logging and log transport
in tropical high forest

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
As recorded information on methods, production and costs of logging and transport in the developing world — and especially in tropical high forest — is scarce, one of the main purposes of this manual is to focus attention on the analytic approach needed to quantify output and costs data. An important element of tropical high forest logging is examined: the influence of physical and economic conditions on production. Production and cost data are presented, as far as available information permits, for the most commonly used logging methods adaptable to this particular situation.
LOGGING AND LOG TRANSPORT IN TROPICAL HIGH FOREST
Log extraction in waterlogged areas by means of blasted ditches, Surinam.

(Bubberman/Vink)
LOGGING AND LOG TRANSPORT IN TROPICAL HIGH FOREST

A manual on production and costs

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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INTRODUCTION

This is a revised and updated version of an earlier report on the same subject (Bendz and Järvholm, 1970).

Although the publication refers to developing countries, perhaps it would be more correct to describe them as those in which the forest industry has not yet been fully developed in respect of logging methods and equipment and where, for the most part, wages are low and unemployment is a major problem. This points to the use of labour-intensive logging methods. Nevertheless, in many tropical regions trees in the high forests are of such size and weight that mechanized equipment must be used to some extent. For these reasons, this study refers as well to equipment and techniques which have a place in mechanized methods.

The following consultants contributed to this revision, which was carried ont by the Forest Logging and Transport Branch of the FAO Forestry Department: M. Bendz, J.A. McNally and C.R. Silversides. These consultancies were made possible through Trust Fund contributions from the Swedish International Development Authority.

Purpose of the study

Written information on methods, production and costs of logging and transport in the developing parts of the world, especially for operations in tropical high forest, is scarce as compared to that available for industrialized countries.

Although the data on which this publication is based have been collected not by detailed time studies but by obtaining “gross production data” from ongoing operations, the almost complete absence of documentation on the subject warrants its publishing. However, as methods and output from the operations are continually changing, it is likely that revision of this study will be necessary within a few years.

The first purpose of this paper is to focus attention on the analytic approach needed for the quantification of output and cost and on the influence
of physical and economic conditions on production. Lack of understanding of this approach is no doubt one of the main reasons why the great amount of information that is in fact available with logging firms and experts all over the tropical parts of the world has not been organized, quantified and interpreted. Another reason is the lack of systematic logging research in developing countries.

The second purpose is to present production and cost data as far as available information permits. This has been possible only for the most commonly used methods of operation. The diagrams and tables in the following report present information as averages. The production figures should be regarded as descriptive rather than normative measures of output now common in tropical logging. They give the production and costs to be expected in logging and transport under conditions as defined, assuming technique and efficiency prevailing in the early 1970s. Examples of production under different conditions accompany each of the main graphs. They should prove helpful in visualizing existing ranges of conditions and in interpolating for new situations.

Compared with the earlier report of which this study is a revision there has been a general increase in production for all operations described.

Sources of information

The study is based on the following sources of information.

FIELD STUDIES

The first report was based on studies in seventeen countries visited during 1966-68 by associate experts working with FAO. This publication includes additional information from field studies in another ten countries visited by experts during 1968-72. The studies encompass some thirty weeks of field work in more than a hundred different logging areas.

The reliability of production and cost data available within logging enterprises varies greatly. Records on costs are scarce, as firms often want to keep them secret. Therefore, the chief method used was to visit ongoing operations and to interview logging staff at all levels, using a standardized set of questions which included a number of duplications for checking the validity of stated figures. The influence of tree, stand and terrain factors was also systematically questioned.

QUESTIONNAIRES

Questionnaires sent to logging enterