placed side by side or in a bunch and bucked at the same time, the table will not hold. The working conditions will be superior to those in the stump area, but more delays will be encountered from skidder interference or lack of wood.

When working at roadside, time adjustments for slope and underbrush and snow, as explained in Section 11.1, should not be applied.

13.4 Piling Short Wood

If short wood is being made manually in the stump area to be forwarded to roadside, it should be piled or bunched, so that it may be easily recovered with self-loading mechanical forwarders. To estimate production and cost, proceed as follows:

(a) find bunching production in m^3 per man day with the formula:

$$PDP = \frac{SH}{0.75 BT (1 - TA)}$$

where PDP = piling or bunching production in m^3 per man day;

SH = shift hours or work day in hours;

BT = bucking time in man hours per m^3 read from Table 17(b);

TA = time adjustments, expressed in decimal form, as set out in Section 11.1.

(b) find bunching cost per m^3 with the formula:

$$CP = \frac{c (1 + f)}{PDP}$$

where CP = bunching cost in US\$ per m^3 ;

c = direct wages per day in US\$;

f = cost of fringe benefits expressed as a percentage of direct wages;

PDP = bunching production per man day.

13.5 Composite Manual Operations

When more than one of the operations of manual felling, delimiting, bucking and bunching is carried on in the stump area as part of a tree length or a short wood logging system, production and cost data may be obtained by combining the appropriate tables in Sections 13.1 to 13.4.

(a) For example, what would be productivity and cost of producing tree lengths manually in the stump area using the power saw for both felling and delimiting, given the following data or conditions:

- (i) a forest stand of trees with an average DBH of 20 cm and an average Class 2 branchiness;
- (ii) a walking quotient (see Section 11.1) of 2.3;
- (iii) an altitude of 500 m;
- (iv) a mean work day temperature of 25°C and relative humidity of 80%;
- (v) average worker body weight of 66 kg;
- (vi) a work day of 8 hours in the work area;
- (vii) average daily wage of US\$ 10.00 plus 40% for fringe benefits;
- (viii) power saw cost of US\$ 5.00 per day.

(b) Production per day may be found by combining the production formulae in 13.1 and in 13.2.

$$\text{PDFD} = \frac{\text{SH}}{(\text{FT} + \text{DT}) (1 + \sum \text{TA})}$$

where PDFD = daily felling and delimiting production per day in m^3 ;

SH = work day or shift in hours;

FT = felling time in man-hours per m^3 ;

DT = delimiting time in man-hours per m^3 ;

TA = time adjustments as set out in Section 11.1

so that $\text{PDFD} = \frac{8}{(0.10 + 0.24)(1 + 0.10 + 0.16 + 0.04 + 0.15)} = 16.2 \text{ m}^3 \text{ per day.}$

(c) The cost of the operation may be found with the following formula:

$$\text{CFD} = \frac{c (1 + f) + \text{CS}}{\text{PDFD}}$$

where CFD = cost per m^3 of felling and delimiting;

c = direct wages per day in US\$;

f = cost of fringe benefits expressed as a percentage of direct wages;

CS = cost of operating power saw in US\$ per day;

PDFD = felling and delimiting production per day.

so that $\text{CFD} = \frac{(10 \times 1.40) + 5}{16.2} = \text{US\$ } 1.18 \text{ per } \text{m}^3.$

14. FELLER-BUNCHERS

Feller-bunchers are one-man operated wheeled or track-mounted machines designed to fell and bunch complete trees ready to be skidded or forwarded to roadside (full tree system) or to be processed into tree lengths (tree length system) or short wood (short wood system) in the stump area. There are essentially two general types:

- (i) those which are equipped with a knuckle boom carrying a felling head fitted with a chain saw or a shear and designed to sever the trees, lift them clear of the ground, swing them to the desired felling direction and bunch them with the butts even;
- (ii) those short-wheel-base machines which have short close-coupled holding arms and shear instead of a knuckle boom and which depend on moving and swinging the entire machine to accomplish the bunching function.

14.1 Knuckle-Boom Feller-Bunchers

14.1.1 Common types

Some knuckle boom feller-bunchers are track mounted; others are mounted on 4-wheel drive articulated chassis with the engine at the rear. Some booms along with operator cab are mounted on turn table or slewing ring; others are pedestal mounted. Some turn tables are fitted with hydraulic levelling devices to provide a level work platform when working on slopes - like the track-mounted Drott (up to 15%) and the wheel-mounted Usa (up to 30%).

Some felling heads are fitted with hydraulically driven chain saw instead of shears, or with concave shear blades to direct the shearing forces downward towards the stump and reduce butt end shattering. The felling head of most machines is designed to take tree diameters up to 45-50 cm and is fitted with multi-tree holding arms or devices so that two, or in some cases three or more, small trees may be sheared and held in the head before being swung to the bunch.

The width of strip which knuckle-boom equipped feller-bunchers can cut varies between 12 and 15 m depending on machine stability. This, along with minimum boom reach, average merchantable tree size and stand density, determines the volume of wood which may be accumulated per bunch. Each set-up covers around 50 m³, i.e., 5 trees in a stand carrying 1 000 trees/ha. Bunch volume in temperate pulpwood forests normally runs between 1.25 m³ and 2.5 m³, but may be smaller or larger.

Both types of knuckle-boom feller-bunchers have advantages and disadvantages. Stability is better with most track-mounted than with wheeled machines due to much lower centre of gravity, but ground clearance is considerably less. The wheeled machines can move more readily over rough ground, but both have severe limitations on steep slopes.

Wheeled machines are more easily serviced and repaired, and therefore have better utilization; they also move faster to and from work areas or the garage. Both types may be worked during darkness, given satisfactory lights on the machine. Neither works well on down grades or on up grades greater than 30%. Felling heads fitted with chain saws are lighter than those with shears, thus permitting a longer boom reach without affecting machine stability.

Production with knuckle boom feller-bunchers does not differ substantially among the various machines when operated by fully proficient and motivated operators on smooth level ground free of underbrush. Considered by small samples, basic production rates are in the order of 0.35 min per tree for European and North American machines, i.e., about 175 trees per productive machine hour. However, considered over a period of weeks or months, production rates are usually much less due to the conditions encountered in normal operations. These are discussed for machines working on the forest floor in Section 11.2 which suggests compensating adjustment percentages which should be applied to basic time per tree or per m³.

In addition to those conditions mentioned in 11.2, others have an effect on feller-buncher production expressed in time per tree or per m³:

(a) the average number of merchantable trees per ha : apply, interpolating if necessary, the following adjustment percentages to basic time per tree or per m³:

<u>Trees per ha</u>	<u>Adjustment percentage</u>
1 500 +	Nil
1 500 - 1 201	+ 10%
1 200 - 901	+ 20%
900 - 601	+ 30%
600 - 301	+ 40%

(b) tree diameter affects production to a slight but insignificant degree, requiring no adjustment.

(c) the ratio of non-merchantable trees that have to be felled and cast aside to merchantable trees felled and bunched also affects production: time adjustment is the direct ratio of the two values and is applied to time per tree or per m³.

Felling and bunching production in m^3/PMH may be found with the following formula:

$$PFBM = \frac{60 \times VT}{0.35 (1 + \sum TA)}$$

where $PFBM$ = feller-buncher production in m^3/PMH ;

VT = average tree volume in m^3 ;

0.35 = basic productive time for a feller-buncher expressed in min/tree;

TA = time adjustment percentages, expressed in decimal form, read from Sections 11.2 and from 14.1.1 above.

Felling and bunching cost may then be found with the formula:

$$FBCM = \frac{C + c (1 + f)}{PFBM}$$

where $FBCM$ = felling-bunching cost in $US\$/m^3$;

C = cost of operating feller-buncher in $US\$/PMH$ as shown in Section 3.3.4;

$PFBM$ = feller-buncher production in m^3/PMH ;

c = direct wages of operator in $US\$/PMH$;

f = cost of fringe benefits expressed as a percentage of direct wages.

14.1.2 Special types

The Koehring Feller-Buncher should be mentioned. This is a large articulated 4-wheeled machine with ground clearance of 85 cm and all 4 wheels hydrostatically driven. The cab and felling boom are turn-table mounted on the front chassis and the engine on the rear chassis. It is designed to fell and bunch trees up to stump diameter of 76 cm, but with its multi-tree felling head is able to fell and hold one tree after another until the holding clamps are full before swinging and depositing them on the bunch; each additional tree so cut and held requires an additional 9 seconds. It is designed to work on up grades to 40% with chain equipped wheels.

14.2 Short Wheel Base Feller-Bunchers

One well-known example of this type of feller-buncher is the Melroe M-970 Bobcat, manufactured by Clark Equipment Company in Gwinner, North Dakota, U.S.A. It is a 4-wheel drive non-articulated machine weighing 5 000 kg, having a wheel base of 115 cm, a ground clearance of 16 cm, a lifting capacity and tipping load of over 2 700 kg, hydrostatic transmission, and infinitely variable forward and reverse speeds which enable the machine to pivot quickly in its own length. Its wheels may be fitted with tracks to provide greater traction and flotation enabling it to perform satisfactorily in about 60 cm of snow. It is essentially, however, a smooth-ground machine.

The bunching shears of the Bobcat are designed to cut trees up to 35 cm in diameter and to shear and hold as many as 4 or 5 small trees before delivering them to the pile. As it carries the severed trees, it is able to make complete skidder-load piles without difficulty. Felling and bunching rates in a hardwood stand have been timed at 3 trees (20-25 cm stump diameter) per minute and 3 piles of 20 trees each in an elapsed time of 15 minutes. Over long periods its production may reach 200 trees per PMH in a clear cut operation. It can operate on grades up to 20% but with lower production on the steeper slopes.

Its small dimensions, its manoeuvrability, and its capability to hold several small trees in its felling head and to work on grades enable it to be used in plantation thinning where ground roughness presents no problems for the low ground clearance of the machine. It has given good results in row thinning, removing every other two rows, but should perform satisfactorily in removing one row and thinning selectively two adjacent rows on each side when the trees are spaced 2.44 m apart, provided potential root damage is not a factor.

The acquisition cost of the Bobcat is in the order of 50-60% of that of the larger heavier knuckle-boom feller-bunchers.

Production expressed in trees or m^3 per PMH and cost per tree or per m^3 may be estimated by applying the formulae in the section immediately above, using basic productive time of 20 seconds or 0.33 min per tree. These machines are often owner-operated on a piecework basis, a situation which provides maximum operator motivation. This point should be considered in developing appropriate adjustment percentages to be applied in the production formula.

15. SKIDDER PAYLOADS

15.1 General

Skidding is a term applied to the transportation of logs or trees by dragging them resting wholly or partially on the ground. The preparation of the logs or trees to be skidded may be done manually with axe or saw or mechanically with feller-bunchers, delimbers and feller-delimbers in the stump area.

Skidding may be done with animals or with machines. FAO publication "Harvesting Man-Made Forests in Developing Countries"(2) covers animal skidding with mules and with oxen, but not with horses, which are little used nowadays in temperate countries and unable to function properly in tropical climates for physiological reasons. Mechanical skidding is discussed at length as well, but is covered in this manual in a somewhat different manner.

Skidders comprise two main types: cable and grapple skidders which suspend the front end of the load behind the machine, and clam bunk or bunk jaws skidders that support the front end of the load on a bunk on the rear chassis. The former type are 4-wheeled-drive articulated machines, the latter normally a 6-wheeled drive articulated machine, with a tandem bogie under the rear chassis and tracks on the bogie tires.

Both types of skidders may, theoretically, be used to skid tree lengths either butts forward or tops forward and complete trees, butts forward. However, this manual gives most attention to the more common method of skidding butts forward.

15.2 General Payload Formula

The normal maximum payload of a skidder working on the normal forest floor on level terrain, whether it be cable skidder, grapple skidder or clam bunk (or bunk jaws) skidder, may be approximated with the formula: $fs.PL = t/TE - r(TW + x \cdot PL)$

where PL = payload in kg; fs ⁽³⁾ = skidding coefficient;

$fs.PL$ = frictional drag of the TE ⁽²⁾ = tractive effort or rim pull of the payload in kg; skidder in kg;

t ⁽⁴⁾ = coefficient of traction; r ⁽⁵⁾ = coefficient of rolling resistance;

TW ⁽¹⁾ = tare weight of the x ⁽⁶⁾ = percentage (in decimal form) of pay-load supported by the skidder.

Notes:

- (1) TW: the tare weight of conventional 4-wheel drive articulated cable skidders averages around 68.GHP kg whereas the tare weight of clam bunk skidders with tandem rear bogie averages around 87.GHP kg;
- (2) TE: the tractive effort or rim pull of conventional cable skidders approximates 115% of tare weight, i.e., 115% of 68.GHP (see note 1 above) or 78.GHP; while that of clam bunk skidders will be around 135% of tare weight, i.e., 135% of 87.GHP or 117.GHP;
- (3) fs: Bennett (20) found that 60% of the weight of a load of tree lengths being skidded, butts forward, with a cable skidder was supported by the machine when suspended from the arch, and that the skidding coefficient fs , i.e., the ratio of required skidding pull to total payload weight, was around 0.48 on normal forest soils in eastern Canada; since this friction was caused by the 40% of the load bearing on the ground, the real coefficient of friction was around 1.20; Bennett also found that 10-15% greater pull was required to start the load than to pull it after being started; it follows then that the coefficient of skidding, when applied to the whole load (for ease in using) would be 110-115% (120% of 40%) or about 0.55 when expressed in decimal form. On the assumption that 70% of the payload is supported by the bunk of a clam bunk skidder when skidding tree lengths, butts forward, the skidding coefficient will be 110-115% (120% of 30%) or about 0.40 in decimal form;
- (4) t : a review of test work carried out in various parts of the world shows that the following coefficients of traction are reasonably reliable:
 - (a) cable or grapple skidder with lug tires: 0.55
 - (b) clam bunk skidders fitted with tracks on the rear bogies: 0.70
- (5) r : rolling resistance is due to soil deformation by the wheels or tracks and to obstacles in the path of the machine; it does not include grade resistance; the coefficient, which is applied to gross vehicle weight, may be approximated with the formula $r = \frac{NHP \cdot E \cdot 4562}{GVW \cdot V}$

where r = coefficient of rolling resistance;
 NHP = net or fly wheel horsepower = 0.90.GHP;
 E = drive train efficiency fraction = 0.85;
 GVW = gross vehicle weight in kg;
 V = travelling speed in m/min

when this formula is applied, r will be found to be around 0.50 for both types of skidders under normal summer forest floor conditions; it is obvious that the coefficient will be higher in very soft or very rough terrain conditions, or in deep snow, and lower on smooth level ground;
- (6) x : this represents the proportion of the tree length load supported by the skidder and forming part of GVW; its value was found by Bennett to be 0.60 for cable skidders and estimated to be around 0.70 for clam bunk skidders; when skidding tree lengths, butts forward.

15.3 Skidding Tree Lengths Butts Forward

The coefficients for use in the general payload formula may differ for each type of skidder, for variations in terrain conditions and according to the form of the material being skidded. However, Table 18 gives approximate values which may be used when skidding tree lengths, butts forward, on level terrain with typical forest floor conditions.

TABLE 18

VALUES OF SYMBOLS FOR USE WITH THE ABOVE SKIDDER PAYLOAD DETERMINATION FORMULA WHEN SKIDDING TREE LENGTHS BUTTS AHEAD ON LEVEL GROUND

<u>Symbol</u>	<u>Cable and grapple skidders</u>	<u>Clam bunk skidders</u>
$f_s^{(3)}$	0.55	0.40
$t^{(4)}$	0.55	0.70
$r^{(5)}$	0.50	0.50
$T_E^{(2)}$	78.hp	117.hp
$T_W^{(1)}$	68.hp	87.hp
$x^{(6)}$	0.60	0.70

Notes (1) to (6): See explanation at foot of formula in Section 15.2.

Skidder load volumes may, however, be limited in practice for several reasons, e.g., cable skidders by the number of chokers in use and/or tree volume; grapple skidders by the bunch size or the number of bunches taken in a load; clam bunk skidders by the length of the merchantable part of the tree and the size of the bunk jaws. Theoretically when payloads are small, skidder travel speeds should be faster, but in practice they may be limited by operator discomfort and vehicle vibration on the rough forest floor. Travel speeds usually lie between 50 m and 75 m per min, with less than 20% difference between empty and loaded speeds.

The formula in Section 15.2 gives skidder loads on level terrain. It is obvious that payloads may be greater when skidding downgrade and less when skidding upgrade. Payload weight under such conditions may be found with the formula above after adjusting the skidding and rolling resistance coefficients to compensate for grade. By applying appropriate formulae, the data given in Table 19 will be obtained.

TABLE 19

SKIDDER PAYLOAD WEIGHTS PER GROSS HORSEPOWER WHEN SKIDDING TREE LENGTHS BUTTS AHEAD (1) (2)

<u>Grade</u>	<u>Cable skidders</u>	<u>Clam bunk skidders</u>
- 20%	70 kg	180 kg
- 10%	48 kg	115 kg
0%	34 kg	80 kg
+ 10%	24 kg	57 kg
+ 20%	17 kg	42 kg

Notes: (1) interpolate for intermediate grade percents;
(2) the payload weights may be converted to m^3 when the weight per m^3 is known.

Applying the data in Table 19, if wood weighs 900 kg per m^3 , the normal maximum payload volume for a 150 hp clam bunk skidder skidding tree lengths, butts ahead, up a 10% grade will be

$$\frac{150 \times 57}{900} = 9.5 \text{ m}^3$$

and skidding down a 10% grade with a 100 hp cable skidder will be

$$\frac{100 \times 48}{900} = 5.3 \text{ m}^3$$

Table 19 is expressed in kg per gross horsepower because tree species vary in weight per unit volume. Knowing the weight of unbarked wood per m^3 , for example, it is quite feasible to compile a table similar to Table 19, reading in m^3/GHP .

Normal maximum payload for grapple skidders will be around 50% less than for cable skidders of the same horsepower due to the added weight of heavier and more rugged rear chassis frame and the cantilever grapple boom arrangement.

15.4 Skidding Tree Lengths Tops Forward

Some calculations show that, given normal tree taper (around 1 cm per m) and top diameter of 10 cm, only around 35% of the load will be supported by the skidder when skidding tree lengths, tops forward, with cable skidders. Applying the coefficient of friction of 1.20 found by Bennett (20), and allowing for the additional force needed to start the load the skidding coefficient f_s will be found to be 110-115% (120% of 50%) or around 0.88.

Applying the general skidder payload formula and using the appropriate coefficient, e.g., a skidding coefficient of 0.88, payloads will be found to be around 25% less than those values shown in Table 19 for skidding tree lengths, butts forward.

15.5 Skidding Full Trees

Bennett (20) found that around 50% of the weight of complete trees was supported by the machine when skidding full trees with cable skidders so that the value of the skidding coefficient f_s would be around 110-115% (120% of 50%) or 0.65, considering the allowance of 10-15% additional force to start the load.

It is estimated that 60% of the payload weight is supported on the bunk when skidding full trees with clam bunk skidders. In the same manner as above, this would give a skidding coefficient value of 110-115% (120% of 40%) or around 0.55.

TABLE 20

VALUES OF SYMBOLS FOR USE WITH THE SKIDDER PAYLOAD DETERMINATION FORMULA WHEN SKIDDING FULL TREES ON LEVEL GROUND

<u>Symbol</u>	<u>Cable and grapple skidders</u>	<u>Clam bunk skidders</u>
f_s	0.65	0.55
t	0.55	0.70
r	0.50	0.50
TE	78.hp	117.hp
TW	68.hp	87.hp
x	0.50	0.60

When the general skidder payload formula is applied using the symbols given in Table 20, the approximate payload weights per gross horsepower when skidding full trees will be as shown in Table 21. A comparison of values in the table with those in Table 19 for tree length skidding shows that approximately 10% less for cable skidder and 15% less for clam bunk skidders, by weight, may be skidded in full tree form than as tree lengths.

An unpublished report in eastern Canada on typical coniferous species gave the ratio of tree lengths (to 8 cm top diameter) to complete trees as being between 65% for trees of 15 cm DBH to 73% for trees of 40 cm diameter. When skidding full trees, if only 70% of the tree is being utilized and 10% less by weight is being skidded, then the merchantable wood per load is some 35% less than when skidding tree lengths and the cost per m^3 some 50% higher. This situation will arise, however, only when full loads are being skidded. If cable skidders, for example, are being used to skid full trees in small wood, and a limited number of chokers are being used, it is very probable that as much utilizable volume will be taken each trip as when working in tree lengths.

TABLE 21

SKIDDER PAYLOAD WEIGHTS PER GROSS HORSEPOWER WHEN SKIDDING FULL TREES
UNDER TYPICAL FOREST FLOOR CONDITIONS (1) (2)

<u>Grade</u>	<u>Cable skidders</u>	<u>Clam bunk skidders</u>
- 20%	59 kg	133 kg
- 10%	42 kg	93 kg
0%	30 kg	68 kg
+ 10%	22 kg	50 kg
+ 20%	16 kg	37 kg

Notes: (1) interpolate for intermediate grade per cents;

(2) payload weights may be converted to m^3 of merchantable wood when the percent of utilizable tree volume and the weight of unbarked wood are known. If 30% of the full tree is waste and unbarked wood weighs 900 kg/ m^3 , then kg of full tree weight per skidder horsepower may be converted to m^3 of merchantable wood per horsepower by applying the factor $\frac{0.70}{900} = 0.00078$ to the values in the table.

16. CABLE SKIDDER

16.1 Skidding Manually Felled and Delimbed Tree Lengths

The operation of manually producing tree lengths and cable skidding them to roadside in eastern Canada is usually performed by a crew of three men, two felling and delimiting (usually with power saw) and the third skidding their production to roadside and piling it as required. There may be a variety of work and skidder arrangements. The common arrangement is for a contractor or logging company to supply the skidder free of charge and to pay the crew at a piecework rate, or at a day rate plus incentive bonus, with earnings divided equally among the crew members (each crew member usually supplies a power saw).

Under this arrangement the skidder operator delivers to roadside the tree length wood produced by the other two crew members. As not more than 10 chokers are normally used, production per trip may be well below the capacity of the skidder as set out in

Table 19, particularly if the wood is small. In such a crew arrangement, skidder PMH ranges around 6 hours per day and production between 40 and 50 m³ per day depending on average tree volume, terrain and skidding distance. Thus with the two cutters determining daily output for the crew, production per crew day may be estimated with the formula (see also Section 13.5(b)):

$$\text{PDFDS} = \frac{2 \times \text{SH}}{(\text{FT} + \text{DT}) (1 + \sum \text{TA})}$$

where PDFDS = cutting and skidding production per 3 man crew in m³ per day;

SH = work day or shift in hours;

FT = felling time in man-hours per m³ (see Table 15);

DT = delimiting time in man-hours per m³ (see Table 16(a) or 16(b));

TA = time adjustments as set out in Section 11.1.

The cost of felling, delimiting and skidding tree lengths to roadside may then be found with the formula:

$$\text{CFDS} = \frac{3c(1+f) + 2\text{CS} + 6C}{\text{PDFDS}}$$

where CFDS = cost of felling, delimiting and skidding in US\$/m³;

c = direct man day earnings in US\$;

f = cost of fringe benefits expressed as a % of earnings;

CS = daily cost of power saw in US\$;

C = skidder operating cost in US\$/PMH calculated with the usual formula

$$C = \frac{2 \times 4A}{\text{LE}};$$

PDFDS = felling, delimiting and skidding production in m³/day.

Considering cable skidding as a separate operation, production in m³/PMH may be found with the formula:

$$\text{PSM} = \frac{60 \times L}{\text{TT} + \frac{2 \text{ASD}}{\text{ATS}}}$$

and cost in US\$/m³ with the formula:

$$\text{SCM} = \frac{C + c(1+f)}{\text{PSM}}$$

where PSM = production in m³/PMH;

L = skidder load in m³;

TT = terminal time per load in minutes (loading, unhooking and delay per trip);

ASD = average skidding distance in m;

ATS = average travel speed in m/min;

SCM = skidding cost in US\$/m³;

C = operating cost of skidder in US\$/PMH;

c = operator direct wages in US\$/PMH;

f = cost of fringe benefits expressed as a percentage of direct wages.

Time in the stump area to choke the trees, hook up and winch in the load may vary between 5 and 20 minutes depending on tree size, terrain and ground cover conditions, number of chokers being used, worker skill and motivation, etc. Unhooking and winding in the chokers at roadside may take from 2 to 5 minutes. Thus terminal times may vary within wide limits, but usually averages around 15 minutes per trip, including delays and personal time.

Travel speeds also may vary within wide limits as may be seen by examining Table 22, as will the load volume itself when small trees are encountered and the number of chokers is limited to the usual ten.

Consider a 100 hp cable skidder costing US\$30 000 skidding average loads of 2 m^3 of tree lengths, butts forward, at an average round trip travel speed of 60 m/minute and working in a broad forest area of mainly level terrain where stand density averages $100 \text{ m}^3/\text{ha}$ and feeder roads are estimated to cost US\$ 2 000 per km. Terminal time averages 15 minutes per load. The skidder works 6 productive hours per day; the operator's direct wages work out to be US\$ 8.00/PMH and fringe benefits 30%. What should be the estimated skidding cost in US\$/ m^3 ?

The operating cost of the skidder excluding operator, will be US\$ 12.00/PMH, calculated by the short formula in Section 3.3.4. The optimum feeder road spacing, disregarding for purpose of this exercise the factors k and p , may be found to be 380 m with the formula in Appendix D,1. so that average skidding distance is around 100 m.

Having determined the above values, production and cost may be calculated with the formulae noted above to be $6.6 \text{ m}^3/\text{PMH}$ (or about 40 m^3 per day) and US\$ 3.40/ m^3 respectively.



Wood extraction by skidder to the road

TABLE 22

SAMPLE CABLE SKIDDER TRAVEL SPEEDS
FROM VARIOUS REGIONS

<u>Region</u>	<u>Speed in m/min</u>	
	<u>Light</u>	<u>Loaded</u>
1) Canada		
(a) Interior of British Columbia		
(1) 92 hp	160	90
(2) 185 hp	140	70
(b) Ontario (grapple skidder)		
(1) Case 1: 125 hp	75	50
(2) Case 2: 125 hp	105	60
2) Sweden		
(a) strip roads	55	50
(b) exit roads	115	90
3) Ivory Coast: 185 hp		
(a) opening trails	17	-
(b) on own trails	80	60
(c) on bulldozer opened trails	105	85

16.2 Skidding Full Trees

The operation of skidding manually felled complete trees differs little from skidding tree lengths. However, only between 65% and 73% as much merchantable wood per trip is skidded using the same number of chokers on the same tree diameters (see Section 15.5).

Cable skidders are sometimes used to skid feller-bunched full trees. In this case a single choker (usually the main winch line) is wrapped around the entire bunch and terminal times are much shorter, usually in the order of 5-8 minutes per load including delays. Production and costs may be calculated for specific situations as in the preceding section. Again, however, it should be noted that between 27% and 35% by weight of trees in northern coniferous temperate forests - and probably more in some regions - is taken by the tops and branches, reducing merchantable payload and increasing skidding cost per m³.

17. GRAPPLE SKIDDER

Grapple skidders, developed in North America, are essentially cable skidders with the following main differences: heavier rear frame and axle, cantilevered boom and grapple in place of the arch, and increase in weight by about 2 000 kg. The winch and line are retained to snug up the grapple while travelling empty and to advance the payload if the vehicle should become mired, drop its load and move forward onto firmer ground.

Grapple skidders are used almost entirely to skid feller-bunched trees to roadside processors. In operation the skidder is backed up to the butt end of a pile of trees, the grapple is extended, opened, placed down over the pile and closed; the load is then lifted by its butt and drawn in toward the rear axle of the skidder. Maximum load capacity is less than that of the corresponding cable skidder due to its greater weight and rolling resistance. When the bunches are small and suitably arranged along the strip road, more than one bunch may be handled in the same load, provided the skidder is adequately powered and traction is sufficient. Tests have shown that each additional bunch picked up adds 1.0 minute to round trip time.

Two clear cut operations in eastern Canada, using 130 hp grapple skidders, provided the data in Table 23.

When using grapple skidders, particularly on full trees, the optimum feeder road spacing will be affected adversely by the relatively small payload and the high vehicle purchase and operating costs. If, for example, a cable skidder costs US\$ 30 000, the corresponding grapple skidder will weigh approximately 2 000 kg more and cost US\$ 10 000 more, to give comparative operating costs of US\$ 12.00 and US\$ 16.00 per PMH. Given a normal payload reduction of 50 percent and having due regard to the difference in terminal time comparative skidding cost/m³ will vary little with the two machines. The grapple skidder has one advantage: the operator does not have to move about on the forest floor and thus may work during inclement weather and possibly during darkness.

Daily production with 125 hp cable and grapple skidders under normal conditions in eastern Canada will run around 35-45 m³ and 45-55 m³ respectively. There are cases on record, however, of well motivated owner-operators producing over 100 m³ with grapple skidders.



Grapple skidder extracting a load of logs

TABLE 23

COMPARATIVE DATA FOR TWO GRAPPLE SKIDDER OPERATIONS IN EASTERN CANADA

	Case I	Case II
A. Type of product	tree length	full tree
B. General conditions		
i) terrain: roughness	normal	smooth
wetness	50% wet or very wet	100% dry
average grade	+ 1.2%	+ 0.6%
ii) volume/ha	200 m ³	320 m ³
iii) average volume/tree	0.14 m ³	0.25 m ³ (1)
iv) average volume/load	1.45 m ³	1.75 m ³ (1)
v) average number of bunches/load	1.3	1.0
C. Average travel speed in m/min		
i) empty	75	100
ii) loaded	50	60
D. Terminal times		
i) manoeuvring and loading	1.0 min/bunch	
ii) unloading and piling	1.0 min/load	
iii) average delay time	0.5 min/load	

Note: (1) merchantable wood

18. CLAM BUNK SKIDDERS

18.1 Wheeled Machines

These are articulated 4-wheeled or 6-wheeled drive machines fitted with cab and engine on the front chassis, a clam bunk on the rear chassis, and a knuckle boom with "loose" grapple usually pedestal-mounted near the point of articulation. They are used to skid bunched full trees or tree lengths from the stump area to roadside.

The payload, which may be expected when working on typical forest floor conditions, depends on engine horsepower and slope of the ground. Approximate payload weights in kg/GHP are shown in Tables 19 and 21, but may be less if the trees are so short that the clam is full before a full payload has been collected. It is considered that the coefficient of rolling resistance for typical skidding machines under typical forest floor conditions is 0.50; it is probably 0.40 in many plantation and pine stands, a condition which would increase the payload, and it may be considerably more on soft ground.

Since these machines work on the forest floor and are man-operated, they are subject to adjustment percentages to basic production time per tree or per m³ to compensate for terrain, climate, operator motivation, etc. (see Section 11.2), but to a less extent for some, such as terrain.

Production time per m^3 may be increased (or, conversely, production rate per unit time may be reduced) by trees left standing within the swing arc of the trees being loaded, by poor bunching, and by improper placement of the bunch in relation to the skidding trail. For best results, trees should be neatly bunched at a low angle to and near the skidding trail with the butt ends forward; the farther from this ideal, the greater should be the time adjustment.

Average round trip travel speed between roadside and loading site normally ranges within 10% of 60 m/min. This is an important factor in determining optimum feeder road spacing.

Unloading time averages 1 minute per load, as the machine is driven out from under the load with the clam open.

18.1.1. Skidding tree lengths

The payload in kg/hp that may be expected when skidding tree lengths under typical forest floor conditions may be read from Table 19 and converted to m^3/hp when the weight of the wood being harvested is known. Thus, given a 160 hp clam bunk skidder working in tree length wood weighing 900 kg/ m^3 , the expected payload on level ground would be

$$\frac{160 \times 80}{900} = 14 \text{ } m^3$$

The basic production time of 0.8 min/ m^3 for loading tree lengths is that obtained by a proficient operator loading on level clear-cut ground from well-made bunches placed at a small angle to and near the trail. Tests indicate that basic production time should be adjusted by + 25% when bunches are placed perpendicular to the trail and that total adjustment for the adverse loading factors mentioned might reach or even exceed + 50%.

Production time per m^3 should not be affected significantly by stand density (bunch size or by small trees as several may be loaded together).

Production, expressed in m^3/PMH , may be estimated with the following formula

$$PCBSM = \frac{60 \times L}{L \times 0.8(1 + \sum TA) + \frac{2 ASD}{ATS(1 - TAT)} + 1}$$

where $PCBSM$ = estimated production in m^3/PMH ;

TA = adjustment factors to be applied to basic production time of 0.8 min per m^3 (see Sections 11.2 and 14);

TAT = terrain adjustment factors (see Section 11.2);

ASD = average skidding distance in m (see Appendix D);

ATS = average travel speed in m/min (see Section 18.1 above);

L = expected payload in m^3

$$= \frac{X \cdot GHP}{W}$$

where X = payload weight in kg/hp read from Table 19;

GHP = gross horsepower of skidder;

W = weight of unbarked wood in kg/m^3 .

The cost of skidding tree lengths with clam bunk skidders may then be found with the formula:

$$CBSCM = \frac{C + c(1 + f)}{PCBSM}$$

where $CBSCM$ = skidding cost in US\$/m³;

C = cost of US\$/PMH, excluding operator, of operating skidder;

c = direct wages of operator in US\$/PMH;

t = cost of fringe benefits expressed as a percentage of direct wages;

$PCBSM$ = production of skidder in m³/PMH.

18.1.2 Skidding full trees

The payload in kg/hp that may be expected when skidding full trees may be read from Table 21. The value read may be converted to m³ of merchantable wood per hp as explained in note (2) appended to the table.

It is reasonable to expect that basic production time per tree for loading full trees would be greater than when loading tree lengths - probably by 25%. Considering also that 35% less merchantable wood per load is delivered to roadside when skidding full trees the basic loading productive time would be around 1.50 min per m³. This basic productive time per m³ would require to be adjusted for the same factors as when skidding tree lengths.

Production, expressed in m³/PMH of merchantable wood, may be estimated with the same basic formula as used for tree lengths:

$$PCBSM = \frac{60 \times L}{L \times 1.5(1 + \sum TA) + \frac{2ASD}{ATS(1 - TAT)} + 1}$$

where $PCBSM$ = estimated production of merchantable wood in m³/PMH;

TA = adjustment factors to be applied;

TAT = terrain adjustment factor;

ASD = average skidding distance in m (see Appendix D);

ATS = average travel speed in m/min;

L = expected payload in m³ of merchantable wood

$$= \frac{X \cdot GHP \cdot 0.70}{W}$$

where X = payload weight in kg/hp read from Table 21;

0.70 = % of merchantable wood in full tree;

GHP = gross horsepower of skidder;

W = weight of unbarked wood in kg/m³.

The production cost of skidding full trees with clam bunk skidders may then be found with the formula:

$$CBSCM = \frac{C + c(1 + f)}{PCBSM}$$

where $CBSCM$ = skidding cost in US\$/m³ of merchantable wood;

C = cost, excluding operator, of operating skidder in US\$/PMH;

c = direct wages of operator in US\$/PMH;

f = cost of fringe benefits, expressed as a percentage of direct wages;

$PCBSM$ = production in m³/PMH of merchantable wood.

A comparison of full tree skidding with tree length skidding using clam bunk skidders shows that production in m³ of merchantable wood per PMH will be down around 45% and cost per m³ will be up around 75%.

There are also to be considered:

- (i) the problem of disentangling the trees and clearing up the clutter of branches and tops at roadside unless hauled away to mill;
- (ii) the effect on feeder road spacing - optimum spacing would be much closer when full tree skidding, thus increasing wood cost.

18.2 Tracked Machines

They consist of a crawler chassis equipped with a clam bunk and a hydraulically controlled knuckle boom fitted with grapple. They are used to skid bunched full trees, butts forward, in the same manner as wheel-mounted articulated machines, loading one or two trees at a time. The low chassis height and the forward placing of the clam bunk makes a much better weight distribution than is possible with wheeled skidders. Travel speed in rather soft ground varies from 40 to 90 m/min. They have better performance on slopes and improved manoeuvrability in wet areas than wheeled skidders.

19. FELLER-SKIDDER

Most feller-skidders are essentially forwarders on which the loading grapple has been replaced with a felling head and the load carrying platform with a clam bunk or bunk jaws. They are then skidders which fell and collect their loads of full trees from the uncut forest instead of from trees which have been felled by other means.

In practice, the machine moves to the back of the strip, turns and starts to fell and load facing the roadside landing. If the machine has a heel-type felling head, it may work down the centre of the strip, otherwise it must work along the face of the uncut forest thus cutting a strip only half as wide and travelling twice as far as a feller-buncher. The felling cycle time per tree is essentially the same as for felling and bunching, i.e., around 20 seconds or 0.33 min. Moving along the strip, however, takes much longer due to both the additional distance covered, the drag of the payload and manoeuvring time and difficulties. Tests indicate that this reaches around 0.12 min per tree to give a basic production time of 0.45 min per tree. However, this production time is subject to the time adjustment percentage described in Section 11.2 for all machines working on the forest floor and in Section 14.1 for feller-bunchers.

Travel speeds between loading site and roadside landing depend on gross machine load, engine horsepower and the terrain. Round trip travel speed will normally average within 10% of 60 m/min.

The average skidding distance for an operation will depend on feeder road spacing (see Appendix D) and the estimated values of the correction factors T and V.

Unloading is a simple function requiring only that the operator open the bunk jaws and drive out from under the load - an operation normally requiring 1 minute.

Feller-skidder production, expressed in m^3/PMH , may be estimated with the following formula when values of the input factors are known:

$$\text{PFSM} = \frac{60 \times L}{\frac{L \times 0.45 (1 + \sum TA)}{VT} + \frac{2ASD}{ATS (1 - TAT)} + 1}$$

where PFSM = fell-skidding production in m^3/PMH ;

TA = adjustment percentages, expressed in decimal form, to be applied to basic production time in min/trees;

TAT = terrain adjustment factor (see Section 11.2);

VT = average volume per tree in m^3 ;

ASD = average skidding distance in m (see Appendix D);

ATS = average round trip travel speed in m/min;

L = expected payload in m^3

$$= \frac{X \cdot 0.70 \cdot \text{GHP}}{W}$$

where X = payload weight in kg/hp read from Table 21;

GHP = gross skidder horsepower;

W = weight of unbarked wood in kg/m^3 .

The cost of felling and skidding may then easily be found with the formula:

$$\text{FSCM} = \frac{C + c(1 + f)}{\text{PFSM}}$$

where FSCM = felling-skidding cost in $\text{US\$}/\text{m}^3$;

C = cost of operating feller-skidder in $\text{US\$}$ per PMH (excluding operator);

c = operator direct wages in $\text{US\$}$ in $\text{US\$}/\text{PMH}$;

f = cost of fringe benefits expressed as a percentage of direct wages;

PFSM = production of feller-skidder in m^3/PMH .

20. FELLER-FORWARDERS

Feller-forwarders fell and accumulate full trees in the same manner as a feller skidder but carry the trees clear of the ground in a load cradle on the rear chassis. These machines must of necessity be large articulated machines with sufficient power to negotiate forest floor conditions with heavy loads and with the length and capacity to carry complete trees while maintaining proper weight distribution. The only such machine known at the present time is manufactured by Koehring Canada Ltd. This is a very heavy machine costing $\text{US\$} 180\,000$ (1976), and weighing 40 000 kg with a payload capacity of 23 000 kg and the capability of working on grades up to 30-35%. The operator cab and pedestal-mounted knuckle boom are mounted on the front, the engine and rear-dumping load cradle on the rear chassis. It is fitted with four 43.5 x 39 tires.

The knuckle boom carries a multi-tree felling head fitted with a 60 cm shear and tree clamps which permit the cutting and accumulating of several small trees in the head before swinging and depositing them in the load cradle on the rear chassis. The advantages of such an accumulating felling head may be seen by examining the data in Table 24, which was compiled from a test following average 8-hour shifts, with a good operator in a deciduous forest averaging 0.22 m^3 per tree including the branches and tops. The complete trees were chipped at roadside. The ground was broken, with grades up to 25%, and the stand consisted of a few very large and many small trees.

TABLE 24
A LOADING RECORD OF KOEHRING KFF FELLER-FORWARDER

Trees per Cycle	Number of Cycles	Min per Cycle	Number of Trees	Min per Tree	Min per Load	m^3 per Load
1	10	0.58	10	0.58		
2	14	0.67	28	0.34		
3	13	0.76	39	0.25		
4	5	0.85	20	0.21		
5	2	0.94	10	0.19		
Sub-totals		0.71	107	0.29	31.0	23.6
Moving in strip	-	0.12	-	0.05	5.5	-
Totals		0.83	107	0.34	36.5	23.6

Three points emerge from examining the data in Table 24:

- (i) each tree cut and held in the accumulation requires an additional 0.09 minutes;
- (ii) an average of 2.43 trees were cut per cycle;
- (iii) each cycle produced an average volume of 0.535 m^3 .

Tests in coniferous forests show productive data of 2.5 - 3.7 trees per minute, 2.7 trees per cycle and other values to support the advantages of the multi-tree head. Overall data gathered on one test showed a production of $22 \text{ m}^3/\text{PMH}$ in stand averaging $0.177 \text{ m}^3/\text{tree}$ with an average forwarding distance of 160 m.

Travel speeds on the forest floor with the Koehring Feller-Forwarder are slow when compared with smaller machines. Some values from various sources are shown below in m/min.

<u>Light</u>	<u>Loaded</u>
27	23
57	42
37	24

Consideration is being given to increasing engine horsepower with the objective of improving travel speeds on the forest floor.

Unloading time is accomplished in one min, performed by tipping the load cradle to the rear.

There is no indication at this time (1976) that the machine will become widely used, for reasons associated with high capital cost and the deficiencies of the full tree system - unless or until technology develops a satisfactory method of utilising full tree chips of coniferous species or of separating bark from wood in chip form, or until the presently un-merchantable parts of the tree are used to produce energy economically.

21. DELIMBERS

Delimiting machines may be classified as single tree delimiters, of which the best known example is the Logma T-310, and multi-tree delimiters, such as the Hydro-AX.

21.1 The Logma T-310 Single-Tree Delimiter

The Logma delimiter was developed in Sweden. It is manufactured and distributed by Kockums Industri AB. It is mounted on the common 6-wheeled articulated base, is powered with 165 hp and weighs over 20 000 kg. It may work either in the stump area or at roadside. It is fitted with a telescopic delimiting boom, with a runout of 7 m and a reach of 12 m.

The Logma is designed to delimit and top directionally felled or bunched trees, working from the top end, and to bunch the tree lengths with butts ends even so that they may be readily bucked in place or skidded to roadside. It needs to delimit only as far as limbs extend down the tree stem. It may process more than one tree at a time if it can get hold of them. It does not work well where residual trees interfere with swinging and piling the delimiting trees. It is almost universally used on bunched trees, produced with feller-bunchers which perform most non-merchantable trees to perform well.

A 1970 study in Sweden (21) produced the following total times per tree:

<u>Average DBHOB in cm</u>	<u>Tree Volume in m³</u>	<u>Time in min/tree</u>
15.5	0.09	0.58
17.6	0.16	0.60
24.8	0.48	0.70

A later study in eastern Canada (22) in spruce and jack pine bunched trees on flat and undulating terrain with rock outcrops and swampy depressions, with a trained operator (4 months) produced the following formula for estimating productive time per tree:

$$HTT = 0.27 + \frac{227}{TH} + 0.35 VT$$

where HTT = total time in min/tree to delimit a tree of medium branchiness;

TH = number of merchantable trees per ha;

VT = average tree volume in m³.

Having due regard to the learning point of the operator and the terrain conditions, it is apparent that the basic productive time in min/tree should be around

$$0.80 (0.27 + \frac{227}{TH} + 0.35 VT)$$

To this value would have to be added the time adjustment percentages (TA) described in Sections 11.2 and 14.1, so that the adjusted productive time should become

$$0.80 (0.27 + \frac{227}{TH} + 0.35 VT) (1 + \sum TA)$$

Trees per ha and average tree volume are already considered in the formula.

The Logma T-310 has been used at roadside in eastern Canada on several integrated (sawlog-pulpwood) operations where mill policy required wood deliveries in tree length form. Production under such conditions, for the same tree sizes, ran around 40% greater than when working in the stump area. However, part of the reduced delimiting cost is offset by the higher costs of skidding full trees and brush disposal cost at roadside or landing.

21.2 The Hydro-AX Multi-Trec Delimber

The Hydro-AX, manufactured by National Hydro-AX Inc., Owatonna, U.S.A. has recently (1976) been accepted widely in temperate North America as a coniferous tree delimber. It is a chain flail type multi-tree delimber normally used at roadside but capable of being used in the stump area as well. It does not, however, top the trees; if this operation is required, it is normally done manually with power saw; neither does it do a clean delimiting job, but this is not mandatory when the wood is to be river driven and/or drum barked, particularly if destined for a kraft pulp mill.

The machine consists of an articulated rubber tired 117 hp skidder-like chassis, with the hydraulically operated delimber mounted on the front end. The delimber consists of a drum 2.75 m long and 0.45 m in diameter, to which 26 chains, 56 cm long and 4 shorter chains (near drum ends) 30 cm long, are attached along the drum in several staggered rows. The drum is semi-covered by a protective shield. It is driven at a selected constant speed by a hydrostatic pump motor, regardless of vehicle speed.

The machine works at roadside on bunched or thinly piled complete trees. In operation, it is driven forward up the pile of trees from the top ends toward the butt ends with the chain flail in operation, moving along as far as there are branches to be removed, then backs down along the same path with the flail still in motion to complete the delimiting operation.

Although delimiting production with the machine at roadside has been variously estimated as "the production of 12 skidders depending on skidding distance", "over 100 m³ per productive hour" and "about 500 m³ per day", production is practically limited only by the supply of optimumly arranged trees.

Delimiting and power saw topping at the roadside landing causes the usual clutter of debris which must be removed at a cost. Delimiting of felled and bunched trees in the stump area would leave the shattered branches and seed cones in the forest (where the silviculturists say they should remain), reduce the skidding cost (theoretically, at least) and the cost of cleaning up the roadside landings, but these advantages may be offset by increased wear and tear on the operating cost of the machine. The pros and cons are still being studied.

The optimum design of flail chains, the best material from which to make them, and the most satisfactory speed at which to rotate the drum are still under study. Tests have been made at speeds from 250 to 500 or 600 rpm. Chain wear and replacement cost is a major problem. In the early development stages a set of chains had to be replaced every 1 200 m³ at a cost of US\$ 400, but much progress has since been made in reducing the cost. One major logging company in eastern Canada reports delimiting over 400 000 m³ of wood during the 1975-76 logging season at a total cost of around US\$ 0.35/m³.

There are two models on the market: a small self-contained self-powered unit which can be attached to the front end of a skidder and a larger model, costing around US\$ 60 000, referred to above. Neither, however, has the capacity to break off limbs cleanly beyond 6-8 cm in diameter.

22. DELIMBER-BUCKERS

There are several such machines, usually called processors, mounted on rubber-tired 6-wheeled articulated vehicles and therefore capable of working in the stump area, and these and one other, with a rigid frame on wheels, capable of working at roadside. All are designed to delimb and buck trees singly and most of them to pile the logs produced.

22.1 Stump Area Delimber-Buckers

These machines fit into the short wood system when used in the stump area. Three machines available are of Swedish design and manufacture: the Kockum, the Volvo and the Ösa 705. The first two are fitted with telescopic tree feeding boom, the last mentioned with knuckle boom. Apart from this difference, their general appearance, operating method and productive capacity are quite similar. While in theory they can work on manually felled trees (a major reason for the long reach telescopic boom), in practice they are almost universally used to process bunched trees.

In operation these machines follow the feller-buncher trail, working on the level or up or down grade to process the trees bunched, when properly placed, perpendicularly to the direction of travel. In operation, the tree butt is dropped into the feed rolls of the delimber, the rolls are activated, and delimiting with knives or wrap-around knife belts and bucking with circular saw take place. Sawlogs are bucked, usually on manual command and shorter pulpwood automatically. Sawlogs are pushed aside and allowed to drop on the ground; pulpwood is usually collected in a load cradle which is emptied when full. Both lengths are then ready to be forwarded. Trees with butt diameter up to around 60 cm may be delimbed with machines.

When producing pulpwood, basic productive time per tree may be expressed with the formula:

- (i) $PDBT = 0.24 + 0.05 NB$ when producing 2.5 m logs (27) and
- (ii) $PDBT = 0.24 + 0.06 NB$ when producing 3 m logs.

when $PDBT$ = basic delimiting and bucking time in min/tree;

NB = average number of pulpwood logs per tree.

The factor 0.90 should be applied to the above time per tree if all saw log lengths are being produced and 0.95 if a mixture of sawlogs and short (2.5 - 3 m) pulpwood lengths are being made.

The basic productive time per tree should be adjusted by the factors described in Section 11.2, so that production in m^3/PMH may be estimated with the usual formula

$$PDBM = \frac{60 \times VT}{PDBT (1 - \sum TA)}$$

where $PDBM$ = delimber-bucker production in m^3/PMH ;

VT = average tree volume in m^3 ;

$PDBT$ = basic productive time expressed in min/tree (see preceding paragraph);

TA = time adjustment factors, expressed in decimal form, read from Section 11.2.

Delimiting and bucking cost may then be found with the formula

$$DBCM = \frac{C + c(1+f)}{PDBM}$$

where DBCM = delimiting and bucking cost in US\$/m³;

C = operating cost of delimiting-bucker in US\$/PMH found as described in Section 3.3.4;

c = direct wages of operator in US\$/PMH;

f = cost of fringe benefits expressed as a percentage of direct wages;

PDBM = delimiting-bucker production in m³/PMH.

Delimiting delays may occur if limbs over 7-8 cm are encountered, which require the operator to stop, reverse and reactivate the feed rolls to sever the limb, or if limbs, tops and debris become entangled in the delimiting head.

22.2 Roadside Delimiter-Buckers

The stump area processors described above may also be used at roadside. Production should be slightly higher due to better working conditions, but any advantage would be more than offset by the disadvantages associated with the production of full trees to roadside and by the cost of clearing accumulated debris from the landing.

22.2.1 The Hahn Processor

The Hahn is a small strictly roadside processor. It is mounted on two axles, one of which is powered and used to manoeuvre the machine during the processing operation. Trees to be delimited are placed on a level roadside landing around 75 m x 75 m or close to the side of and parallel to the road. The processor sits facing or opposite the tree butts. In operation, the knuckle feeding boom places the butts of a tree, or more than one if the trees are small, in the 45 cm delimiting head mounted on a small carriage at the front of the machine. The head closes about the tree and draws it, guided by a track, 2.5 m back to a guillotine shear near the centre of the machine, where it is held while the delimiting head returns to its initial position, shearing off the limbs en route. The operation is then repeated; the guillotine is activated at the appropriate moment, the severed log drops to the ground at the side of the machine and the entire process is repeated until the tree is completely delimiting and bucked. Saw logs may also be produced with the machine.

The machine, processing trees singly, is capable of producing around 1 tree per minute in a stand averaging 0.14 m³ per tree. In a production operation a battery of 4 processors working on a 2-shift basis produced 50 000 m³ of 2.5 m wood in 6 600 PMH at the average rate of 7.6 m³/PMH while working in a stand averaging 0.12 m³ per tree. A detailed study showed that 2 700 trees were processed in 1 530 cycles, i.e., at the rate of 1.76 trees per cycle in a cycle time of 1.1 min and time per tree of 0.63 min.

With the machine costing around US\$ 65 000, processing cost would have been around US\$ 2.00/m³ plus the cost of the operator and the cost of around US\$ 0.40/m³ to clear limbs, tops and debris from the processing area.

The Hahn Processor is a relatively simple delimiting-bucker. An operator is able to become reasonably proficient within a few weeks. It is a processor well suited to small logging operations.

22.2.2 The Arbomatik Processor

The Arbomatik Processor is strictly a roadside single-tree delimber-bucker with a telescopic tree getting boom, a continuous spiked roller feed at 55 m/min and a flying shear for bucking purposes. It works on full trees piled perpendicularly to the road, on which the machine sits when processing. In a stand averaging 0.14 m³/tree, actual production has been checked at 19 m³/PMH and potential production calculated to be about 20% greater.

The manufacturer, Forano Ltd., has discontinued production.

23. FELLER-DELIMBERS

Several types of feller-delimbers are on the market or under development in North America to produce tree lengths in the stump area. Some, like the Drott and the Poclain, are mounted on crawler chassis; others, like the Timberjack TJ-30 and TJ-40, the John Deere X-12TL and the Tanguay, are mounted on rubber-tired articulated bases.

23.1 Tracked Feller-Delimiters

The track-mounted machines are essentially feller-bunchers with feed rolls and delimiting knives incorporated in the felling head. The combined felling-delimiting head weighs in the order of 1 500-2 500 kg depending on the manufacturer, heavy enough to preclude the use of any but heavy-duty carriers.

In operation the machine generally works along the face of the uncut forest, cutting a strip between 5 and 11 m wide depending on the machine and operator practice. The tree is severed with a shear, lifted vertically, swung to an open and convenient processing area, tipped to a horizontal position more or less parallel to the machine. The delimber knives are closed and the feed rolls are set in motion; the tree is drawn through the delimiting knives, topped automatically at a pre-set diameter and dropped to the ground. The phases of the operation are thus sequential, the next felling operation being delayed while the tree is being processed. The bunching is not always suitable for grapple skidding; but the tree lengths may always be skidded with cable and clam bunk skidders.

Production with track-mounted feller-delimiters varies within wide limits, depending on tree size, terrain conditions, and operator skill and motivation. Time studies show that basic productive time is around 0.65 min/tree in a stand averaging 0.05 m³/tree in volume and increases 0.05 min/tree for every increase of 0.05 m³ in average tree volume. This is due to both the weight and the length of the larger trees. Basic productive time is the time/tree which a fully proficient operator can make when working on clean level ground in a clean coniferous stand averaging 0.05 m³/tree and containing 1 200 or more trees/ha. As for other machines working on the forest floor, it is subject to the time adjustment factors described in Sections 11.2 and 14.1. Having determined the adjusted productive time per tree, production and cost values may be obtained by applying the same basic formulae as for feller-bunchers set out in Section 14.1.

Delimiting quality is excellent with these delimiting heads but the system has some deficiencies. Not all heads are fitted with a topping shear; the tree lengths can be piled with butts even only with difficulty and additional time, or not at all; production, expressed in m³/PMH, is much affected by tree volume, as is the case with all single-tree processors. Strip width is less than with corresponding feller-bunchers due to the extra weight of the delimiting mechanism at the outer end of the boom. Use of this type of feller-delimiter is not spreading.

23.2 Wheeled Feller-Delimiters

Most wheeled feller-delimiters comprise essentially an articulated or knuckle felling boom, a delimiting conveyor or telescopic boom fitted with delimiting knives and, in most cases, a tree length load cradle with dumping arrangement. There are no wheeled feller-delimiters which may be considered fully developed. The nearest to that stage is the Timberjack TJ-30, a small-tree processor quite unsuited for large or long trees. However, due to the great interest in eastern North America in the tree length system at this time (1976) for reasons which have been mentioned elsewhere, several manufacturers have feller-delimiters in various stages of development. This is quite contrary to the situation in Sweden, for example, where the emphasis is on the short wood system with 80% of the wood being processed mechanically in the stump area.

Clark Equipment, John Deere, Forano and Tanguay are working on feller-delimiters, none of which are, however, beyond the prototype or preproduction stage (1976), and Eaton Yale (Timberjack) is working on the TJ-40, a larger version of the TJ-30. Koehring Canada has gone one step further and has a true tree length harvester (forwards as well as fells and delims) in the preproduction stage, a very large machine with a payload capacity of 18 000 kg (see Section 25). The John Deere and Forano machines are mounted on large basic skidder chassis; the Clark and Tanguay machines are larger and heavier. The Forano machine has the delimiter incorporated with the felling head in the same manner as the track mounted feller-delimiters. Some have load cradles to accumulate the processed tree lengths; some, at present, drop each processed tree on the ground.

The basic productive time in min/tree for some of these machines, derived from test data, is given below. Basic productive time may be defined as in Section 23.1 above. Basic times are subject to the adjustment factors described in Sections 11.2 and 14.1, since these machines work on the forest floor. Having determined adjusted productive time in minutes per tree, production in m^3/PMH and cost in US\$/ m^3 may be estimated with the usual formulae (see Section 14.1).

23.2.1 The Timberjack TJ-30

Conceived as a plantation row thinning machine and prototyped in Australia, the TJ-30 was developed by Eaton, Yale Ltd. for use in natural forests. It weighs slightly over 13 000 kg and is mounted on the basic 94 hp Timberjack 330 skidder chassis. It is designed to fell, and process small-diameter trees. Maximum felling shear capacity is around 30 cm tree butt diameter.

In operation the tree is reached with a short (3.6 m) swinging "inverted" knuckle boom, clamped, sheared, lifted, lowered back over the machine and laid into the delimiting head on a horizontal telescopic boom, and held with the felling clamp; it is then automatically delimbed, topped and ejected sidewise into a 2 250 kg load cradle, which is side dumped when full. The felling boom is then free to get another tree. Maximum delimiter stroke is 10 m; thus limiting the maximum length of merchantable stem which can be processed without shifting the tree forward with the felling boom and clamp. Each such shift forward increases by about 2.5 m the stem length which may be processed but increases harvesting time per tree by about 20%. Normal strip width is around 5 m.

Basic productive time was found to be in the order of 0.65 min per tree in a stand averaging $0.05 m^3$ per tree. Increase in tree volume increased basic time by 0.05 min for each $0.05 m^3$ increase in volume, an amount which would have to be added to basic productive time when necessary.

Care must be exercised when lowering the tree onto the delimiter mechanism of the TJ-30 because of shock loads to the superstructure.

23.2.2 The Tanguay Feller-Delimiter

The machine weighs 50 000 kg and is powered with a 230 hp engine. It is mounted on 6 wheels, a single axle at the front with 33.25 x 35 tires and tracks. It travels backward while at work.

It is equipped with a knuckle felling boom with a 7.5 m reach and a 45 cm shear. The delimiter is conveyor type extending beyond the front (rear while working) of the machine and fitted with 4 feed rolls and 3 delimiting knives. The felled tree is swung to the rear (front while working) of the machine, lowered to a horizontal position and dropped into the delimiter infeed end. Delimiting and topping are automatic; the processed tree is conveyed to the rear and ejected to either side. While the delimiting is going on, the operator fells another tree. The machine can move or harvest, but cannot perform both actions simultaneously.

Basic productive time per tree was determined from test data to be 0.47 min/tree. However, this basic time is subject to the usual adjustments (see Sections 11.2 and 14.1).

24. SELLER-DELIMBER-BUCKERS

These are machines that fell trees and produce short wood in the stump area. They are not considered to be true harvesters as they do not transport the processed wood to roadside. Again as in the case of feller-delimiters, some are track mounted, others are mounted on articulated rubber-tired chassis.

24.1 Track-Mounted Feller-Delimiter-Buckers

These machines are feller-delimiters with the additional short-wood bucking function built into the felling-delimiting head. As the tree is drawn through the delimiting knives by the feed rolls, it is stopped at the appropriate point usually by a butting plate, the bucking shears (actually the felling shears) are activated, the log is severed and allowed to drop to the ground.

Productive capacity of this type of machine has been tested and found to be around 25% less than for corresponding feller-delimiters, so that production in m^3/PMH may be found by taking basic productive time to be 0.85 min/tree and applying the usual formula including the time adjustment factors outlined in Sections 11.2 and 14.1:

$$PFDEM = \frac{60 \times VT}{0.85 (1 + \Sigma TA)}$$

These track mounted processors are subject to the same deficiencies as the corresponding feller-delimiters. The head weighs in the order of 2 000-2 500 kg, a heavy weight to be hung at the outer end of a knuckle boom expected to fell and handle complete trees. As in the case of track-mounted feller-delimiters, use of these machines is not expected to spread.

24.2 Wheel-Mounted Feller-Delimiter-Buckers

These machines are principally of Swedish design and manufacture: the Kockum, the Volvo and the Usa. They are essentially delimiter-buckers on which the tree feeding grapple has been replaced with a light felling head capable of also dragging the felled tree and feeding it into the delimiting head. The tree cannot be lifted and held in a vertical position as with a feller-buncher head.

For practical purposes, production with these machines varies little among them and differs little, if any, from that of corresponding delimber-buckers. This is based on being able to reach out, fell and bring trees to the delimiting head at approximately the same rate at which they can be processed. Tests show that in the case of delimber-buckers, each - the feeding boom and the processor - occasionally is forced to wait a few seconds for the other. This waiting time is not expected to be greater when using a felling boom instead of the feeding boom. Production and cost formulae will therefore be found in Section 22.1, which are equally applicable to felling-delimiting-bucking.

25. FELLER-DELIMBER-FORWARDERS

These machines are Tree Length Harvesters in that they fell, delimb, accumulate and forward tree length wood to roadside. They are, perforce, large machines. Koehring Canada Ltd. has a prototype selling for US\$ 210 000 and undergoing field trials at present (1976). It weights 45 000 kg and has a payload capacity of 18 000 kg to give total gross weight of 63 000 kg. It is a 4-wheeled articulated machine with the cab and pedestal-mounted boom on the front chassis and engine, load cradle and limbing rail and carriage on the rear chassis. All four wheels are hydrostatically driven and designed to take 43.5 x 39 tires. The knuckle boom carries a 60 cm multi-tree felling head, enabling several small trees to be accumulated in felling head clamps prior to delimiting.

The delimber is manually controlled (not automated), is capable of delimiting several trees simultaneously but at present (1976) has no means of topping them.



Feller-delimber-forwarder laying down cut tree on rail-mounted delimiting carriage

In operation the felling boom cuts the tree - or several if the trees are small - swings it to the rear, lays it down on the rail mounted delimiting carriage, holds it while the delimiting knives remove the branches at a speed of 3 m/sec, and then deposits it in the load cradle.

No detailed breakdown of unit production time is available but production in one 8-hour shift during the field test reached 115 m^3 delivered to roadside in a stand averaging $0.14 \text{ m}^3/\text{tree}$. A test also showed a production rate of 124 trees/PMH at an average of 2.7 trees per cycle at a cycle time of 1.3 minutes.

26. FORWARDING

26.1 General

Forwarding is the transportation of wood from stump area to roadside with the payload carried clear of the ground. Both traction and rolling resistance will be greater for the same payload than when skidding, but the frictional drag of the payload will be non-existent.

Forwarding, as a separate operation, is an essential part of the short wood system (except for harvesters which forward their own production). Tree lengths and full trees may also be forwarded, but the practice of forwarding full trees is not likely to become common at the present stage of mill technology. If trees are being delimated mechanically in the stump area, it is logical that the additional operation of bucking into short wood should be done at the same time. There is no sound reason to forward full trees which have already been felled unless the entire trees are being delivered to mill or chipped at roadside.



Articulated short wood forwarder

26.2 Forwarding Short Wood

Forwarding of short wood may be done manually, with animals or with machines. Loading and unloading may be done manually or mechanically, and the wood may be piled down at roadside or offloaded to another vehicle to avoid a rehandling cost.

The operation of forwarding is discussed at considerable length in Chapter 8 of FAO manual "Harvesting Man-Made Forests in Developing countries" (2). The manual refers to forwarding with manpower, with oxen and trailers, with modified skidders (packsacking), with small crawler, agricultural type and non-articulated 4-wheel drive tractors towing trailers, and with the specially designed self-loading all-wheel drive machines, called forwarders, some capable of carrying payloads up to 16 000 kg of short wood. Much space is given to the various components of mechanical forwarding operations and a detailed form is shown for estimating production and cost.

26.2.1 Self-loading short wood mechanical forwarders

For those who are more concerned with approximating production and cost values quickly, the following method may be used. It is required to know

- (1) stand density in m^3/ha ;
- (2) log length in m;
- (3) forwarder payload capacity in m^3 ;
- (4) grapple closed area or diameter (see Table 25);
- (5) forwarder acquisition cost in US\$;
- (6) average strip width in m.

To obtain production in m^3/PMH proceed as follows:

- (1) read grapple capacity (GC) in Table 25;
- (2) knowing stand density and strip width, read strip length (SL) per m^3 of forwarder load in m (Table 26);
- (3) take average grapple loads to be 0.70 GC when loading and 0.90 GC when offloading;
- (4) take average grapple cycle time to be 0.50 min;
- (5) take average forwarder travel speeds on level clean ground to be 40 m/min (ATSS) while loading in the strip and 60 m/min (ATS) on the trail to and from roadside;
- (6) find optimum feeder road spacing with the usual formula (Appendix D.1) and average forwarding distance (Appendix D.3) or measure the distance on the ground.
- (7) estimate the value of time adjustment factors (TA) that should be applied to compensate for poor terrain conditions, climate, operator training, operator skill and motivation and personal delays (10%) as set out in Section 11.2;
- (8) apply the formula.

$$PFM = \frac{60L}{\left(\frac{0.50L}{0.70GC} + \frac{L \times SL}{ATSS} \right) (1 + \sum TA) + \frac{2 AFD}{ATS (1 - TAT)} + \frac{0.50L}{0.90GC} (1 + TAP)}$$

where PFM = production in m^3/PMH ;

L = forward payload in m^3 ;

GC = grapple capacity in m^3 ;

SL = strip length per m^3 of payload;

ATSS = 40 m/min = average travel speed while loading in the strip under optimum conditions;

AFD = average forwarding distance in m ;

ATS = 60 m/min = average travel speed while travelling to and from roadside;

TA = time adjustment factors to be applied to basic productive time;

TAT = terrain adjustment factor (Section 11.2);

TAP = personal adjustment factors (Section 11.2)

Forwarding cost per m^3 may then be found with the formula

$$FCM = \frac{C + c(1+f)}{PFM}$$

where FCM = forwarding cost in US\$/ m^3 ;

c = direct wages of operator in US\$/PMH;

f = cost of fringe benefits expressed as a percentage of direct wages;

PFM = forwarding production in m^3/PMH ;

C = $\frac{2.4A}{LE}$ = cost in US\$/PMH, excluding operator, of operating forwarder;

where A = acquisition cost of forwarder in US\$;

LE = life expectancy in PMH, as read in Section 3.3.3.

26.3 Forwarding Tree Lengths

Tree lengths are normally skidded to roadside. However a prototype forwarder for such wood has been under development in eastern Canada since 1970 (23). Called the Dungarvon Tree-Toter or Forwarder, it has a rotating (40°) rather than an articulating frame, a ground clearance of 90 cm, positive drive to all four wheels and 38.5 x 35 lug type tires. The machine weighs around 28 000 kg in unloaded condition and is designed to carry a payload of 26 000-28 000 kg. Its estimated purchase price was US\$ 150 000 in early 1976, i.e., US\$ 5.35/kg. It is powered with a 318 hp engine and a transmission to provide 6 speed ranges from 0.6 to 35 km/hr at 2 250 rpm. Its weight to gross horsepower ratio is 170.

The objective of the development programme was a vehicle which could haul loads of 28 m^3 of tree length wood at relatively high speed on the forest floor for distances of several km economically in order to reduce the need for expensive feeder roads. The forwarder is required to be loaded with a separate loader in the stump area from bunched wood. It is thus strictly a carrier. Loading rate with a special hydraulic grapple during field tests was 2.26 m^3/min . Unloading by means of a hydraulic side dump arrangement averaged 3 minutes per load. Average round trip travel speed was 187 m/min .

Development work on the forwarder is continuing. It is likely that a self-contained loader will be incorporated on the machine.

TABLE 25

CALCULATED CAPACITY (1) IN m^3 OF GRAPPLES OF VARIOUS SIZES
($1 m^3 = 1.67 m^3 t$) (2)

Closed grapple Area in m^2	Inside diameter in cm	Log length in metres					
		1 $F = 0.67$	2 $F = 0.64$	3 $F = 0.61$	4 $F = 0.58$	5 $F = 0.55$	6 $F = 0.52$
0.20	50	0.14	0.26	0.37	0.47	0.55	0.63
0.25	56	0.17	0.32	0.46	0.58	0.69	0.78
0.30	62	0.20	0.38	0.55	0.70	0.83	0.94
0.35	67	0.23	0.45	0.64	0.81	0.96	1.09
0.40	71	0.27	0.51	0.73	0.93	1.10	1.25
0.45	76	0.30	0.58	0.82	1.04	1.24	1.40
0.50	80	0.34	0.64	0.92	1.16	1.37	1.56
0.55	84	0.37	0.70	1.01	1.28	1.51	1.71
0.60	87	0.40	0.77	1.10	1.39	1.65	1.87

Notes: (1) grapple capacity = area in m^2 x log length in metres x factor F
where F = ratio of wood volume inside bark to stacked volume of unbarked wood
(2) $m^3 t$ = stacked volume
(3) the value of the factor F will vary somewhat with log length because longer logs tend to lie less closely together when grouped.

TABLE 26

STRIP LENGTH PER m^3 OF FORWARDER PAYLOAD

q = volume per hectare in m^3	SW = Strip width in metres		
	10	15	20
20	50	33	25
30	33	22	17
40	25	17	12
50	20	13	10
60	17	11	8
70	14	10	7
80	12	8	6
90	11	7.5	5.5
100	10	6.5	5
120	8	5.5	4
150	6.5	4.5	3.5
200	6	3.5	2.5

27. SHORT-WOOD HARVESTERS

Short wood harvesters are machines that fell, delimb, buck and top the trees in the stump area, transport the processed wood to roadside, and offload it to truck or trailer or pile it down at roadside. The Koehring KH3D Shortwood Harvester which produces 2.5 m³ wood is the only production machine capable of doing this. It was designed especially for eastern Canadian conditions. It is 10 m long and 4.6 m wide. It weighs around 43 000 kg light and has a payload capacity of around 14 000 kg, i.e., around 15 m³ of the common coniferous species found in eastern Canada. It is fitted with 37.5 x 39 tires which provide a ground clearance of 86 cm, and a climbing capacity of 40% grades when fitted with chains. The price of the machine is presently (1976) around US\$ 230 000. There are about 150 at work at the present time.

This is an articulated machine with the operator's cab, the knuckle tree getting boom, the offloading boom and the processing tower mounted on the front and the engine and load cradle on the rear chassis. The tree boom is fitted with a 50 cm felling shear, with optional multi-tree feature. It has a capacity of over 1 100 kg at full reach of 6 m. The trees are processed at an angle of 35° from the vertical to allow the branches to fall clear off the machine. It can process trees up to a diameter of 40 cm. The engine develops 210 hp, to give the loaded vehicle a weight to gross power ratio of 210, low for work on difficult terrain.

The machine is operated by one man, who manipulates the tree boom to shear the tree, lift and hold it in a vertical position, then swing and thrust it laterally into the holding jaws near the top of the processing tower. As soon as the jaws close, the operator goes after another tree while the processing and stowing proceed automatically. In this operation the delimber head moves up the tree 2.5 m, shearing off the limbs en route, while at the same time the tower moves to the leaning position. The stroker cylinder then moves down, the first log is sheared off and "kicked" onto two conical feed rolls which propel the log into a channel beneath the load cradle. It is then "stuffed" upward hydraulically into the cradle. The processing operation is continued until a pre-set top diameter is reached, at which time the top is sheared and allowed to drop to the ground and the tower returns to the vertical (with respect to the machine) position ready to receive the next tree. A time of 6 seconds is required to process each 2.5 m log.

When a load has been processed, the machine travels to roadside, where the operator uses the knuckle offloading boom and grapple to pile the wood at roadside or on truck or trailer. Travel speeds vary widely according to terrain conditions. Tests show speeds light and loaded on flat firm forest floor averaging 65 m and 50 m/min respectively, and as low as 30 m and 20 m/min respectively on soft ground with the machine sinking from 15 to 60 cm. Upgrade travel speeds, particularly loaded, are also low due to the high weight-power ratio.

Offloading requires 1.0 minute per cycle using a grapple with a closed capacity of 1.5 m³ of 2.5 m wood and piling the wood on the ground neatly so that it can be measured for payment of government dues. This includes rotating every second grapple load 180° to alternate butts for wood measurement purposes. The cycle time of 1.0 minute is double that for forwarders offloading to trucks or trailers with a grapple 25% smaller. Offloading to trailers would probably be somewhat faster.

On good terrain where the Harvester is able to maintain a level position, using the optional multi-tree felling head and processing two or more trees simultaneously works reasonably well. The problems are associated with the log conveying and stuffing operation.

Harvester production depends to a major extent on tree volume. When harvesting trees below 15-16 cm DBH, the processor may have to wait for the tree; with larger trees the reverse may be true; normally, however, with a proficient operator, this is not the case and the processor usually determines the rate of production. Production is affected also by tree spacing (the number of merchantable trees per ha), terrain and operator



Short wood harvester for complete processing of trees in the stump area & forwarding to roadside training (learning curve), skill and motivation. Table 27 shows an approximate relationship among DBHOB, merchantable volume and number of 2.5 m logs per tree.

TABLE 27 (1)

APPROXIMATE RELATIONSHIP AMONG DBHOB, MERCHANTABLE VOLUME
AND NUMBER OF 2.5 m LOGS PER TREE

<u>DBHOB in cm</u>	<u>Merchantable volume in m³</u>	<u>Average Number of 2.5 m logs/tree</u>
10	0.026	1.6
12.5	0.057	2.6
15	0.102	3.6
17.5	0.161	4.4
20	0.232	5.1
22.5	0.315	5.7
25	0.41	6.2
27.5	0.51	6.7
30	0.63	7.1
32.5	0.75	7.4
35	0.88	7.7
37.5	1.03	7.9
40	1.19	8.0

Note: (1) for use when no other regional data are available.

Harvesting production in m^3/PMH may then be expressed with the formula below when harvesting trees singly:

$$PHM = \frac{60 \times L}{L(0.25 + 0.10NL + 0.10x + 0.20y)(1 + \sum TA)} + \frac{2AFD}{ATS(1 - TAT)} + UL(1 - TAP)$$

where PHM = production in m^3/PMH ;

L = average payload in m^3 ;

NL = average number of logs per tree;

x = percentage of merchantable trees in the stand between 12 and 14 cm DBH;

y = percentage of merchantable trees in the stand below 12 cm DBH;

VT = average merchantable tree volume in m^3 ;

TA = adjustment factors to be applied to basic processing time per tree (Sections 11.2 and 14);

AFD = average forwarding distance in m ;

ATS = average round trip travel speed in m/min ;

TAT = terrain adjustment factor (Section 11.2);

UL = offloading time in minutes per load;

TAP = personal adjustment factors (basic, learning, skill and motivation).

Harvesting cost in $US\$/m^3$ may then be found with the formula:

$$HCM = \frac{C + c(1 + f)}{PHM}$$

where HCM = harvesting cost in $US\$/m^3$;

C = cost of operating harvester, excluding operator, in $US\$/PMH$;

c = operator direct wages in $US\$/PMH$;

f = cost of fringe benefits expressed as a percentage of direct wages;

PHM = harvesting production in m^3/PMH .

28. ROADSIDE CHIPPING

Kraft pulpmills in many regions of North America are using in the mill furnish a percentage of full tree chips, mainly hardwood, produced at roadside with portable chippers. These units are generally semi-trailer mounted, range from 8 to 12 m long and weigh from 10 to 30 tons. They comprise essentially a feed-in conveyor fitted with pressure feed rolls, 2-knife or 3-knife chippers powered with 375-400 hp or 450-550 hp respectively, a knuckle-boom loader with grapple for feeding the conveyor, and a pneumatic pipe to carry the chips into a trailer van or other vehicle. Chipper discs range up to 1.7 m in diameter.

One loader operator may run the machine, assisted, when necessary, by a man on the ground with a power saw to remove oversize butts, large hardwood branches and other troublesome growths that might cause chipping problems. Production varies with species, tree size and season of the year. Observations give production with 2-knife chippers of 20-40 tons of green chips per PMH, and 150 tons/shift in winter and 200 tons in summer.

Chipping at roadside may fit into any of the three major logging systems, but is generally associated with full tree chipping of hardwood species at roadside. The use of

full tree chips from softwood species in most manufacturing plants is restricted by technology's inability up to the present time to devise an economical method of segregating and separating bark from wood chips. The operation of keeping a roadside chipper supplied with trees normally involves the use of feller-bunchers and grapple skidders or feller-skidders.

Forwarders, however, are better suited to the chipping system as the trees are carried clear of the ground from the stump area. Skidded wood gathers sand and dirt en route. This accelerates chipper wear, and both increases maintenance cost and lowers chip quality progressively. In some severe conditions (from skidding), chipper knives have to be changed and sharpened after each hour's chipping - a 30-minute job.

The main advantages realised from full tree chipping are:

- (a) a much greater volume of wood fibre from each unit area of forest land (from 40% to 100% depending on circumstances), resulting eventually in a shorter hauling distance to mill;
- (b) higher man day productivity - double, in some cases;
- (c) cheaper wood fibre at the mill;
- (d) more attractive cutover areas, easier to regenerate either naturally or artificially.

There are some disadvantages:

- (a) the bark influences mill production rates and costs and product appearance;
- (b) creates screening problems as well as, in some cases, rechipper problems with twigs and oversize chips.

29. SLASHERS

29.1 Canadian Slashers

The term "slasher" in the context of this manual refers to mobile machines for bucking tree length wood into short wood at roadside or final landing. They are therefore component machines of the tree length system. Many slashers are in use in eastern North America to produce 1.22 m logs and multiples thereof up to 5 m in Canada and Northern U.S.A., and 1.6 m logs farther south. All consist primarily of a conveyor trough fitted with driven rolls, a knuckle boom with heel-boom type grapple to feed the conveyor, two or three manually controlled cut-off saws and, for certain situations, a knuckle boom with short wood grapple. All are, of necessity, long and heavy machines, riding on pneumatic tires and stiffened with a pair of stabilising legs at the heavy end when working.

Tree length wood to be slashed with the above-mentioned machines should be piled perpendicularly to, and with butt ends towards the road. This reduces skidding distance and improves skidding production. The landing is required to be cleared of standing trees but does not need to be bulldozed - the tree lengths are left lying on the forest floor. The slasher sits on the road while working.

Roadside slashers producing 2.45 m logs require a 3-man crew, one to operate the feeding boom and keep the conveyor supplied with tree lengths, one to operate the conveyor rolls to advance the tree lengths and operate the saws, and the third to remove the slashed wood from the load "basket" and pile it at roadside. Each operator works from a weatherproof cab. Several trees are normally dropped into the conveyor trough simultaneously and slashed together, the smaller the trees, the greater the number.

When 1.22 m wood is produced at roadside, the third operator is not required, as the slashed wood is carried from the saws by a short conveyor, dropped pell-mell into truck body boxes and hauled immediately to the final landing. When tree lengths are slashed at

river side or on a winter dumping area which is flooded during high spring run-off period, the slashed wood is also carried from the saws by conveyor and allowed to drop into the river or onto the ground pell-mell.

Normal production, with the crew working on day wage basis, ranges around 40-45 m³/PMH when working at roadside, regardless of the log length produced, at a cost of around US\$ 1.10/m³. Production at final landing, where the tree lengths are piled, higher and less moving is required, averages around 50-55 m³/PMH and sometimes reaches 70 m³/PMH at a cost well under US\$ 1.00/m³. There is a record of one mobile slasher in eastern Canada having produced more than 300,000 m³ of short wood during the 1975-76 logging year with a well-motivated crew.

Mobile slashers of the above type cost around US\$ 140 000-175 000, depending on the manufacturer and design frills, and have a life expectancy of at least 15 000 productive hours. There are slashers working with over 30 000 hours on their records.

29.2 Other Buckers and Slashers

There is a variety of other less productive bucking and slashing devices in use in various regions of the world, many used by logging operators who have insufficient use for such highly productive machines as described above. There are a number of these in North America, particularly in the United States, many constructed in local machine shops to fit into a specific local logging system.

Roadside slashers are also used in Sweden (24), but to a less extent than in Canada due to prevalence of the shortwood logging system. Some, such as the Logma and the Hallefors, are constructed on used truck chassis to produce 3 m logs or both 3 m wood and sawlogs. These use a single knuckle boom and grapple for both feeding the slasher saw and removing and piling the logs produced. A longer and heavier Swedish roadside slasher is the Morenius (24), which resembles to some degree the Canadian slashers described above. It uses two operators, one to operate the single knuckle boom to feed the machine and one to operate the saws.

There are also grapple mounted hydraulically powered saw buckers, like the 30 hp Ösa 770, incorporated with knuckle boom loaders. In operation the loader grasps one or more tree lengths near the butt end, bucks the grapple load to the appropriate lengths, piles the grapple load in the designated place, grasps the remaining tree length again and repeats the procedure until bucking has been completed.

30. CABLE YARDING SYSTEMS

Cable yarding is the transportation of raw forest products from the stump area to a point at roadside, with one of the various wire rope high lead or skyline yarding systems available. The latter are commonly called cable crane systems. As a general statement, ground skidding methods are more economical than cable yarding where there is a choice between the two. The limiting factors for ground skidding are steepness (around 6%) and roughness of the ground and the problems associated with erosion on mountainous areas, and the bearing capacity of the soil on flat terrain.

Because of the overall wood cost reductions possible, there has been throughout the world a gradual increase in ground skidding and a corresponding decrease in cable yarding. The change-over in some countries has been emphasised by the scarcity of specialised labour, and the reluctance of younger workers to undergo the long training period necessary to instal and operate the more complex and attractive cable yarding systems. Recent developments in cable crane equipment and techniques, such as the radio-controlled cranes and the mobile spar, have tended to shift the break-even cost point back toward cable yarding, but not to such an extent that the trend will likely be reversed.



Mobile cable crane equipment extracting logs in thinning operations

Cable yarding systems may be classified as:

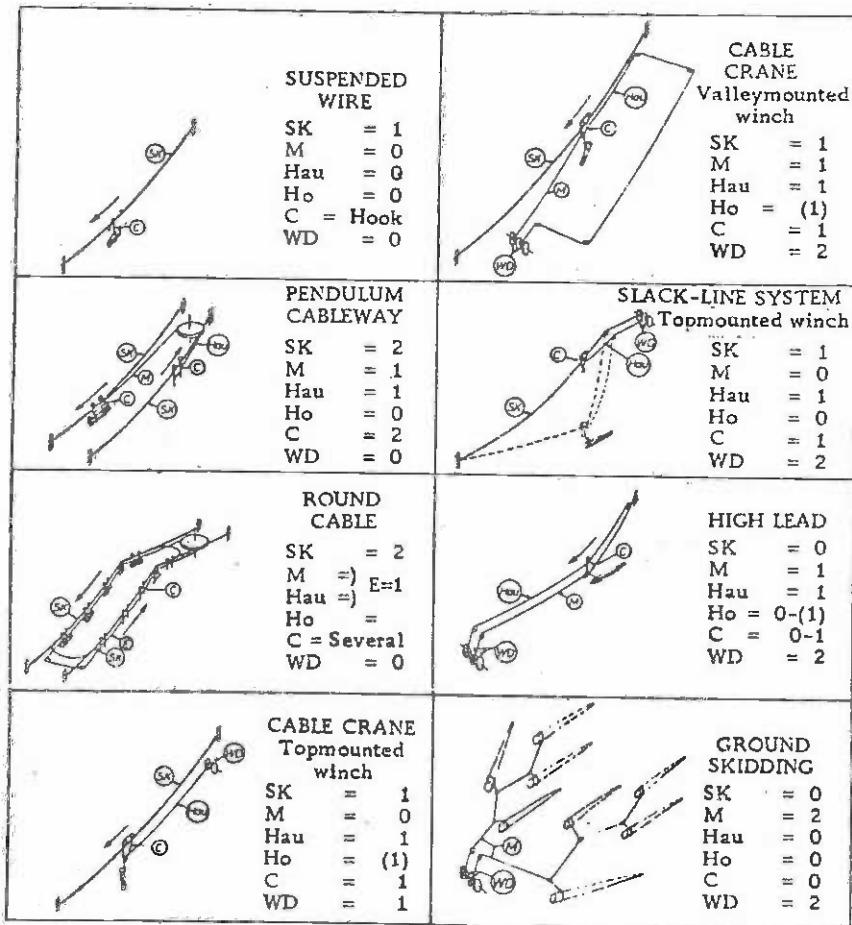
- (a) short distance systems, up to 700 m long, serving the minor or primary transport phase and delivering the logs direct to feeder road;
- (b) long distance systems, up to 1 500-2 000 m, which may, on occasion take over the function of the feeder road as well.

The latter system may be installed permanently if road construction is economically impracticable due to high costs and low stand density and site productivity in the area.

Cable yarding systems may also be classified as

- (a) high lead systems with a maximum yarding distance of 300 m;
- (b) cable cranes or skyline systems, both short distance (up to 700 m) and long distance (up to 2 000 m).

Table 9 lists briefly some of the characteristics and practical limitations of some cable yarding systems regarding lengths and payloads as they apply to temperate zones. Figure 9 illustrates some cable yarding systems used in Europe, and other publications describe many of those in use on that continent as well as in Japan and the Pacific Northwest of North America (1)(8).



SK = skyline

Ho = hoist line

M = main line

C = carrier

Hau = haulback line

WD = winch drum

Figure 9 - Some cable yarding system illustrations.

30.1 Some High Lead Yarding Systems

High lead systems, as the name implies, are those yarding systems in which the front end of the log is given a lifting effect by the head spar or a skyline of some sort to reduce dragging forces and hangups. Several of these are mentioned briefly: the true high lead and some skyline systems.

The true high lead is the simplest cable system and is used widely, chiefly for uphill yarding, where distances do not exceed 300 m and ground disturbance and erosion are not problems. It consists of a yarder with 2 yarding drums and a smaller straw-line drum (for rigging setups), a head spar (nowadays a mobile spar), main and haulback lines, butt rigging and chokers.

The running skyline is also a high lead yarding system in that the logs are not necessarily carried clear of the ground. Its use is limited to 700 m. It comprises a head spar and tail holds, a yarder with 3 interlocking drums and a strawline drum, the haulback (which serves as the running skyline), main and slack pulling lines of the same size, and a carriage riding on the haulback skyline and carrying tong line and chokers. It derives

its advantages from the facts that no large-diameter single skyline is required and that the drum assembly is fitted with an infinite ratio interlocking system which permits the line to be tensioned or slackened at any time. The maximum permitted tension in the line may be predetermined and set according to payload weight and yarding road profile. The running skyline system has a number of obvious advantages over the conventional high lead system: wider feeder road spacing, less damage to the soil, lateral yarding possible, etc.

A logging company in South America, working in an area where the ground has such a low load-bearing capacity that ground transport is not practicable, uses a modified North Bend System to ground yard bundled 1.5 m wood for distances up to several hundred metres. The output of such a system depends on yarding distance and terminal time to hook and unhook the loads. Output figures, for example, for yarding distances of 100, 500 and 1 000 m are in the order of 10, 5.5 and 3.5 m^3/hour respectively. The average trip payload is 0.85 m^3 .

30.2 Some Fixed Skyline Yarding Systems

There are a number of fixed skyline yarding systems and variations thereof, which carry the turn of logs clear of the ground. Several of these are variations of the Tyler system developed in the Pacific North West of North America. Some are radio controlled. Probably the best known of the latter is the Norwegian radio controlled cable crane, which allows felling and minor transport to be combined into a single operation.

The Norwegian system comprises a mobile power plant, a fixed skyline, a carriage, an endless carriage-pulling line and a grooved winch drum around which the endless cable is wound several times. The system is limited to a yarding distance of 700 m. The worker at the top end fells, delimbs and tops the trees, fits the chokers and attaches them to the carriage tong line and sets the carriage on its way by means of the radio controlled winch. The bucker at the lower end unhooks the load, returns the carriage to the feller and completes the processing operation. Production per 2-man crew day under average conditions is around 16 m^3 .

A modification of the Tyler yarding system is used in one region of South America on level low-load bearing ground to swing yarded 1.5 m wood to truck road in bundles averaging 1.13 m^3 . It comprises head and tail spars, a 2-drum winch, standing skyline, main line, carriage and endless carriage pulling line wrapped several times around its drum. It can be, but is seldom, used for distances up to 1 000 m. Average output of the system varies with yarding distance and terminal times; for example, average output for distance of 100, 500 and 1 000 m is around 9.5, 6.1 and 4.2 m^3/hour respectively.

30.3 Optimum Spacing of Long Distance Cable Cranes

Under some very rugged and steep terrain conditions where truck roads are economically impracticable, long distance cable cranes may have to be constructed and lateral skidding used to bring the wood from the stump area to the cable crane. A problem of major importance is to find the optimum spacing of such system in a broad forest area where several setups may be required. Theoretically it should be possible to apply the same principles as used to determine the optimum feeder road spacing for a given skidding or forwarding method (see Appendix D).

The initial capital cost of the stationary parts of the cable crane (spars and skyline) less their salvage value at the end of the operation together with cost of clearing the right-of-way and of installing, maintaining and dismantling those stationary parts may be likened to the cost of constructing and maintaining a feeder road; the operating parts of the cable crane (yarder, moving lines and carriage) may be likened to the skidder and the operating cost/PMH, including yarder operator (but not the lateral skidding crew) depreciation, interest, fuel, operating repairs, etc. may be calculated; lateral skidding and main line loads are identical, as well as the volume of wood to be harvested per hectare;

travelling time for lateral skidding $t(1 + p)$ in the optimum feeder road spacing formula expressed in min/m should be known from experience, with the value of p approaching or perhaps at times exceeding 2.0 to cover angle skidding in steep slopes and delays.

Practical application of the formula may be difficult or it may result in an impracticable lateral skidding distance since the cost of the skyline installation is fixed and cannot be modified at the will of the logging manager as can be a feeder road standard.

It is a fundamental principle that minimum overall logging costs per m^3 will be attained when the three costs - road, variable (travelling) skidding or forwarding and variable (travelling) hauling, all expressed as a cost per m^3 - are identical (see Appendix I). This is based on the principle, among others, that there is a choice respecting the amount of money that may be spent on the road. When this principle is violated - as is the case when erecting a cable crane (in place of constructing a feeder road) - the minimum overall cost possible under the circumstances may still be realised when variable skidding and variable hauling costs/ m^3 are equal. In respect to cable cranes, this will occur when the travelling portions of lateral skidding and main line hauling costs are equal. Since these operations are performed by the same equipment, their operating costs/PMH or PMM are identical, as are their payloads as well. It follows therefore that the optimum cable cranes spacing may be found by equating these costs, or even more simply, by equating travelling times to produce the following formula:

$$ASD \cdot t (1 + p) = AHD \cdot T \quad \text{so that } OCCS = \frac{4 \cdot AHD \cdot T}{t(1 + p)}$$

where OCCS = optimum cable crane spacing in metres;

ASD = average lateral skidding distance in m, measured perpendicularly to the skyline;

AHD = weighted (according to location of the wood to be harvested) average main line hauling distance;

t = average time in min/m required to haul the lateral skidding line out to the logs and to skid in the load; (ascents and descents of the line may be considered as fixed time and disregarded);

T = average travelling time, empty and loaded, in min/m for each load;

p = a factor to cover angle skidding to the skyline on steep slopes and delays in the loading zone (see paragraph 2 of 30.3 above).

31. SECONDARY TRANSPORTATION

31.1 General

Secondary transportation covers the movement of the wood from roadside to final landing, whether that be river, railroad, barge or mill. This manual is restricted to transportation by truck; it will not consider river driving, barging or rail hauling. It covers loading at roadside and unloading at destination.

There are two major types of loaders (knuckle boom and front end loaders), several major types of hauling equipment and numerous unloading methods. This manual can do no more than review them briefly and point out some of the critical criteria.

The most suitable type of rig for a specific project depends on the form of the material to be hauled, the road characteristics, desired travel speeds and vehicle dimension and weight regulations. A further associated point is that, given suitable conditions, hauling is more economical with combination rigs than with "straight trucks" (see 31.2) by a considerable margin.

31.2 Hauling

31.2.1 Vehicle configurations

The term "straight truck" usually refers to an automotive vehicle designed to carry the load directly on its own body structure. A combination rig comprises a truck-tractor (usually called by the term "tractor") and one or more trailers. A trailer train is a combination rig consisting of a tractor and two or more trailers.

Some of the possible configurations are shown in Fig. 10. In addition to these are:

- (a) double semi-trailer rigs, in which the king pin of the rear semi rests on the rear bogie of the first semi-trailer;
- (b) trucks with tandem front axles, one of which may be driven;
- (c) articulated centre frame steered trucks with front and rear bogies, under development in Canada by The Rubber Railway Company, Cambridge, Ontario;
- (d) the dirigible axle full trailer manufactured by Kockum in Sweden.

There is also some special hauling equipment on large wheels and low pressure tires which is able to travel over very poor feeder roads and even to penetrate beyond the normal roadside landing which has built-in speed sufficient to make it economical to haul reasonably long distances on forest roads. Such a machine is the Volvo EM 860 TC articulated hauler.

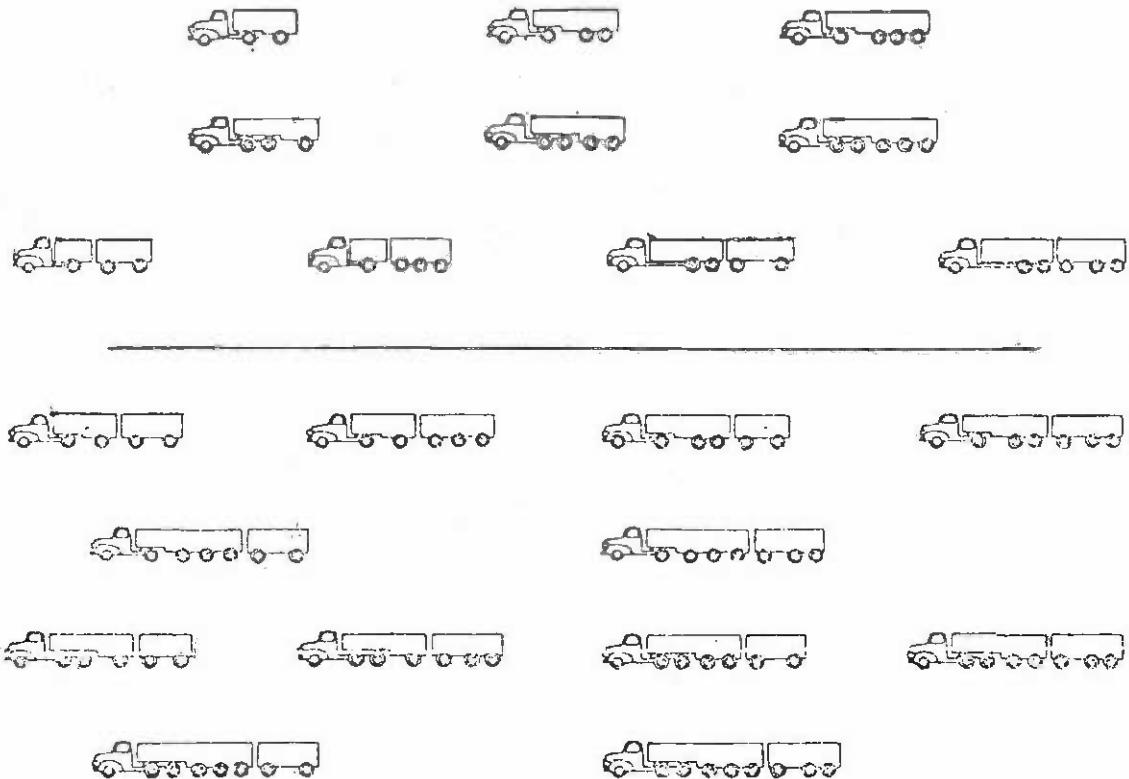


Figure 10 - Some typical truck-tractor combination rigs.



Unloading of tandem axle semi-trailer to be connected with truck head for log transport

There are advantages and disadvantages to each of the two basic types of combination rigs: tractor-semi-trailers and tractor-full-trailers. The semi-trailer rig must be used to haul tree lengths and full trees; it can be manoeuvred more easily around restricted feeder roadside landings; it is more stable (less tendency to jackknife) at high speeds. The double semi-trailer rig is equally stable, but no better than the full-trailer rig for manoeuvring or for hauling tree lengths.

It is easier to have a greater proportion of the gross combination weight on the powered axles of a loaded tractor-full-trailer rig when loaded, but problems might be encountered on steep adverse grades when returning light to the roadside landing unless the trailer is loaded on the tractor. It may be necessary for the same reason to load the rear semi of a double semi-trailer rig when running light. There are several means of doing this: tractor mounted winch, heavy duty log loading and unloading equipment, A-frame and winch, etc.

A tractor-full-trailer rig (a truck towing a full trailer) will offtrack on the curves less than the corresponding semi-trailer rig unless the trailer tongue is so long that this advantage is lost. It may be a choice between a long trailer tongue and some loss of stability (respecting jackknifing).

Some comments may be in order concerning hauling rigs in general. The most compact loading may be attained when hauling short wood loaded crosswise - when log lengths exceed 2 m. Experience has shown that logs up to 5 m in length may be hauled in this manner. The vehicle platform for such an operation need only be 2 main I-beam rails with an open framework headboard at the front and substantial stakes at the rear together with self-tightening load-binding devices running from front to rear. Short wood may, of course, be hauled loaded lengthwise on both straight trucks and combination rigs.

Tree lengths are normally hauled butts forward, but when load width and height are restricted, as on most public roads, the upper half of the load may be loaded tops forward to obtain a bigger payload and better weight distribution. If all butts are forward, it is normal practice for the rear bunk to be 20-25% shorter and from 30-50 cm higher than the front bunk.

31.2.2 Horsepower requirements

The horsepower of the hauling truck-tractor must be great enough to overcome the four resistances affecting every hauling rig: rolling, grade, air and chassis friction, and to allow travel at a desired speed under specific conditions. Altitude must also be considered, particularly if gasoline power plants are used, since gasoline engines lose power at the rate of 1% for each increase of 100 m in altitude (6).

Table 28, expressed in pounds but convertible to kg, gives approximate rolling resistances of some commonly encountered road surfaces and their equivalent grade resistances (10 pounds = 4.5 kg = the resistance equivalent to 1% adverse grade). Air resistance may be disregarded at speeds less than 50 km/hr (6). Chassis friction is usually taken as 15% of net or flywheel horsepower, though it may vary between 10% and 20% depending on transmission gear and number of driving axles (6).

Weight-power ratio is the ratio of gross vehicle or combination weight to net or flywheel horsepower. It will provide a short method of approximating the suitability of a tractor engine for a specific hauling job. The ratio should be low enough to provide the desired road speed, yet not so low that the rig is needlessly overpowered. Table 29 (6) expressed in the English system of measurement but convertible to the metric system, shows the weight-power ratios necessary to overcome various combined rolling and grade resistances at various speed up to 30 mph (about 50 km/hr).



A heavy duty logging truck in tropical high forest operations

TABLE 28
SUGGESTED UNIT ROLLING RESISTANCES

Road class	Class description	Surface condition	Unit rolling ⁽¹⁾ resistance	Equivalent grade %
1	Rigid pavement	Smooth, best	8	0.8
		Average, fair	9	0.9
		Poor, rough	10	1.0
2	Flexible pavement; treated and packed gravel	Smooth	10	1.0
		Average, fair	13	1.3
		Poor, rough	15	1.5
3	Sand-clay, gravel, crushed gravel or stone surface; untreated; deforms under load	Smooth, well-compacted with little or no loose surface material	15	1.5
		Smooth, well-compacted with thin layer of loose or muddy surface material	18	1.8
		Fair, average, some washboard	20	2.0
		Poor, rough, heavy washboard	25	2.5
		Smooth, well graded, dry (not sand)	25	2.5
4	Natural soil and earth roads	Rough, dry (not sand)	28	2.8
		Rough, damp, soft	40	4.0
		Sand, damp	75	7.5
		Sand, dry	100	10.0
		Mud, deep, with bottom	100	10.0
5	Ice, hard-frozen snows; frozen summer roads; no surface deformation	Smooth, no loose snow	10	1.0
		Average, scarified, frozen summer gravel and natural soil roads	15	1.5
		Poor, rough	20	2.0
6	Snow; sub-grade not frozen deeply	Well-packed, 2 inches thick, not hard-frozen	30	3.0
		Poorly packed	50	5.0

Note: (1) expressed as pounds per 1 000 pounds of gross vehicle or combination weight.

TABLE 29

WEIGHT-POWER RATIOS REQUIRED TO OVERCOME VARIOUS RESISTANCES
AT VARIOUS VEHICLE SPEEDS UP TO 30 MPH

Combined grade and rolling resistances ⁽¹⁾	Vehicle speed in miles per hour					
	5	10	15	20	25	30
1%					1 275	1 060
2%			1 060	800	640	530
3%		1 060	710	530	425	355
4%		800	530	400	320	265
5%	1 275	640	425	320	255	210
6%	1 060	530	355	265	210	175
7%	910	455	300	230	180	150
8%	800	400	265	200	160	135
9%	710	355	235	175	140	120
10%	640	320	210	160	130	105
11%	580	290	195	145	115	
12%	530	265	175	135		
13%	490	245	165			
14%	455	230				

Note: (1) Where road rolling resistance is expressed in grade % with 10 pounds of unit rolling resistance (pounds of rolling resistance per 1 000 pounds of gross vehicle weight) equalling the resistance due to a 1% adverse grade; so that, for example, the value of 4% in the left-hand column represents one of the combined resistances below:

Adverse grade	Unit rolling resistance
0%	40 pounds
1%	30 pounds
2%	20 pounds
3%	10 pounds

The use of the table may best be illustrated with two examples (given in English measure since reference is made to Table 29):

(1) An operator is required to gross loads of 100 000 pounds at a speed of 20 mph up a 2% grade on a gravel road which has a unit rolling resistance of 20 pounds (i.e., 20 pounds per 1 000 pounds of gross vehicle weight), and wants to know how powerful the engine will be required.

The total resistance is equivalent to a 4% adverse grade. Reading across from 4% in the left-hand column of the table, the weight-power ratio will be found under 20 mph, indicating that an engine generating 100 000 : 400 = 250 net horsepower will be required.

An operator is hauling on a gravel road with a unit rolling resistance of 20 pounds with a semi-trailer unit fitted with an engine generating 300 gross horsepower and wants to know the gross load weight that can be hauled up a 4% grade at 20 mph.

A 300 GHP engine generates $300 \times 0.935 = 280$ NHP (see 3.3.5). Total resistance = 4% adverse grade + 20 pounds URR = 6%. Reading across from 6% in Table 29, the value of 265 will be found under 20 mph. The gross load which can be hauled = $265 \times 280 = 74\,000$ pounds.

31.2.3 Vehicle dimension and gross weight regulations

The envelope dimensions of a hauling rig, both light and loaded, must satisfy pertinent regulations respecting overall length, width and height. This is referred to in Chapter 6.

The total weight of a loaded rig and, normally, its axle loads also must satisfy pertinent regulations, if subject to such restrictions. Most public highways, if properly engineered, are built to support certain axle loads with normal axle spacing (50 in = 1.27 m in North America). However, by increasing the spacing of axles of a bogie and/or using triple-axle bogies under a trailer, axle capacity will be increased with no greater deteriorating effect on the road (see Tables in Appendix B). Private roads are not normally subject to either vehicle dimension or weight restrictions.

The weight distribution of a hauling rig by axle or bogie is usually supplied by the manufacturer. Knowing the payload unit weight, it is usually a straightforward mathematical exercise to calculate the weight distribution of the loaded rig by axle (6).

It is particularly important that the proportion of the gross load supported by the powered axles be great enough to permit sufficient traction to be developed to overcome the maximum rolling and grade resistances encountered on a hauling job (see Section 4 in Appendix C). This is vital where steep grades and/or poor traction conditions prevail. The proportion should approach 40%, but should not be below 30%.

31.2.4 Tires (6)

Tires represent a substantial part of the cost of operating a hauling rig and should be given high consideration. They should have the required carrying capacity to support the load and should be operated within certain tolerances respecting overload, underload and travel speeds. Tire treads should be the most suitable for each wheel position on the rig; for example, high-traction tires for the powered wheels and smoother tires for all other positions unless traction tires are needed for increased tire hold on forest roads during braking. Some tires, such as the Michelin M+S4, are particularly good mud and snow tires.

Radial steel cord tires are considered by most logging managers to be superior to bias cord tires for several reasons: allowable higher speeds, lower fuel consumption by 5%-10%, less subject to heat buildup (better heat dissipation). The choice must be made between tubeless and tube-type tires, between wide singles and duals, between conventional and wide singles on the tractor front axle (the latter increases steering effort).

31.2.5 Other vehicle components

Design and capacity of suspensions, front and rear axles, wheels, braking system, clutch, transmission, drive lines, etc., are largely the responsibility of the vehicle manufacturer. However, the logging manager and his engineer should be able to assure themselves of their adequacy. They should be more concerned with certain trailer components, such as bunks for saw logs or tree lengths, parking legs, king pin offset and trailer overhang (since their position affects load distribution and axle loadings), cab and parking leg clearances when turning, load binders and many other items.

The front wheels of tractors hauling combination rigs should not be equipped with brakes, unless required by law or regulation, in order to reduce the possibility of jacking the rig or running off the road with locked front wheels during the braking process, particularly on a curve.

All these matters are discussed at length in the University of New Brunswick publication "Trucks and Trailers and their Application to Logging Operations" (6).

31.2.6 Costing hauling equipment

The operating cost of hauling equipment should be expressed as a cost per standing hour and a cost per travelling hour, since they differ at a ratio of around 1 to 3. The subject is discussed in Chapter 3 and in Appendix H.

Acceptance of this manner of costing hauling equipment means that the variable or travelling portion of the hauling cost is inversely proportional to travel speed, so that, for example, doubling the travel speed will halve the hauling cost per m³. This illustrates the advantages of engineering, building and maintaining haul roads well.

The operating cost of trucks and trailers per standing hour and per travelling hour may be approximated with the calculation shown in Table 30.

TABLE 30

FORM B FOR APPROXIMATING THE OPERATING COST PER HOUR
FOR TRUCKS OR TRUCK-TRACTORS AND TRAILERS

Item	Operating cost per hour		
	Truck or Truck-Tractor	Trailer	Total
(1) $\frac{C_1}{15\ 000}$	-	x	x
(2) $\frac{C_2}{20\ 000}$	-	-	x
(3) c (1 + f)	-	x	x
(4) Cost/standing hour	-	xx	xxxx
(5) $\frac{2.4 \times C_1}{10\ 000}$	-	x	x
(6) $\frac{2.4 \times C_2}{15\ 000}$	-	-	x
(7) Cost/travelling hour	-	xxx	xxxxx

where C₁ = acquisition cost of truck or truck-tractor;

C₂ = acquisition cost of trailer;

c = operator's hourly wage rate;

f = cost of fringe benefits expressed as a percentage of direct wages.

3.1.2.7 Application of truck and trailer operating costs

This may best be illustrated with an example:

(a) Find the hauling cost, excluding loading and unloading, assuming the following input data:

- (1) truck-tractor costs US\$ 45 000; semi-trailer costs US\$ 15 000;
- (2) operator direct wages are US\$ 2.00 per shift hour; fringe benefits 50% of direct wages;
- (3) average payload is 34 m³;
- (4) loading time is 30 min and unloading time is 10 min per load;
- (5) there is a delay allowance of 10 min/load waiting at terminals;
- (6) hauling distances and speeds are as follows:

	Average hauling distance in km	Average round trip travel speed in km/hr
(i) feeder road	1	10
(ii) secondary road	10	30
(iii) main road	40	60

(b) The solution may be developed as follows:

- (1) using Table 30, the operating cost of the hauling rig will be US\$ 6.75 per standing hour and US\$ 20.00 per travelling hour;
- (2) terminal costs in US\$/m³, excluding loading and unloading costs, will be as below:

	Time/load in hours	Cost in US\$ per m ³
Loading	0.50	0.10
Unloading	0.17	0.034
Delays	0.17	0.034
Total per trip	0.84	0.17

(3) travelling cost in US\$/m³/km may be calculated as below:

	Average hauling distance in km	Average travel speed in km/hr	Round trip		Travelling cost	
			Travel time in hrs	Cost in \$	per m ³	per m ³ /km
Feeder road	1	10	0.20	4.00	0.12	0.12
Secondary road	10	30	0.67	13.30	0.39	0.04
Main road	40	60	1.33	26.70	0.79	0.02
Total	51	32	2.20	44.00	1.30	0.025

The overall hauling cost, excluding loading and unloading, may then be expressed as a fixed rate of US\$ 0.17 per m³ plus a travelling rate of US\$ 0.025 per m³/km. However, it should be noted that the hauling rate on the feeder road is 6 times the rate on the main road and 3 times the rate on the secondary roads, and that possibly it would pay to upgrade the poorer roads.

31.3 Loading

31.3.1 General

Loading of raw forest products is usually done mechanically. In certain regions where the raw material is short and light enough to be handled by one man, loading may be done manually. This is particularly the case where wage rates are low and labour is plentiful. An operation in Colombia, for example, hand loads 1.5 m logs and split logs manually with 2-man crews at the rate of 5-6 tons per man hour. The practice is still in effect to some degree in eastern North America where much 1.22 m wood is still made, when operations are small and trucks are operator-owned.

In some tropical regions short logs may be hand rolled up skids onto the vehicle by pushing or by parbuckling with ropes of manila or similar material. Animal power may be used to provide parbuckling power when available. Loading may also be done with elephants in some south-east Asian countries where these animals are used for skidding purposes.

There are many different ways of using machines to load hauling vehicles. Tractors and winches of all kinds may be used to load material of saw log length by lifting or parbuckling with or without benefit of A-frame, gin pole, or mast and swinging boom. Sometimes the winch may be mounted on and powered by the hauling vehicle through its transmission. In some cases bulldozers are used to push large logs up skid poles onto the hauling vehicle. Such methods as outlined above are of particular use when logs are large and the operation is too small to afford the capital outlay for more modern loaders.

There are two general types of roadside mechanical loaders: those with knuckle boom and appropriate grapple, and those fitted with log fork (front end loaders) or grapple (such as the Cary-Lift loader) and travel between log pile and hauling rig during the loading operation. Both types are mobile and most of the machines can be used to load shortwood, tree length or full tree, though some have severe limitations; for example, front end loaders loading shortwood less than 2 m long. Stiff-boom cranes, fitted with log grapple, are also used to a small extent to load saw logs and longer material. Some shortwood forwarders and harvesters have the capability of offloading directly to hauling rig and thus saving a rehandling cost. When this is practised, spare trailers, either semi or full type, are usually parked at roadside.

31.3.2 The Pettibone Cary-Lift shortwood loader

This loader is built in a series of sizes. It is mounted on a non-articulating 4-wheel drive-and-steer chassis and fitted with a hydraulically operated continuous-rotation pulpwood grapple of appropriate size to handle shortwood from 1.22 m to 5-6 m in length. It is best suited for 2.5 m wood, and works best on level and smooth landings. The loader proper is cantilevered in such a way that the grapple load can be retracted near the chassis for better weight distribution when travelling.

In operation, the loader moves to the log pile, reaches forward and grapples a load, lifts it and draws it back close to the chassis, turns and travels to the hauling rig, lifts the grapple load and thrusts it forward over the centre line of the hauling rig, then lowers and opens the grapple slowly to allow the logs to spread out on the rig without jack-strawing.

The Cary-Lift Super 20 is commonly used in pulpwood operations in eastern North America. It carries a grapple with a 2.4 m² closed area, capable of holding 3.5 m³ of 2.5 m wood. However, in practice the average grapple load is considerably less due to problems concerned with grasping a full grapple load at the log pile at all times and levelling off the truck or trailer load. A test gave the following data when loading 2.5 m wood:

(1) average grapple load 2.2 m^3

(2) minutes per grapple cycle:

- (a) grappeling load at log pile 0.37 min
- (b) releasing load at truck 0.35 min
- (c) turning and travelling to and from log pile 0.45 min
plus 0.02 min/m of distance between log pile and truck
- (d) delays (arranging wood on log pile and truck load, unproductive travelling and other delays) 1.03 min

From these data the following formula may be derived:

$$LT = \frac{1.3 + 0.02 TD}{AGL}$$

where LT = loading time in min/ m^3 ;

TD = average distance in m between truck and log pile;

AGL = average grapple load in m^3 ;

The same formula may be applied to other Cary-Lift loaders.

31.3.3 Stiff-boom crane loaders

Various sizes of cranes from $\frac{1}{2}$ to $\frac{1}{4}$ cubic yard (North American nomenclature) are used in some regions to load both short wood and tree lengths, but mainly in 2.5 and 5 m wood. Some are crawler mounted; others are mounted on wheeled carriers. Crawler machines may work off the road, following up the rollway of logs, but move slowly between rollways; wheeled machines can travel much faster but must work on firm ground.

Various types of grapples, all wire rope controlled, are in use, including a double grapple for handling 2 ranks of 1.22 m wood simultaneously. Tag lines are required to restrict and control the movement of the grapple. An operator requires a long training period to attain full proficiency. Single grapples weigh 1 300-1 600 kg and cost in the order of US\$ 6 000-7 000. Double grapples are heavier and more costly. Cranes have a very long life expectancy. Grapple and wire rope operating (repair and replacement) costs run around US\$ 1.50 and 1.25 per PMH respectively.

Cranes have a loading rate of $125-150 \text{ m}^3/\text{PMH}$, but normally lose much time - sometimes as much as 50% of shift time - waiting and moving.

31.3.4 Knuckle boom loaders

Knuckle boom hydraulic loaders may be turntable mounted on their own mobile carriers or on the platform of a 6 x 4 truck of suitable GVW capacity. All wheeled loaders are equipped with outriggers. When the loader is truck mounted, the engine driving the hydraulic loader pumps is installed on the turntable. They may be fitted with a pulpwood grapple for loading shortwood or with a heel boom grapple for loading tree lengths. Small knuckle boom loaders may be mounted on the truck frame behind the cab of a hauling truck or at some point farther back on a combination rig to form a self-loading hauling unit.

Table 31 gives some typical grapple payloads which various sizes of knuckle boom loaders can handle at various boom reaches.



Truck mounted hydraulically operated loading crane

TABLE 31

SOME TYPICAL NET PAYLOAD CAPACITIES OF KNUCKLE BOOM LOADERS
EXPRESSED IN kg

Type of loader mount	Max. boom reach in m	Typical net payload capacity ⁽¹⁾ in kg at various boom reaches in m		
		3 m	6 m	Maximum
Truck	6	5 000	2 350	-
Platform	7.5 ⁽²⁾	8 500	4 100	3 000
	9 ⁽²⁾	17 700	8 600	5 000
	6.5	2 200	900	850
	6.5	1 600	730	700
4-wheel carrier	9	18 000	8 700	5 000
Truck frame behind cab	6	3 500	1 200	-

Notes: (1) net payload capacity is the gross capacity less weight of the grapple;

(2) counterweight with heel boom grapple.

(a) Loading tree lengths with heel boom grapple

For this type of operation, the tree lengths are piled in a rollway perpendicularly to and with butts toward the road. In operation the hauling rig and the loader must manoeuvre until the former is facing the hauling direction and the loader, whether truck or carrier mounted, is backed into position in front of and close to it. This takes in the order of 3 minutes per load. The loader reaches out, grapples a load of tree lengths 3-4 m from the butt end, heels it against the heel boom, raises the entire load, swings it and lays it down on the semi-trailer by reaching back over the truck-tractor cab. If the loader cannot reach enough wood to complete the load, both the loader and the hauling rig move to a new position. After the loading operation has been completed, the loader must be driven from the road at some point to allow the hauling rig to be on its way.

Tests indicate that

- (i) total fixed time per trailer load ranges between 5 and 7 minutes;
- (ii) average grapple loads runs around 1.05 m^3 ;
- (iii) average grapple cycle time ranges between 0.55 and 0.60 minutes, depending on operator proficiency;
- (iv) loading rate runs around $1.75 \text{ m}^3/\text{min}$, excluding the fixed time mentioned in (i) above.

Loading time in minutes per truck-trailer load and loading cost per m^3 may then be determined with the following formulae:

$$(1) \text{LT} = 6 + \frac{0.55 \text{ L}}{\text{GL}} \quad \text{and}$$
$$(2) \text{LCM} = \frac{\text{LT} / \bar{C} + o(1 + f)}{60 \text{ L}}$$

where LT = loading time in minutes per truck-trailer load;

LCM = loading cost in US\$/ m^3 ;

L = truck-trailer load in m^3 ;

GL = average grapple load in m^3 ;

C = operating cost of loader in US\$/PMH, including carrier but excluding operator;

c = operator direct wages in US\$/PMH;

f = cost of fringe benefits expressed as a percentage of direct wages.

(b) Loading 2.5 m logs crosswise with knuckle boom and pulpwood grapple

Some knuckle boom loaders for handling short wood have excavator (tracked) base and superstructure, together with appropriate boom and pulpwood grapple. Other loaders are mounted on wheels as described in the previous section.

Logs, the length of which approximate the maximum allowable load width, such as 2.5 m, are usually loaded crosswise on the truck or trailer as this provides the most compact form of load as well as easy unloading by dumping or pushing off.

For this type of loading operation, the wood is usually ranked in one or more rows along the roadside. The loader sits at the side of the hauling rig, grapples the wood and transfers it to the truck or trailer. It is a straightforward operation - the reverse of a forwarder offloading at roadside. Contrary to the situation when loading tree lengths, there is no need for the loader and the hauling rig to waste time jockeying into position preparatory to loading and/or moving to a new loading position.

The loading rate will vary with the size of the loader and grapple and the proficiency of the operator. The loading operation comprises

- (i) a fixed time per load to position the hauling rig, pull away when loading has been completed and apply the self-tightening load binders, and
- (ii) a variable loading time per m^3 .

As soon as one hauling rig has pulled away, another may take its place, thus wasting a minimum of loading time.

On a typical hauling operation in eastern Canada using a typical knuckle boom loader and $1.2 m^3$ grapple, the time to transfer $42 m^3$ of $2.5 m$ wood to a trailer was 30 minutes at the rate of $1.4 m^3/min$.

31.3.5 Front end log loaders

Front end log loaders are mounted on a crawler tractor chassis with some suspension changes or on a 4-wheel drive articulated chassis. All are equipped with a log fork with or without extension arms 50-60 cm long to increase lifting height and a "kicker" to assist in removing logs from the fork at high lift. Crawler mounted log loaders range from 15 000 to 20 000 kg and wheeled log loaders from 15 000 to 35 000 kg and cost in the order of US\$ 5.50-6.00 per kg. The horizontal skid tines of the log fork range in length from 150 cm to 220 cm depending on the size and weight of the machine.



Truck loading by wheeled front end loader with log fork

Front end loaders are used normally to load material of saw log length and longer, including tree lengths which is loaded lengthwise onto the hauling rig. They may also be used to load 2.5-3 m logs lengthwise, and 2.5 m logs crosswise by loading the truck or trailer from the rear, but the practice is not recommended.

In operation these loaders must, like the Cary-Lift mentioned earlier, travel between log or tree length pile and hauling rig carrying the loaded fork in the air. The load cannot be successfully skidded on the fork tines. This requires that the ground, for best loading performance, be level, firm and cleared of stumps and other entangling debris. For this reason the roadside landing is often bulldozed for this type of summer operation - an additional expense not encountered when heel boom loading with knuckle boom loaders sitting on the road.

When the ground is soft, under summer conditions, loading of tree lengths must be done with heel boom loaders as mentioned earlier or with large loaders with long knuckle boom, fitted with special grapple, able to reach out and pick up several tree lengths at their centre of gravity while sitting at roadside, and swing and place them on the hauling rig. Such a large loader is able to rotate the load of tree lengths 180° beneath the boom and load them either butts or tops forward as required.

Tree length loading rate with front end loaders depends on several factors: size and horsepower of the machine, proficiency of the operator, lifting height, conditions of the landing, distance between pile and trailer, and piling direction in relation to the road. Some tests in eastern Canada show that

- (1) there is little difference in loading rate between wheeled and crawler machines of the same hp;
- (2) fixed time per load (waiting for hauling rig to be prepared to receive logs and to drive away after loading has been completed, rearranging load, etc.) averages around 5 minutes.
- (3) average grapple load in m^3 = 1.5% of loader GHP rating;
- (4) average loader cycle time, excluding fixed time, ranges between 1.50 and 1.75 min;
- (5) average loading rate, disregarding fixed time, is around 1% of loader GHP rating, when expressed in m^3/min .

Loading time in minutes per truck-trailer load and loading cost per m^3 may be found with the following formulae:

$$(1) \quad LT = 5 + \frac{1.6L}{GL} \quad \text{and}$$

$$(2) \quad LCM = \frac{LT \sqrt{C + c(1+f)}}{60L}$$

where LT = loading time in minutes per truck-trailer load;

LCM = loading cost in US\$/ m^3 ;

L = truck-trailer load in m^3 ;

GL = average grapple load in m^3 ;

C = operating cost of loader in US\$/PMH;

c = operator direct wages in US\$/PMH;

f = cost of fringe benefits expressed as a percentage of direct wages.

Reviewing the matter of tree length loading, it is evident that front end loaders are capable of loading at a higher rate than knuckle boom loaders fitted with heel boom attachments, but have difficulty arranging the tree lengths on the trailer neatly and evenly (load distribution). Consequently they are unable to build as large loads. Under some circumstances and with some machines, the reduction may reach 20%.

31.4 Unloading

There are many methods of unloading hauling rigs. Much depends on the circumstances. When unloading into open water, shortwood is usually end dumped, side dumped or pushed off with a bulldozer - like "pusher" with long arms and a pusher plate. When unloaded on lake or river ice or a landing to be flooded later, the same procedure may be followed, or the wood may be unloaded and piled with the same type of equipment as used in the loading operation and at approximately the same cost/m³. Tree lengths or full trees are not usually unloaded for water transportation unless with stiff boom or other crane in bundle size packages.

Saw logs, tree lengths and full trees may be unloaded and stored with front end loader, stiff boom crane and grapple or bridge crane, or unloaded onto a slasher or sorter deck with a pusher type machine or a powered pulling device for immediate further processing. They may also be pushed off onto the ground to be slashed and hauled away or dumped into open water on a landing. Large powerful front end loader type of machines capable of picking up and carrying an entire trailer load of tree length or full tree wood are coming into wider use.



Crawler mounted front end loader unloading roundwood at the final landing

APPENDIX A

THE U.S. FOREST SERVICE ROAD CLASSIFICATION SYSTEM
AND TRANSPORT COSTS FOR MINNESOTA PULPWOOD

Hauling rates are based on drivers' wages, including compensation insurance and other payroll taxes, cost of equipment, depreciation insurance and all operating costs. The costs were based on 1968 data for wages, truck, trailer and loader selling prices, insurance rates and tire and fuel costs. Current depreciation rates of straight-line six-year life and 6 percent interest rates were used. All adjustments were made on a comparison basis with the 1957 R-7 truck hauling cost study on the Byrnes-Nelson-Coogin report on log hauling costs.

TABLE 32

HAULING COSTS FOR MINNESOTA PULPWOOD BY
ROAD QUALITY AND TRUCK SIZE
(in dollars per cord-mile)

Road Class	Truck size - mean load (cords)				1/
	4	6	8	10	
High speed, 45 mph	US\$ 0.09	US\$ 0.08	US\$ 0.08	US\$ 0.06	
Class I - 35 mph	.13	.12	.11	.08	
Class II - 25 mph	.18	.17	.16	.12	
Class III - 16 mph	.26	.24	.24	.18	
Class IV - 8 mph	.47	.43	.46	.34	
Class V - 4 mph	.85	.78	.86	.65	
Fixed costs (standby, delay, load, unload)	US\$ 1.78	US\$ 1.65	US\$ 1.41	US\$ 1.81	

1/ Truck description - all are equipped with loader:

- 4 cords, flat bed, 4 x 2, single axle, GVW 28 000 lb;
- 6 cords, flat bed, 6 x 4, tandem axle, GVW 37 000 lb;
- 8 cords, truck tractor, 4 x 2, single axle, with 28-30 ft platform bed, GVW 59 000 lb;
- 10 cords, truck tractor, 6 x 4, tandem axle, with 30-35 ft platform trailer, GVW 72 000 lb.

ROAD CAPACITY AND SERVICE CLASS DESCRIPTION

High Speed Highways, Average Running Speed 45 mph

This class of road includes the best highways where trucks are able to maintain a high average speed. However, consideration should be given to delays through towns, etc.

Cost Haul Class I, Average Running Speed 35 mph

This class includes federal state and primary country highways with concrete or bituminous pavement of well stabilised gravel surfacing. The design speeds for highways in this group will fall within the range of 40 - 60 mph. Truck running speed for this group will range from 30 - 40 mph, with an average of 35 mph. If a section of a highway in this class has a quarter mile or more of sustained adverse grades of 6 percent or greater, that portion should be considered as a Class II road.

Cost Haul Class II, Average Running Speed 25 mph

This class includes county secondary, township and forest roads with a design speed of 30 mph and truck running speed averaging 25 mph. Roads in this class will be two-lane width or single-lane with intervisible passing sections. The roadway surface may have bituminous, compacted gravel or stabilised soil wearing course, well maintained. Horizontal alignment is limited to minimum radius curves of 300 ft and maximum grades of 7 percent. If a section of a road within this group has a quarter mile or more of sustained adverse grades exceeding 7 percent, that portion should be considered as a Class III road.

Cost Haul Class III, Average Running Speed 16 mph

This class includes country, local, township and one-lane forest roads with a design speed of 20 mph and truck running speed of 16 mph. One-lane roads will have passing sections, but not always located at intervisible points. The roadway will usually have fair gravel or soil wearing surface with intermittent blade maintenance. Horizontal alignment is limited to minimum radius curves of 200 ft and maximum grades not exceeding 10 percent. If a section of a road within this group has a quarter mile or more of sustained adverse grades exceeding 10 percent, that portion should be considered as a Class IV road.

Cost Haul Class IV, Average Running Speed 8 mph

This class includes roads, regardless of jurisdiction, that are single-lane in width and lack adequate passing sections. These roads will classify as low service facilities with little or no consideration given to design speed during route selection or construction. They will usually have winding alignment with numerous sharp curves. The vertical alignment closely follows the rolling natural ground line with hidden dips and undulating grades. Maximum grades may be up to 12 percent. Roads in this class are usually unsurfaced with limited spot graveling on unstable sections. Drainage is usually limited to natural drainage channels where they cross the roadway. Truck running speeds may range from 6 - 11 mph with an average of 8 mph.

Cost Haul Class V, Average Running Speed 4 mph

This class includes the poorest service roads within the sale area. They are usually narrow and undrained with winding alignment and rolling grades. They are average one-lane dozer-constructed roads with low protruding rocks and stumps in the driving surface and with limited or no passing sections. Truck running speeds may range from 3 to 5 mph with an average speed of 4 mph. Do not allow for short sections (up to 400 ft) out of landings as this cost is taken care of in standby time.

APPENDIX B

EQUIVALENT GROSS AXLE LOADS

Roads are built to carry specified design single-axle loads. However, hauling rigs usually are fitted with a dual or, on occasion, a triple axle bogie under the rear end of truck and/or trailer. Table 33 shows the relationship between various single axle loads and their equivalent dual and triple axle loads when axle spacings are 1.22 m and 2.44 m respectively and the axles are fitted with dual wheels and tires. However, heavier axle loads may be carried with no more effect on the road when axles are spaced more widely.

For example, on the public roads of the Province of Ontario, Canada, which has some of the more complex and detailed highway weight regulations, the maximum allowable gross weights for dual and triple axle bogies shown in Tables 34 and 35 are permitted (9). This means, for example, that roads designed to carry 15 900 kg on dual axles spaced 1.22 m apart will carry 18 000 kg equally well when the axle spacing is increased to 1.83 m. This is a very important point to remember when planning forest roads and hauling equipment for a logging operation.

TABLE 33
AXLE LOAD EQUIVALENCE (3)

Single Axle Load in kg	Equivalent Number of 8200 kg Single Axles	Equivalent Loading in kg	
		Dual Axle 1/3/	Triple Axle 2/4/
6 350	0.38	11 350	14 200
7 275	0.71	12 950	16 200
8 200	1.00	14 500	18 100
9 100	1.93	16 200	20 200
10 000	2.99	17 800	22 200
10 900	4.45	19 400	24 300
11 800	6.44	21 000	26 200
12 700	9.05	22 600	28 200
13 600	12.45	24 200	30 200

1/ Axle spacing of 1.22 m.

2/ Distance between first and third axles of 2.44 m.

3/ Values are approximately 75 % greater than for corresponding single axles, e.g., a road designed to carry a single axle load of 9 100 kg on dual tires will carry a dual axle load of 16 200 kg when the axles are spaced 1.22 m apart.

4/ Values are approximately 120 % greater than for corresponding single axles and 25 % greater than for corresponding dual axles, e.g., a road designed to carry a single axle load of 9 100 kg will carry a triple axle load of 20 200 kg when the distance between the first and third axles is 2.44 m.

TABLE 34 (9)

MAXIMUM ALLOWABLE WEIGHT FOR DUAL AXLE

Column One	Column Two
Axle Spacing in Inches	Maximum Allowable Weight in Pounds
40 or less	20 000
More than 40 and less than 48	32 000
48 "	35 000
51 "	35 500
54 "	36 000
57 "	36 500
60 "	37 500
63 "	38 000
66 "	38 500
69 "	39 000
72 or more	40 000

TABLE 35
MAXIMUM ALLOWABLE WEIGHT FOR TRIPLE AXLE

Column One	Column Two
Axle Spacing in Inches	Maximum Allowable Weight in Pounds
80 or less	35 000
More than 80 and less than 96	40 000
96 " " " 111	44 000
111 " " " 114	44 500
114 " " " 117	45 000
117 " " " 120	45 500
120 " " " 123	46 000
123 " " " 126	46 500
126 " " " 129	47 500
129 " " " 132	48 000
132 " " " 135	49 000
135 " " " 138	49 500
138 " " " 141	50 000
141 " " " 144	50 500
144 " " " 147	51 000
147 " " " 150	51 500
150 " " " 153	52 500
153 " " " 156	53 000
156 " " " 159	54 000
159 " " " 162	54 500
162 " " " 165	55 000
165 " " " 168	55 500
168 " " " 171	56 000
171 " " " 174	56 500
174 " " " 177	57 000
177 " " " 180	57 500
180 " " " 183	58 500
183 " " " 186	59 000
186 " " " 189	59 500
189 " " " 192	59 500
192 or more	60 000

APPENDIX C

GEOMETRIC CONSIDERATIONS FOR FOREST ROADS

The minimum safe design speed of a road expressed in km/hr may be taken as the sustained speed plus 20 km/hr. Sustained speed may be defined as the speed below which the loaded vehicle should not have to drop for reasons other than traffic congestion. A number of geometric considerations affecting the safe design of the road are referred to below.

1. Lane and Shoulder Width

Primary or main roads will often be two travel lanes wide so that vehicles may meet or pass without slowing down. The optimum lane width for two-lane roads is overall loaded vehicle width plus 1.22 m. Reduction in lane width may be expected to cause some reduction in vehicle spot speeds (as much as 1 km/hr for each 30 cm reduction) and in vehicle speeds when passing or meeting other vehicles (as much as 1 km/hr for each 5 cm reduction) (3).

If practicable, a primary or main road should have a shoulder width not less than 1.22 m to ensure no adverse effect on vehicle speed. Speed may be expected to drop by 1 km/hr per 6 cm decrease in shoulder width, particularly when meeting other vehicles (3). Thus the overall width of a main two-lane road carrying vehicles 2.5 m wide should be about 10 m including shoulders and correspondingly wider for wider vehicles. In practice, width of forest roads depends to a great degree on traffic density and expected life of the road.

Secondary roads are usually single lane or intermediate width roads with the same load bearing capacity as primary roads and with turn-outs or meeting places at appropriate intervals. When meeting at such points it is customary to give a loaded hauling vehicle the right of way.

When the radius of curvature is less than 150 m the travelling surface of a roadway should be widened on the inside of the horizontal curves to allow for offtracking. Off-tracking may be defined as the difference in the path of the first inside front wheel and the last inside rear wheel as a vehicle, whether truck or combination rig, negotiates a curve. Its magnitude depends on the radius of curvature and the wheel bases of the component units of the rig, and it may be calculated precisely when these are known (6). However, such a calculation is not considered necessary when designing forest roads. Table 36 lists approximate offtracking values for loaded semi-trailer rigs of various overall lengths negotiating curves of various radii. A normal combination rig consisting of a truck and full trailer will offtrack less than the corresponding semi-trailers.

The values given in Table 36 represent the additional width which should be added to the travel surface of a single lane road or to each lane of a two-lane roadway. The widening should be tapered off at each end of the curve.

2. Crown and Superelevation

Both primary and secondary roads should be crowned to ensure positive drainage from the traffic lanes. The recommended crown slope on gravel-surfaced roads is 2-3 cm per metre of lane width, i.e., 2 - 3 %, when the surface material is hard packed and smooth (3,7) and 4 - 5 cm per metre when it is coarse and rough (3).

Figure 11 shows a typical road cross-section as recommended by Odier, Millard, dos Santos and Mahra (7).

Horizontal curves should be superelevated to counteract the centrifugal forces developed by the vehicle when rounding the curve. Superelevation should extend the full width of the roadway. Its magnitude on a given curve should depend on vehicle speed and the coefficient of friction for lateral sliding: the higher the speed on a given curve

with known coefficient the greater should be the superelevation. It should never be so great that the vehicle will slip toward the inside ditch when travelling very slowly or standing still. On the other hand it should never be so little that the centrifugal forces developed by a moving vehicle will cause it to slide toward the elevated side of the road. Superelevation should never exceed 10 cm per metre (0.10)(7); under winter snow and ice conditions on northern forest roads and slippery road soil conditions wherever they occur, it should not exceed 5 cm per metre (0.05)(3); and in some cases may be dispensed with altogether for safety reasons and speeds reduced accordingly.

TABLE 36

APPROXIMATE OFFTRACKING DISTANCES FOR SEMI-TRAILER RIGS OF VARIOUS
OVERALL LOADED LENGTHS ON VARIOUS CURVES

Vehicle Overall Loaded Length in m	Radius of Curvature			
	40 m	50 m	100 m	150 m
12	.60	.40	.20	.05
13	.75	.55	.25	.075
14	.90	.69	.34	.20
15	1.05	.82	.42	.27
16	1.20	.96	.50	.33
17	1.35	1.10	.58	.40
18	1.50	1.25	.67	.48
19	1.65	1.38	.73	.55
20	1.80	1.52	.82	.62

1/ Values given in metres.

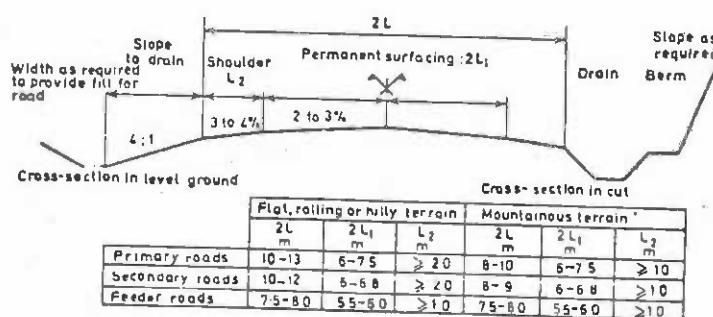


Figure 11 - Typical standard cross-section of road.

The relationship among design speed, radius of curvature, superelevation and coefficient of friction for lateral sliding may be expressed with the formula (7):

$$V = \sqrt{127 \times R (e \pm fs)}$$

where V = design speed in km/hr;
 R = radius of curvature in m;
 e = superelevation expressed in decimal form;
 f_s = coefficient of friction for lateral sliding.

The coefficient of friction for lateral sliding will vary slightly with vehicle speed. Values for use in the formula may be found in Table 37. Some authorities recommend that a uniform f_s value of 0.15 or 0.16 be used in the formula.

TABLE 37
COEFFICIENTS OF FRICTION f_s FOR LATERAL SLIDING

<u>Safe Design Speed in km/hr</u>	<u>Value of Coefficient f_s</u>
20	.17
40	.16
60	.15
80	.14
100	.13

Feeder roads are normally neither crowned nor superelevated due to the low speeds at which the hauling vehicles must travel over such roads.

3. Sight Distances

The driver of a vehicle should be able to see far enough ahead to be able to bring his vehicle to a safe stop upon sighting an obstruction in his roadway lane. This distance is called the non-passing sight distance. It is particularly important where the road is allowed to carry animal traffic as well. It should be provided at all points of the road for the planned speeds or, conversely, vehicle speeds should be restricted if topographic or other conditions prevent desirable sight distances from being realised. Passing sight distances, i.e., the distance required to overtake and pass another vehicle in the face of oncoming traffic, is not considered important in forest road design. While sight distances apply to both horizontal and vertical curves, the former are the more important in forest road design.

Basic sight distance comprises the distance the vehicle travels between the time the driver sees the obstacle and the time the brakes take hold plus the distance it travels while being brought to a stop. It depends on vehicle speed, grade, coefficient of traction and the time it takes the driver to see the obstacle and apply the brakes. Its value may be approximated with the formula (3):

$$SD = 1.25V + \frac{V^2}{255(f \pm g)}$$

where SD = sight distance in m;
 V = vehicle speed in km/hr;
 f = coefficient of traction;
 g = grade % expressed in decimal form.

Coefficients of traction for use in the formula may be read from Table 38. Thus, given a road design speed of 50 km/hr, a downgrade of 2% and a coefficient of traction of 0.20 on a slippery road, the driver should, for safe driving reasons, have a clear view of at least 117 m measured along the centre of the travel lane.

TABLE 38
COEFFICIENT OF TRACTION OR FRICTION FOR RUBBER TIRES
ON VARIOUS ROAD SURFACES

<u>Road Surface</u>	<u>Static Coefficient of Traction</u>
Concrete (Portland cement)	.70
Asphaltic Concrete	.60
Gravel, hard packed	.60
Soil, firm	.50
Sand	.15 - .40
Mud	.15 - .40
Snow, hard packed	.20 - .25
Snow, hard packed, well sanded	.33
Snow, 2" dry, loose, on gravel	.30
Snow, 1" dry, loose, on ice	.25
Ice, free of snow	.12

Where there is two-way traffic on a single-lane road, twice the stopping distance as calculated by the above formula should be provided to permit the two approaching vehicles to stop safely.

It is not always practicable to provide safe sight distances for the desired vehicle speeds because of topographic difficulties or other construction problems. When such is the case, and maximum safety practices are required, maximum road speeds should be posted at appropriate places.

4. Grades

Adverse grades on forest roads should be restricted in magnitude to those which will permit the vehicle to maintain pre-selected speeds, either loaded or light, without wheel slippage, and favourable grades to those on which full control of the vehicle can be maintained at all times. Every effort should be made to hold maximum grades on primary roads to 6%, on secondary roads to 8% and feeder roads to 10%. Table 39 gives some desirable design characteristics for primary, secondary and feeder roads in various types of terrain as proposed by Odier, Millard, dos Santos and Mahra (7). While the authors classed roads as primary, secondary and feeder as in this manual, their definitions referred to settled country. Nevertheless, it is felt that the data given in the table should be helpful in designing forest roads.

However, the specifications given in the table do not necessarily fit all forest roads. For example, forest feeder roads in firm soils are seldom built 7.5 - 8 m wide, width more often is closer to the length of a bulldozer blade. The table, however, does contain much useful information.

TABLE 39

DESIGN CHARACTERISTICS FOR ROADS IN DIFFERENT TYPES OF TERRAIN

<i>Characteristic</i>	<i>Terrain</i>	<i>Design speed km/h</i>	<i>Min. radius of curvature m</i>	<i>Max. gradient %</i>	<i>Max. length of grade m</i>	<i>Formation width (Permanent surfacing and shoulders) m</i>	<i>Width of permanent surfacing m</i>
<i>Road type</i>	Flat or rolling	80-110	190-360	4	None	10-13	6-7.5
	Hilly	55-80	90-190	5-7	600 over 4%	10-13	—
	Mountainous	40-55	50-90	7-9	400 over 6%	8-10	—
Secondary	Flat or rolling	60-80	110-190	5	None	10-12	6-6.8
	Hilly	50-60	75-110	5-7	None	10-12	—
	Mountainous	35-50	35-75	7-9	750 over 6%	8-9	—
Feeder	Flat or rolling	50-60	75-110	7	None	7.5-8	5.5-6
	Hilly	35-50	35-75	7-9	None	7.5-8	—
	Mountainous	25-35	30-35	9-12	1 000 over 9%	7.5-8	—

1/ The absolute minimum radius of curvature shown here takes account of a superelevation of 10 % and a sideway force coefficient of 0.16.

On adverse grades wheel slippage will occur if tractive effort exceeds the frictional reaction at the road surface (6). Tractive effort, expressed in kg, is the rim pull delivered to the tires at their point of contact with the ground. Its value depends on net engine torque, total gear reduction, drive line efficiency and the radius of the loaded tires; its value may be calculated. Frictional reaction, also expressed in kg, is the product of the coefficient of traction and the weight on the powered wheels of the vehicle.

The maximum adverse grade which can be climbed without wheel slippage, sometimes called the critical grade, depends on the coefficient of traction and the proportion of the gross vehicle or combination weight on the powered or driving wheels. Its value may be closely approximated with the formula (6):

$$GR = \frac{f \times AW \times 100}{GW}$$

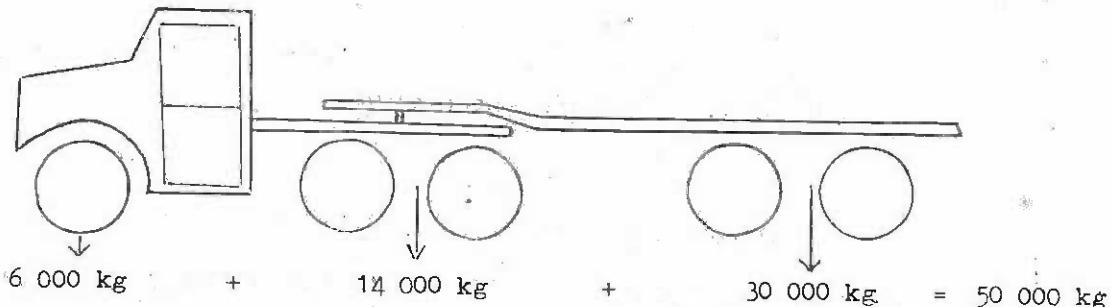
where GR = grade percent;

f = coefficient of traction as given in Table 38;

AW = weight in kg on the driving wheels;

GW = gross vehicle or combination weight in kg.

For example, given a heavy duty 5-axled semi-trailer rig grossing 50 000 kg with the weight distributed as below:



and a coefficient of traction of 0.20, the maximum adverse grade which can be negotiated will be:

$$\frac{0.20 \times 14 000 \times 100}{50 000} = 5.6 \%$$

If adverse grades greater than 5.6 % have to be built into the road, either a better surfacing, i.e., one with a higher coefficient of traction, will have to be provided, or the rig will have to be redesigned to carry more than 14 000 kg on the rear wheels of the truck-tractor when loaded.

Under winter hauling conditions in northern forests traction may be improved by sanding the hills; in tropical forests only a more granular surfacing material will improve the traction coefficient. In the above example only 28 % of gross weight is carried on the driving wheels; in practice this percentage should approach 40 %. There is often much difficulty climbing grades with the empty rig for the same reason as noted above - lack of sufficient weight on the driving wheels and/or a low coefficient of traction. The same remedies apply as for a loaded rig - improve the traction or increase the weight on the driving wheels by, for example, loading the trailer on the truck-tractor for the return trip to the loading point in the forest.

Weight on the driving wheels may also be increased by powering the front wheels of the truck-tractor or one or more of the trailer axles. However, the use of such devices increases vehicle purchasing, operating and maintenance costs, and therefore hauling costs, and should be avoided.

The forces which must be overcome in climbing grades - rolling, grade, air and drive train and associated resistances - also act to slow a vehicle on down grades (6). They must be considered in the design of vehicle brakes and other devices to control the rig when travelling downhill. Their discussion is beyond the scope of this manual. However, the forest road engineer should consider all the above points in conjunction with the equipment design engineer and the manager responsible for delivering the wood.

5. Rights-of-Way

The desirable width of a cleared forest road right-of-way widths on straight forest roads approximately as shown in Table 40 and, when necessary, sufficient widening on the inside of horizontal curves to allow proper sight distances to be realised and desirable speeds maintained. The geometric considerations are shown in Figure 12 (3). Required sight distance, measured along the centre line of the inside lane, may be calculated as described in Section 3 of Appendix C and the middle ordinate, i.e., the required distance from the centre line of the inside lane to the obstruction, may be found with the formula (3):

$$M = \frac{5.730}{D} \quad (\text{vers } \frac{SD}{200})$$

where M = middle ordinate in feet;
 D = degree of horizontal curvature;
 S = required sight distance in feet measured along the centre line of the inside lane.

TABLE 40
RECOMMENDED CLEARED RIGHT-OF-WAY WIDTHS

<u>Design Speed in km/hr</u>	<u>Cleared Right-of-Way Width in m</u>
30	20
40	22
50	25
60	27
70	30
80	33
90	35
100	38

However, the right-of-way widths given in Table 40 should be considered as a guide only. Steep and/or rocky terrain on the inside of a curve may prevent desired sight distance from being realized without exorbitant expenditure, in which case speed should be reduced and appropriate maximum safe speed limit posted. Furthermore, it may be desirable to leave steep slopes uncleared for soil stabilisation and/or aesthetic reasons.

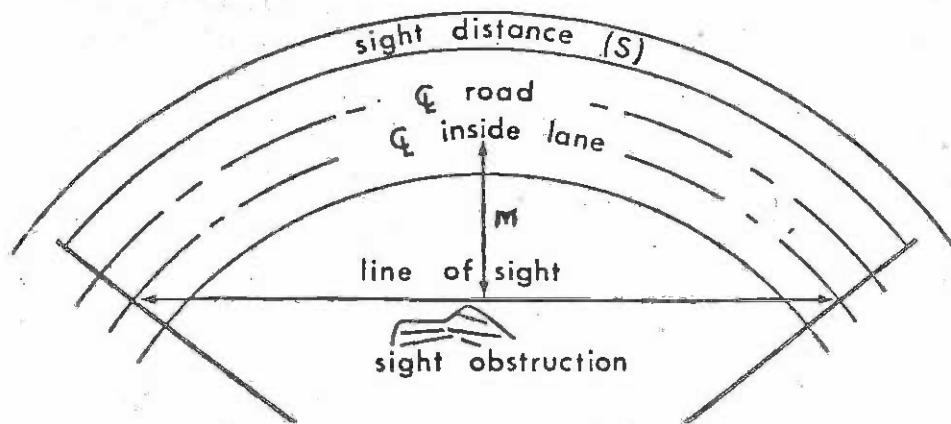


Figure 12 -Sketch showing minimum cleared width on horizontal curves to maintain desired line of sight.

In tropical countries and temperate zone deciduous forests, where tree canopies are wide spreading, the right-of-way should be widened, where appropriate, to let in sunlight to help dry the roadway. On the other hand, on very sandy roadways the right-of-way should be narrower to preserve moisture.

In northern countries where blowing snow is a winter problem, the right-of-way should be restricted in exposed terrain and a 30 m - 40 m strip of forest left uncut under the clear cutting system, usually on both sides of the road. Such strips also serve in summer to reduce the dust problem and as a fire break and fighting control line in case of forest fire. However, leaving such strips and opening up the uncut forest in softwood stands in temperate zones with unnecessarily wide rights-of-way will expose the forest to blow down or wind throw and, in the case of some species, such as Abies balsamea in eastern North America, to sun scald damage.

Road right-of-way widths in man-made forests may be governed by other considerations: the fact that most roads during the planting and tending phases do not need to be wide or to carry heavy loads, the fact that many plantation roads are more or less permanent after the first rotation, a desire to utilise the area to the maximum and, particularly in the case of pine plantations, the need for adequate fire control lanes.

APPENDIX D

FEEDER ROAD DENSITY

Feeder roads are those which lie beyond the secondary roads; they form the fingers of the road network; they penetrate to the secondary landings to which skidding and forwarding systems deliver the harvested wood; occasionally they penetrate to the primary landing in the stump area. When using a specific skidding or forwarding machine, there is a feeder road density (m/ha) or a spacing which will result in the lowest combined cost of constructing the feeder road and skidding or forwarding. This is called the optimum feeder road density (ORD) or spacing (ORS). It is attained when the travel portion of the skidding or forwarding cost equals the cost of building the feeder road and maintaining it during the hauling period.

Under ideal forest conditions on flat or gently rolling terrain where feeder roads are straight and parallel and skidding or forwarding is carried on perpendicularly to the road and equidistantly on both sides, the loads are offloaded where the road is reached, average skidding or forwarding distance is one quarter of the feeder road spacing. However, this situation rarely, if ever, occurs in practice. Sometimes a feeder road may follow the border of a swamp, lake, river, or other topographic feature, so that skidding or forwarding is done from one side only. If the spacing is optimum, the road serves less wood and costs more per m³; average skidding distance is greater and therefore the cost of skidding.

1. Optimum Feeder Road Spacing

While feeder road density, expressed in m/ha, is the more readily used in calculating feeder road cost per m³, feeder road spacing is the more practical guide for the logging engineer laying out a feeder road network in a forest being opened up for logging.

The optimum feeder road spacing may be found with the formula:

$$ORS = k \sqrt{\frac{40 \times R \times L}{q \times c \times t \times (1 + p)}}$$

where ORS = optimum feeder road spacing expressed in m;

R = cost in US\$ per km of constructing and maintaining the feeder road;

L = average skidder or forwarder load in m³;

q = quantity of wood harvested, expressed in m³/ha;

c = operating cost of skidder or forwarder, including operator, in US\$ per minute;

t = time in minutes for skidder or forwarder to travel 1 m loaded and return light;

k = a correction factor, with a normal value between 1.0 under the ideal conditions described in the previous paragraph, when skidding or forwarding is done equidistantly on both sides of the feeder road, and 0.71 or $\sqrt{0.50}$ when skidding or forwarding is done from one side only; it is used to cover, as well, situations where the feeder roads are winding, meet in junctions or terminate as dead-end roads;

p = a correction factor, normally with a value between 0 and 0.5, to be used in situations where skidding or forwarding trails, i.e., the strip roads, are winding or do not end at the closest point on the feeder road, or where an allowance is made for delays along the route due to low-bearing soils, hangups and so on.

It should be pointed out that the spacing distance derived with the formula may be considered only as an approximate value because of the imprecise values of several of the factors in the formula. For example, if the formula gives an optimum spacing of 400 m, a spacing between 350 m and 450 m will give quite satisfactory results. This allows some leeway in siting feeder roads to avoid obstacles that might increase the cost of constructing the road.

An examination of the optimum feeder road spacing formula will show that quadrupling the quantity of wood harvested per ha will halve the feeder road spacing; this will (a) require twice as much road to be built but at half the cost per m³ and (b) halve the skidding distance and therefore the travelling portion of the skidding cost, thus bringing about an overall reduction in the logging cost.

Pierre-Yves Perrin has developed a computerized system by which several road network alternatives may be compared and feeder road standards and spacing judged simultaneously (14).

2. Optimum Feeder Road Density

Having determined optimum feeder road spacing as above, the optimum feeder road density may be found with the formula:

$$\text{ORD} = \frac{10\ 000}{\text{ORS}}$$

where ORD = optimum feeder road density in m/ha;
 ORS = optimum feeder road spacing in m;

Optimum feeder road density may also be found directly with the formula:

$$\text{ORD} = 50 \sqrt{\frac{q \ c \ t \ x \ 1\ 000 \ x \ T \ x \ V}{R \ x \ L}}$$

where ORD = optimum feeder road density in m/ha;
 q = quantity of wood harvested in m³/ha;
 c = operating cost of skidder or forwarder including operator in US\$/min;
 t = time in minutes for skidder or forwarder to travel 1 m loaded and return light;
 T = a correction factor, normally with a value between 1.0 and 1.5, to be used in the same situations as the factor k in the ORS formula in the previous section;
 V = a correction factor, normally between 1.0 and 2.0, to be used in the same situation as the factor p in the ORS formula in the previous section;
 R = cost of constructing and maintaining the feeder road in US\$/km;
 L = average skidder or forwarder load in m³.

Optimum feeder road density or spacing is discussed in several other publications also (1)(2)(13).

3. Average Skidding or Forwarding Distance

Under the ideal forest situation the average skidding or forwarding distance was found by Segebaden (17) with the formula:

$$Mg = \frac{2.5}{V}$$

where Mg = average skidding or forwarding distance in km;
 V = feeder road density in m/ha.

Using the symbols defined in sections 1 and 2 of Appendix D above the same formula would be expressed as:

$$ASD = \frac{2.5 \times 1000}{ORD}$$

where ASD = average skidding or forwarding distance in m = 1 000 Mg ;
 ORD = optimum road density in m/ha = V .

When other than ideal situations exist the correction factors mentioned earlier must be incorporated with the formula so that:

$$ASD = \frac{2.5 \times T \times V \times 1000}{ORD} \quad \text{or} \quad \frac{T \times V \times ORS}{4}$$

where ASD = average skidding or forwarding distance in m;
 ORD = optimum feeder road density in m/ha;
 ORS = optimum feeder road spacing in m;
 T and V = correction factors as defined in section 2 above.

4. Feeder Road Cost Calculation

The cost of constructing and maintaining a feeder road during the harvesting system may be found with the formula:

$$RC = \frac{R \times RD}{1000 q}$$

where RC = feeder road cost in US\$/m³;
 R = feeder road cost in US\$/km;
 RD = road density in m/ha;
 q = quantity of wood served, expressed in m³/ha.

5. Costing the Travel Portion of Skidding or Forwarding

The cost of the travel portion of the skidding or forwarding operation may be found with the formula:

$$TC = \frac{ASD \times c \times t}{L}$$

where TC = travel cost in US\$/m³ of skidding or forwarding;
 ASD = average skidding or forwarding distance in m;
 c = operating cost, including operator, of skidder or forwarder in US\$/min;

t = average time in minutes for skidder or forwarder to travel 1 m and return light;

L = average skidder or forwarder load in m^3 .

If feeder road density or spacing is optimum, the cost calculated in this manner should equal the cost of the feeder road as calculated in section 4 and the lowest combined cost of the two operations will have been realised. If this condition is deviated from, the combined cost will be greater.

6. Feeder Roads in Relation to Overall Minimum Harvesting Cost

The above sections deal with the lowest combined cost of skidding or forwarding and feeder road construction and maintenance. The overall objective of any forest operation, however, is the minimum cost of the wood on the final landing. It has been shown that major haul roads should not be underbuilt - that there is less expectation of an overall loss through building a high-standard road.

When a feeder road is brought into the picture major consideration should be given to attaining overall minimum wood cost at the point where the feeder roads join the secondary road. This minimum cost will be attained when the three costs listed below, expressed on the same basis, such as cost per m^3 , are brought into balance:

- a) feeder road construction and maintenance;
- b) travel portion of skidding or forwarding cost;
- c) travel portion of feeder road hauling cost.

This matter is discussed at some length in Chapter 4 and Appendix 3 of FAO publication "Harvesting Man-Made Forests in Developing Countries" (2).

7. Some Machine Costing Considerations

Operating cost values for skidders, forwarders, trucks and trailers, tractors and other mobile equipment mentioned in this appendix should include the cost of operator or operators.

Trucks and trailers should be costed by the hour, with a value per standing hour and per travelling hour, since the latter may be as much as two or three times the former. This difference is due to the principle that fuel, oil, repairs and maintenance costs accumulate, for practical purposes, only while the machine is travelling. Costing by the travelling hour presents the premise that hauling costs per unit volume is inversely proportional to travel speed, so that doubling the travel speed will halve the hauling cost. Hauling trucks should be fitted with appropriate tachographs for the determination of standing and travelling hours, vehicle speed, etc.

The costing of skidders and forwarders is subject to the same hourly breakdown of time to some extent but to a much lesser degree, since normally the engines of these machines continue to run to operate a winch or some form of loading mechanism during the loading and unloading phases. For this reason such machines are usually costed on the basis of engine hours read from an engine hour meter.

Methods of costing Machines is discussed at considerable length in Appendix H and in a number of available publications (1)(2)(10)(11)(12).

APPENDIX E

COMPARATIVE PRODUCTIVITY RATIOS, PURCHASE PRICES AND HOURLY
OPERATING COSTS OF CRAWLER TRACTORS FITTED WITH S-BLADE
PROTECTIVE CANOPY AND TOWING WINCH

There are several crawler tractor companies manufacturing a wide range of machines and distributing them throughout the world. The purchase price, operating cost and productivity of these machines, complete with protective canopy, S-blade, and towing winch, depends on machine horsepower, but varies little among manufacturers. The chart in Figure 13 shows approximate purchase price, operating cost (excluding operator) and relative bulldozing productivity of machines of various horsepowers. It is interesting to note that one curve serves for the three items.

The following notes relate to the chart:

- a) purchase prices are given in US\$ and no allowance is made for unusually high import duties;
- b) purchase prices include S-blade, towing winch and protective canopy and run between US\$ 5.00/kg and US\$ 6.00/kg, decreasing from US\$ 6.00/kg for the smaller machines developing 75 hp to 125 hp to US\$ 5.00/kg for those developing 275 hp - 300 hp;
- c) direct drive models cost around 5 % less than the corresponding power shift models shown on the chart;
- d) the productivity ratio curve on the chart refers to power shift models; productivity of corresponding direct drive models is around 15 % less;
- e) the approximate hourly operating costs, based on engine hour meter readings, given in the chart include depreciation, interest, insurance, fuel oil, lubricants, repairs and servicing, but exclude operator wages and fringe benefits;
- f) the weight-power ratio of crawler tractors, i.e., their weight per net or flywheel horsepower, normally lies between 110 kg and 125 kg;
- g) fully equipped standard crawler tractors have a ground bearing pressure of between 0.5 kg/cm² and 0.7 kg/cm²; some manufacturers have developed low ground pressure models up to 175 hp - 200 hp for use on low-bearing soils; they have longer track frames and wider track shoes and, fully equipped, develop ground pressure around 50 % of that of standard machines; they weigh 15 - 20 % more than standard tractors and cost progressively more as horsepower increases: from 5 % for 75 hp models up to 15 % for 180 - 200 hp.

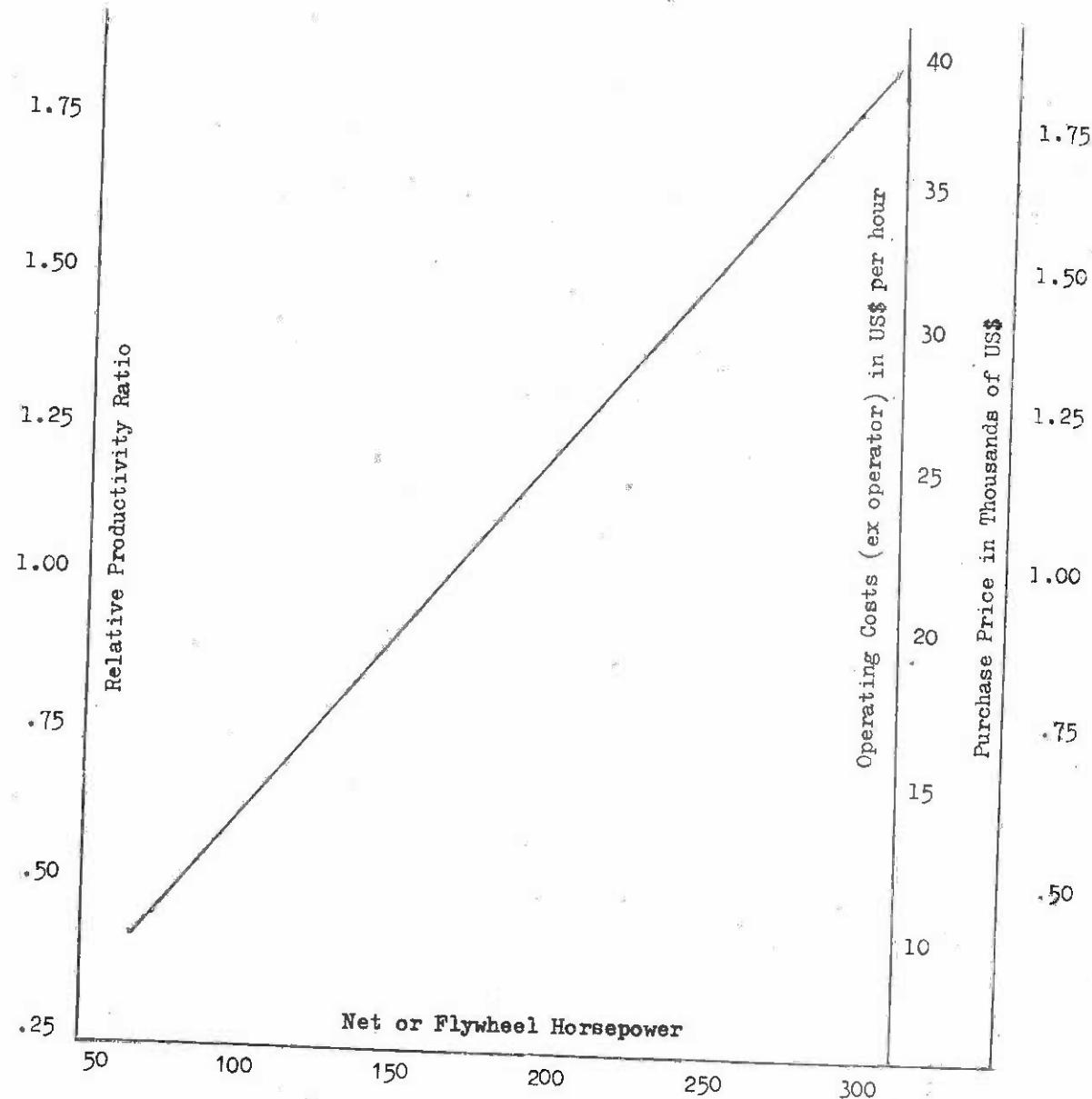


Figure 13 - Chart showing approximate relative productivity ratios, purchase prices and hourly operating costs of power shift crawler tractors with S-blade towing winch and canopy.

APPENDIX F (4)

ROAD SUBGRADE STABILIZATION WITH LIME

Summary Sheet for Hydrated Lime

Total Mileage Treated: 1 956

Objective: Clay sub-base stabilization

Soils: Clay - type CL (Unified System)

Application: Proportions - 4 % and 5 % lime, by weight.

Procedure - The clay was thoroughly scarified, the lime was applied and then the application was wet down. The materials were thoroughly mixed, lightly compacted and then allowed to cure for 3 days.

The mixture was re-mixed, more water was added and compaction was carried out to 95 % of standard Proctor. A curing period of 7 days followed.

Cost per Mile: Not reported. The cost per square yard was US\$ 0.50.

Beneficial Effects:

- (a) The soil became non-plastic.
- (b) Benkelman beam deflections were reduced by almost 50 %.
- (c) California Bearing Ratios were increased by almost 450 %.
- (d) Clay content was in one case decreased by 86 %.

Non-beneficial Effects: Distress was reported on one section but was thought to be due to a lack of adequate gravel cover over the stabilized layer.

Additional Remarks:

- (a) The benefits of lime stabilization occur with time.
- (b) The durability of the treatment under field conditions of freeze-thaw is still under study.

Case History No. 11

December, 1968

Stabilizing Agent: Hydrated lime.

Date of Application: 1966

Location: Southwestern Quebec (public highway).

Mileage Treated: 1 691

Objective: Clay sub-base stabilization.

Soils Data: Classification - type CL (Unified System)

Engineering properties -	Liquid Limit	45.7 %
	Plasticity Index	23.3 %
	Degree of Shrinkage	40.5 %
	Natural Moisture Content	27.7 %

Site Data:

Road in question was partly new construction and partly a rebuilding of existing road.

Stabilized layer has a total of 18 inches of base and asphaltic pavement over it.

Ditches appear to carry to below the stabilized layer.

Application:

Proportion - Laboratory tests determined a 4 % lime content by weight to be optimum. This was used in the field. (Checked using pH measurements).

Procedure -

- (a) The clay was taken from a nearby pit and placed on the road in a thickness which after compaction was 6 inches. This was left, closed to traffic, for two months.
- (b) The clay was scarified thoroughly immediately prior to stabilization.
- (c) The lime, from sacks, was spread uniformly over the clay, after which water was added to keep the mixture damp. Where pH tests showed the content to be low, more lime was added.
- (d) A pulvi-mixer was used to thoroughly mix the water, lime and clay; light compaction with a multi-tire roller was then carried out.
- (e) After a 3-day curing period, the soil-lime was re-mixed using a pulvi-mixer; water was again added.
- (f) The mixture was re-compacted to 95 % of standard Proctor, finishing with a smooth wheel roller.
- (g) A 7-day curing period followed in which a light application of bitumen (0.25 gal/sq.yd.) was used to retain moisture.

Cost per Mile:

Not reported. The cost per square yard, everything included, was US\$ 0.50.

Beneficial Effects:

- (a) Plasticity index reduced to zero (non-plastic).
- (b) Clay content reduced by 86 % and silt content increased by 56 %.
- (c) The degree of shrinkage reduced to 21.3 %.
- (d) Benkelman beam deflections reduced from 0.095 inches to 0.050 inches over a two-week period.
- (e) California Bearing Ratio values increased from 10.3 % to 45 % 34 days after treatment.

Non-beneficial Effects:

Not reported.

Remarks:

The benefits from lime stabilization occur gradually with time. The long-term durability of the treatment is still under study. The designers now consider the road to be overdesigned. Bearing capacity has increased since the end of construction. Benkelman beam deflections are still low.

Case History No. 12

November 10, 1968.

Stabilizing Agent: Hydrated lime.

Date of Application: 1966

Location: Northwestern Quebec.

Mileage Treated: 2 section - 700 yards

Objective: Clay sub-base stabilization.

Soils Data: Classification - clay A-7-5 (A.A.S.H.O. System)
Engineering properties - Plasticity Index = 20

Site Data: 32-foot wide haul road, owned by the Department of Lands and Forests.

Application: Proportion -
(a) One section, 4 % lime, by weight.
(b) One section, 5 % lime, by weight.

Design -
(a) Basis - vehicles of 70 000 lb GVW.
(b) 4 % lime - conventional design was to be a total thickness of 22 inches of gravel over the sub-grade. In fact, 12 inches of gravel over 6 inches of lime-stabilized clay were used.
(c) 5 % lime - conventional design was to be a total thickness of 22 inches of gravel over the sub-grade. In fact, 6 inches of gravel over 8 inches of lime-stabilized clay were used.

Procedure -
(a) New road construction was involved; therefore the road was ditched and shaped, and the profile was developed before treatment.
(b) The lime was spread over the desired area at the specified rates. It was then mixed intimately with the soil, water being added to achieve the optimum moisture content.
(c) After mechanical compaction, the treated sections were sealed to prevent the evaporation of moisture. A curing period of 7 days was permitted before construction continued.

Cost per Mile: Under study.

Beneficial Effects: (a) Benkelman beam deflections on the 4 % lime section were:
1967 - 0.070 inches
1968 - 0.070 inches
(b) Benkelman beam deflections on the 5 % lime section were:
1967 - 0.200 inches
1968 - 0.200 inches

Non-beneficial Effects: The 5 % lime treated section appears to be showing some signs of distress on the surface.

Remarks:

The distress on the 5 % lime treated section is felt to be due to the overly thin layer of gravel, rather than to the presence of stabilized clay alone.

Vehicles presently hauling are 125 000 lb GCW with only 5 axles. The design thickness for this condition would be 32 - 36 inches, total base. However, no modifications have yet been made to provide for the increased loads.

APPENDIX G (4)

ROAD SURFACE STABILIZATION WITH CALCIUM CHLORIDE

Summary Sheet for Calcium Chloride (Solid State)

Total Mileage Treated: 95 +

Objectives: Usually dust abatement and/or surface stabilization.

Soils: Typically gravels.

Application: Proportions - 4 to 6 tons per mile with one reported application of approximately 10 tons per mile.

Procedure - The spreading of the material was usually accomplished by water at some stage.

Mixing was usually accomplished with a grader.

Cost per Mile: US\$ 481 to US\$ 771, with one report as low as US\$ 317.

Beneficial Effects:

- (a) Dust abatement was achieved.
- (b) A very hard running surface usually formed which could be graded only in wet weather. Normal maintenance costs were reported substantially reduced in most cases.
- (c) There was some evidence that the treated roads withstood the spring break-up better than untreated roads.
- (d) The smoothness of the resulting surface seemed to improve with the quality of the gravel; crushed material was the best.

Non-beneficial Effects: (a) Where silt and clay were present in large proportions in the gravel, the treatment was reported to have caused dangerously slippery conditions in wet weather.

Additional Remarks: (a) Under some circumstances, spreading equipment should be washed prior to idle periods in order to prevent "lumping" of the material and damage to the equipment.

Summary Sheet for Calcium Chloride (Liquid State)

Total Mileage Treated: 185

Objectives: Dust control and/or surface stabilization.

Soils: Sand or gravel

Application: Proportions - range from 3 tons/mile to 15.8 tons/mile (the latter in 3 applications).

Procedure - a tank truck with a distributor bar applied the material under pressure, usually after the road surfaces had been newly graded and shaped.

Cost per Mile: US\$ 240.00 to US\$ 455.00 for one application; up to US\$ 835.00 for multiple applications.

Beneficial Effects:

- (a) Dust abatement was achieved.
- (b) A very hard surface usually formed, which could be graded only in wet weather. Normal maintenance costs were reported to be reduced in most cases.
- (c) The annual loss of surface materials was sharply reduced.
- (d) There was some evidence that the treated roads withstood the spring break-up better than untreated roads.
- (e) Penetration was deeper than for roads treated with the solids application and the benefits occurred almost immediately rather than after a time lag.
- (f) Washboarding rarely occurred.
- (g) Truck damage due to jarring was reduced.

Non-beneficial Effects:

- (a) In one instance pot-holes developed so as to require grading after two weeks, whereupon washboarding started.
- (b) Heavy rain soon after application probably will reduce the effectiveness of the treatment.
- (c) Under certain conditions, the surface can become slippery when wet.
- (d) Some increase in rusting of mechanical equipment has been noticed.

Additional Remarks:

- (a) Strict attention must be paid to the materials which are treated, as coarser materials do not acquire the same benefits.
- (b) Treatment must be started as soon after break-up as hauling can start; in many cases one application per season will not be adequate.

APPENDIX H

DERIVATION OF MACHINE COSTING FORMULAE

The derivation of the formulae used in estimating the value of the various components in the operating cost of a machine are discussed below:

1. Depreciation

Depreciation is a means of recovering the original investment in a machine. Of the various methods of calculating depreciation for costing purposes, the so-called "straight line" method based on the number of hours from service meter or recorder readings is normally used. Other methods may find their justification in accounting procedures but have no place in the calculation of realistic machine operating costs.

There is no way of knowing precisely the economic life of a machine because of factors relating to obsolescence, severity of use, quality of maintenance and so forth.

The amount to be depreciated should include import duties, sales or purchase taxes, transportation charges and all other costs incurred to deliver the machine to its place of work, less the estimated trade-in or salvage value which is usually taken as 10 percent of the total original cost. Depreciation per unit of time is then found by dividing this net amount by the estimated life of the machine expressed in the same time units, thus:

$$\text{depreciation} = \frac{\text{original machine cost} \times 0.90}{\text{machine life in units of time}}$$

2. Interest

Interest for inclusion in machine operating cost is calculated by applying to the average annual investment in the machine the interest rate at which money may be borrowed to finance its purchase. It is expressed as a cost per unit of time by dividing annual interest by the number of time units in the year, thus:

$$I = \frac{\text{AAI} \times i}{\text{Time units in year}}$$

where I = interest per hour or other unit of time;

AAI = average annual investment;

i = rate of interest expressed in decimal form.

While for quick and easy calculation the average annual investment is often taken as 60 percent of the delivered cost of the machine, it may be more accurately calculated with the following formula:

$$\text{AAI} = \frac{C(Y + 1) + V(Y - 1)}{2Y}$$

where AAI = average annual investment;

C = delivered cost of machine;

V = estimated salvage or trade-in value of machine;

Y = estimated life of machine in years.

In some regions of the world, interest is not normally included in the operating cost record of a machine. However, it must be included when the operating costs of two or more logging machines, and hence logging methods, are being compared. To leave it out might lead to inaccurate machine rates and to erroneous decisions in selecting the logging method.

3. Insurance

Insurance is normally designed to cover public liability and property damage and loss of machine from fire, theft or other hazard. Its annual value is usually taken as a percentage of original machine or average annual investment and converted to a rate per machine or other time unit. The percentage rate depends on local practice but normally lies between 1 and 5 percent applied to annual average investment. The following formula may be used:

$$IN = \frac{\text{delivered cost of machine}}{\text{units of time per year}} \times 0.60 \times r$$

where IN = insurance cost per hour or other time unit;

r = percentage rate expressed in decimal form.

4. Taxes

This item refers to annual taxes relating to the machine proper. It includes the annual cost, if applicable, of licensing the machine, but not fuel taxes which are part of fuel cost. The annual cost of taxes is converted to a rate per hour or other time unit with the following formula:

$$\text{Taxes} = \frac{\text{annual tax amount}}{\text{average hours (or other time units) per year}}$$

5. Operating Labour

The cost of operating labour comprises the direct wages of operator or driver and helpers used with the machine together with the indirect cost of labour fringe benefits. The latter cost must be established and expressed as a percentage of direct labour cost. Labour cost per machine hour may be found by dividing labour cost per unit period (day, week, month or year) by the number of machine hours or other appropriate time units in the period. Thus:

$$\text{Operating labour} = \frac{\text{labour cost for period}}{\text{PMH (or other time unit) in the period}} \times (1 + f)$$

where f = cost of labour fringe benefits expressed as a percentage of direct labour cost;

PMH = productive machine hour.

6. Fuel

Fuel consumption depends on engine hp and load factor. Load factor is a term used to express actual fuel consumption as a percentage of the maximum capacity of the engine to burn fuel. Thus, an engine continuously producing full rated hp is operating at a load factor of 100 percent.

Value of the load factor depends on severity of service. A crawler tractor on bulldozing work on a logging operation in temperate climates normally operates at a load factor of 65 - 70 percent; in plantation work in hot climates, it may be somewhat less. Mechanical forwarders, most of which have weight-power ratios loaded in the range of 160 - 180, operate at an average load factor of 55 - 70 percent, depending on operating conditions and operator efficiency. Weight-power ratio is the ratio of gross vehicle weight (GVW in kg) to net engine hp. In an eastern Canadian 80-km tractor trailer pulpwood haul over a main gravel

road on undulating terrain with an average downgrade loaded of about 0.4 percent, the weight-power ratio loaded was about 140, two-way travel speed averaged about 70 km/h and the average load factor was calculated at 72 percent (76 percent loaded and 65 percent light on the return trip to the woods).

Canadian-type wheeled skidders using chokers in eastern Canada, operating in many cases under quite severe physical conditions, skid relatively small loads, limited in many cases by tree size (average 0.14 - 0.16 m³) and the number of chokers carried. Even when trees are larger maximum loads are not always hauled. The result is that engines are not usually operated at full hp even when the skidder is loaded and the load factor ranges between 45 and 50 percent. On the other hand, in developing countries where labour is plentiful and cheap, terrain is normally good, trees (except in early commercial thinnings) are large and machines represent the major cost component of an operation, the tendency is to skid maximum loads at all times and thus to work the engine hard. Under such conditions the average load factor may range between 60 and 65 percent.

Considering the above points, a load factor value of 60 percent may be used for estimating purposes without producing a significant error in the machine operating cost.

The fuel consumption of a diesel engine using No. 2 fuel varies between 0.16 and 0.18 kg per brake hp hour, depending on engine design and speed, ambient temperature and efficiency of the engine. For calculating purposes, a mean value of 0.17 kg may be used. Fuel consumption of gasoline engines is in the order of 0.21 kg per brake hp hour.

Gross horsepower is the brake horsepower of the engine when operating with fuel system, air cleaner and fuel and water pumps only. Net horsepower is the brake or flywheel horsepower developed when operating with fan, exhaust system, generator or alternator and other ancillary attachments as well. Net horsepower is usually within a range of 7 - 15 percent less than gross hp. Engine horsepower is usually quoted as gross, but some manufacturers may quote a net figure.

While the weight of fuel varies somewhat depending on ambient temperature and pressure it may be taken as 0.84 kg/l for No. 2 diesel fuel and 0.72 kg for gasoline. Fuel consumption may be calculated with the following formula:

$$\text{LMPH} = \frac{K \times \text{GHP} \times \text{LF}}{\text{KPL} \times 100}$$

where LMPH = litres used per machine hour;

K = kg of fuel used per brake hp/h;

GHP = gross engine hp at governed speed (revolutions per minute);

LF = load factor in %;

KPL = weight of fuel in kg/l.

By substituting in the formula the appropriate values, as given above, for symbols K, LF and KPL the formula becomes:

(a) LPMH = 0.12 x GHP for diesel engines, and

(b) LPMH = 0.175 x GHP for gasoline engines.

Fuel cost per machine hour may then be estimated with the formula:

(a) FC = 0.12 x GHP x CL for diesel engines, and

(b) FC = 0.175 x GHP x CL for gasoline engines.

where FC = fuel cost per machine hour;

GHP = gross brake horsepower of the engine;

CL = cost of fuel per litre.

Thus, if fuel costs 0.15/1, the estimated fuel cost of a Caterpillar D7F tractor developing 180 net or flywheel horsepower would be around:

$$0.12 \times \frac{180}{0.935} \times 0.15 = \text{US\$ } 3.47 \text{ per hour.}$$

The best way to obtain fuel consumption data is from similar machines working under similar conditions. When this is not practicable, the most satisfactory method is as above. Attempts to develop short-cut methods of costing fuel consumption have not been particularly successful, because of the variables that enter into the exercise. The most critical of these is load factor. Experience in a region and a few spot checks on specific machines will quickly enable its value to be established within reasonably accurate limits.

7. Oil and Grease

The cost of oil and grease, including hydraulic oils, varies with engine hp and the capacity and complexity of the hydraulic system. For such machines as tractors, trucks, skidders and front-end loaders, which have no or relatively small hydraulic system, the cost per machine hour may be approximated with the following formula:

$$\text{COG} = \frac{\text{GHP} \times 0.20}{100}$$

where COG = cost of oil and grease per PMH;

GHP = gross hp.

In such machines as forwarders, processors and harvesters which may have major and relatively complex and high pressure hydraulic systems, the cost per machine hour, expressed in cents, may exceed 50 percent and even approach 100 percent of gross hp. For example, a harvester with an engine hp rating of 200 may have an oil and grease cost of well over US\$ 1 per machine hour. The cost of oil and grease for feller-bunchers and knuckleboom loaders will fall between the cost for crawler tractors and that for harvesters. Thus, the formula may be expressed in this manner:

$$\text{COG} = \frac{\text{GHP} \times}{100}$$

where COG = cost of oils and greases per PMH;

x = factor with the following values;

- (a) 0.25 for tractors, trucks, skidders, graders and front-end loaders;
- (b) 0.35 for feller-bunchers and knuckleboom loaders;
- (c) 0.60 for processors, harvesters and forwarders.

8. Servicing and Repairs (Except Tires for Hauling Rigs)

It is very difficult to form sound cost estimates of servicing and repairing mechanical equipment unless experience with similar machines working under similar conditions is available. It has become the practice to relate lifetime servicing and repair costs to one or more of the following factors:

- (a) purchase price;
- (b) delivered cost less taxes;
- (c) depreciation,

and to express it as a cost per PMH. They are based on the assumption that the life span of the machine has been estimated realistically.

Although servicing and repair cost of a machine actually increases with age, it is normally averaged over machine life and expressed on a "straight line" basis in the same manner as depreciation. In practice, annual depreciation charges decrease each year while servicing and repair costs increase, so that the two together give a fairly equal annual value over the life of the machine, thus making the "straight line" calculation reasonably realistic when both cost components are considered in this manner.

Experience in eastern Canada shows that servicing and repair costs may vary between 75 and 150 percent of depreciation (when machine life is realistically estimated), depending on the complexity and development stage of the machine, its type of work, its working milieu and the care which the operator takes. The cost consists of two items:

- (a) labour, including fringe benefits, and
- (b) parts and material.

In eastern Canada these make up approximately 50 percent each of the total cost, with labour cost being based on a "garage charge-out rate" which may range between US\$ 10 and US\$ 15 per machine hour.

In developing countries, the cost of parts and material often differs substantially from that in industrialised countries, but labour cost is much lower. As a general rule in eastern Canada, lifetime servicing and repair cost of a reasonably well developed logging machine is considered to equal the delivered cost of the original machine. It is suggested that the same ratio be used unless or until more accurate data are available, hence the following formula:

$$\text{Servicing and repairs} = \frac{\text{delivered cost of machine}}{\text{normal life in hours}}$$

9. Tires (For Hauling Rigs Only)

Tires of hauling rigs are sometimes costed on a mileage basis. There is nothing wrong with this method, particularly where the trucks are operating continuously under the same loads and/or over the same type of roads. However, on most logging operations several types of roads are encountered from rough low-speed roads where tires are often subject to sidewall damage, to smooth, paved high-speed roads where hazards are few and heat is probably the greatest tire enemy. It seems obvious therefore that tire costing on the basis of travelling hours will be as reliable as, or even more accurate than, costing on a mileage basis. It is also more easily used in costing procedures.

It is also obvious that experience with similar equipment and tires on similar operations will provide the best information on tire cost. When this is not available, other means must be found. Much will depend on construction of the tire, tire load and inflation pressure, road surface, travel speed, ambient temperature and numerous other factors.

The original tires should be depreciated or written off with the truck or trailer in the case of log hauling rigs. Thus, tire costs will cover repairs to the original tires and the cost of, and repairs to, replacement tires during the life of the unit. This may be found by evaluating the following expression:

$$\frac{B}{Y \cdot Z} + \frac{(T + B)(Y \cdot Z - A)}{Z \cdot Y \cdot A}$$

where B = life repair cost of a set of tires;

T = replacement cost of a set of tires;

Y = life of truck or trailer in years;

Z = travelling hours per year;

A = life of a set of tires expressed in travelling hours;

$Y \cdot Z$ = lifetime travelling hours of truck or trailer;

$\frac{B}{Y \cdot Z}$ = lifetime repair cost of original tires;

$\frac{T + B}{Y \cdot Z}$ = cost of replacement set of tires and repairs to those tires spread over machine life;

$\frac{Y \cdot Z - A}{A}$ = number of sets of replacement tires required during machine life.

On the rough basis that (a) a hauling rig should spend 10 000 h of its life travelling; (b) tire life should be about 2 000 travelling hours; and (c) recapping and repairs per tire amount to 50 percent of the original cost, four replacement sets of tires will be needed during the lifetime of the hauling rig at a cost of:

$$\text{CST} \times 1.5 \times 4$$

and tire cost per travelling hour will be found with the following formula:

$$TC = \frac{\text{CST} \times 1.5 \times 4}{10 000} = 0.006 \times \text{CST}$$

where TC = tire cost per travelling hour;

CST = cost of set of replacement tires.

The labour cost of changing tires and carrying out minor tire repairs may be, for convenience sake, included with servicing and repair labour.

10 Calculation Sheet

Form A in Chapter 3 is a sheet which may be used to estimate the operating cost of a machine. It is suitable for trucks as well as for those machines, such as crawler tractors, which have no distinct travelling function.

APPENDIX I

INTERIOR HAUL ROADS FOR LOWEST COMBINED COST OF FORWARDING AND HAULING

The Principles

The road system over which the wood from a specific area is hauled to final landing normally comprises a series of roads of different calibre starting with the extraction or interior roads within the immediate logging area and gradually increasing in standard until the final landing is reached. R.G. Belcher has shown in Woodlands Section Paper No. 2484: "Minimization of Trucking Costs" that, for lowest combined cost of road and hauling, it is better to overbuild rather than underbuild main roads, i.e., that there would be less expectation of an overall loss through building a high standard road than making a poor road.

As far as interior or extraction roads - those lying within and serving only the immediate logging area - are concerned, Woodlands Section Paper No. 2258: "Mechanized Logging and Road Requirements" developed the principle that the cost of an interior haul road and the variable (travelling) costs of forwarding and of hauling over that interior road, expressed in the same terms, must be equal or in balance if lowest possible logging cost is to be achieved. This principle is based on acceptance of several premises:

- 1) that there is a measure of flexibility - some freedom of choice - in the amount of money spent per mile of extraction road;
- 2) that average round trip speed on the interior road is proportional to road cost per mile;
- 3) that variable (travelling) hauling cost is inversely proportional to travel speed so that, for example, doubling the speed will halve the cost;
- 4) that the operating costs of forwarding and hauling equipment be developed on the basis of standing and travelling hours, and that they be applied on this basis.

The logging operator is often faced with the problem of determining the service standard to which a road should be built and the amount of money which can economically be spent on it. In the case of main roads, or extraction roads which will later become secondary or main roads, the total volume of wood to be served must be considered. It is obvious that the road should be built initially to its final standard in order to achieve minimum costs beginning with its initial use. The problem being considered here concerns those interior roads which are at the "end of the line" and will never serve more than the wood immediately around them.

Application of the optimum road spacing formula gives the extraction road spacing which will produce lowest combined cost of 1) forwarding or skidding and 2) road construction and maintenance. The formula was developed by equating variable or travelling part of forwarding cost per cunit. This could be done since variable forwarding cost per cunit varies directly and extraction road cost per cunit inversely with road spacing, permitting the two components to be equated for minimum cost. Thus

$$\frac{S}{4} \times \frac{c \cdot t (1+p)}{L} = \frac{R}{8Sd}$$

where S = optimum extraction road spacing in chains;
S = average forwarding distance in chains;
 $\frac{1}{4}$ = cost per travelling minute of the forwarding or skidding equipment;
t = average round trip travelling speed in minutes per chain of forwarding distance, i.e., time to travel one chain loaded and return light;

L = average forwarder or skidder load in cunits;
R = road construction and maintenance cost per mile;
d = stand density in cunits per acre;
p = a delay factor.

so that

$ct(1+p)$ = variable forwarding or skidding cost per cunit-chain;
 $8Sd$ = cunits of wood served per mile of extraction road;
 $\frac{R}{8Sd}$ = extraction road cost per cunit.

Solving for optimum road spacing S, the equation becomes:

$$S = \sqrt{\frac{LR}{2dct(1+p)}}$$

This means that spacing the extraction roads as indicated by application of the formula will ensure that variable forwarding and road costs per cunit will be equal, and lowest combined cost of the two operations realized.

It is evident likewise that the combined costs of constructing and maintaining an interior road and hauling over it, when expressed on the same basis, will be a minimum when these component costs are equal. It is a fact, based on the method of costing trucks by standing and travelling hours, that variable (travelling) hauling cost varies inversely with travel speed. Earlier in this section the premise was adopted, and in practice it seems sound within limits, that extraction road cost is directly proportional to travel speed since there is a measure of flexibility in deciding how much money should be spent on the road. Under these premises since one cost varies directly and the other inversely with travel speed, they may be equated for minimum combined cost. Thus

$$D \times X \times \frac{ct(1+p)}{L} = \frac{R}{8Sd}$$

where D = length of extraction road in miles;
 $D \times X$ = average hauling distance in miles;
c = cost per travelling hour of the hauling equipment;
t = average time in hours required to travel one mile loaded and return light;
L = average load in cunits;
R = road construction and maintenance cost per mile;
S = optimum road spacing in chains;
d = stand density in cunits per acre;
p = a delay factor;

so that

$\frac{ct(1+p)}{L}$ = variable hauling cost per cunit-mile;
 $8Sd$ = volume of wood served per mile of extraction road;
 $\frac{R}{8Sd}$ = extraction road cost per cunit.

Extraction roads are usually constructed to reduce the cost of skidding or forwarding. Therefore the latter cannot be ignored in reaching the objective of lowest total cost of skidding or forwarding, hauling and extraction road construction and maintenance. Under proper planning, application of the optimum road spacing formula will ensure minimum combined cost of extraction roads and forwarding. Likewise, minimum combined cost of extraction road and hauling will be attained when these two costs are brought into balance. It follows therefore that the extraction road standard should be one that, on its spacing, will keep variable forwarding and variable hauling costs per cunit in balance. Therefore, a comparison between these two values for the road being considered will indicate whether the standard is correct, too high or too low, and so direct attention toward the possibility of a change in standard. To do this, the value of each should be developed in terms of R , the road cost per mile, and the two results formed into an equation which may be solved for R - the road cost which will produce equal road and variable forwarding and hauling costs, and the lowest possible combined cost, all expressed on a cunit cost basis.

A copy of Woodlands Section Paper No. 2258: "Mechanized Logging and Road Requirements" may be found in Appendix XIII. Reference should be made to it for greater details concerning the subject under discussion. A copy of R.G. Belcher's paper referred to above is not included since it deals with main roads, which are not under study.

Application of the Minimum Combined Cost Principle

An extensive area bordering on a main road and extending back one mile carries a relatively uniform stand averaging 12 cunits per acre. The logging operator plans to process the wood by the cut-bunch method and forward it to roadside or trailer with forwarders carrying 3-cunit loads, costing \$18.00 per hour worked, and travelling at an average round trip speed of 1.5 mph (so that a time of one minute is required to travel one chain loaded and return light). Extraction roads are to be built at intervals to the full depth of the area. The operator has freedom to decide concerning the service standard of the extraction road and the amount of money to be spent per mile. He has decided that he can arrange this expenditure so that travel speed will be directly proportional to road cost R and, in terms of R , equal $.01R$, i.e., his hauling trucks will be able to average 5 mph if he spends 500 per mile, 10 mph if he spends \$1000, and so on to a limited degree. He will use truck-semi-trailer rigs loading 12 cunits and costing \$18.00 per travelling hour.

The operator wants to know, in order to realize minimum possible overall costs:

- 1) the optimum spacing for his extraction roads;
- 2) how much he should spend per mile of road.

He realizes that, in seeking the answer to his problem, cost per standing hour, loading method (hot or pre-loading), and the ratio of trailers to truck-tractors do not enter the picture except that the road cost must cover his trailer parking areas if he pre-loads.

The solution requires:

- 1) application of the optimum road spacing formula to find an answer in terms of R ;
- 2) determination of variable forwarding cost

$$\frac{S}{4} = \frac{c t (1+p)}{L}$$

and variable hauling cost

$$D \times X \times \frac{o t (1+p)}{L}$$

both in terms of R , and equating the two results to find R , the correct road cost per mile.

A. Apply the optimum road spacing formula:

$$S = \sqrt{\frac{LR}{2 d c t (1+p)}} = \sqrt{\frac{3R}{2 \times 12 \times .30 \times 1 \times 1.10}} = \sqrt{.615 R}$$

B. Find the variable forwarding cost per cunit:

$$\frac{S}{4} \times \frac{c t (1+p)}{L} = \frac{.615 \sqrt{R}}{4} \times \frac{.30 \times 1 \times 1.10}{3} = .0169 \sqrt{R}$$

C. Find the variable hauling cost per cunit for the wood to be served by each extraction road of length D where the wood is evenly distributed along the road so that $X = .5$, i.e. the average hauling distance is half the length of the road:

$$D \times X \times \frac{c t (1+p)}{L} = \frac{1 \times .5 \times 18 \times 2 \times 1.10}{.01R \times 12} = \frac{165}{R}$$

D. Equate values from B and C and solve for R:

$$.0169 \sqrt{R} = \frac{165}{R}$$

$$\text{so that } R = \$455.$$

E. Find optimum extraction road spacing from A above:

$$S = .615 \sqrt{R} = .615 \sqrt{455} = 13.1 \text{ chains.}$$

Thus if an amount of \$455 is spent per mile of extraction road, the following results show up:

- 1) optimum road spacing = $.615 \times 21.3$ = about 13 chains;
- 2) each mile of road will serve 8Sd = 1 250 cunits;
- 3) average hauling speed = $.01 \times 455$ = 4.5 mph;
- 4) variable forwarding, variable hauling and road costs will be equal and cost as shown below to produce the lowest possible combined cost:

Symbol	Cost per Cunit
Variable forwarding	$.0169 \sqrt{R}$
Variable hauling	$\frac{165}{R}$
Extraction road	$\frac{R}{8Sd}$
Totals	\$1.08

If the premises adopted for this exercise cannot be maintained, the principle of minimum combined costs as explained earlier cannot be applied. Under the conditions set out, the values given above show the lowest possible combined cost of road construction, variable forwarding and variable hauling. One of the key premises was that truck travel

speed on the extraction road was proportional to road cost - for this specific problem equal to $.01R$ where R equals road cost per mile.

If, however, terrain conditions are such that the operator has no choice but to spend, for example, \$1 000 instead of \$455 per mile on the road, the premises are violated and the principle does not hold. Under such a situation, the operator would have the following options:

- A) leave the road spacing undisturbed at 13 chains and spend \$1 000 per mile on the roads;
- B) re-apply the road spacing formula with R , the road cost, equal to \$1 000.

These options would provide the following comparative data:

	<u>Option A</u>	<u>Option B</u>
Extraction road spacing in chains	13.1	19.5
Cunits served per extraction road	<u>1 260.</u>	<u>1 870.</u>
Variable forwarding cost per cunit	\$0.36	\$0.535
Road cost per cunit	.795	.535
Variable hauling cost per cunit, when average travel speed = 4.5 mph	<u>.36</u>	<u>.36</u>
Combined cost per cunit	<u>\$1.515</u>	<u>\$1.43</u>

Again if the operator were obliged to spend \$2 000 per mile on extraction roads, the combined cost of road, variable forwarding and variable hauling would be even higher: \$2.31 under Option A and \$1.87 under Option B, using the same average hauling speed of 4.5 mph.

Thus it is evident that, when the principle of minimum combined cost cannot be maintained, the lowest combined cost will be achieved when the extraction roads are spaced according to the optimum road spacing formula and maximum hauling speeds, having due regard to the road, are maintained. It is also obvious that, since winter extraction roads normally cost much less than summer extraction roads, the combined cost of extraction roads, forwarding and hauling will be a minimum under winter conditions and that this fact should enter into the formulation of logging plans.

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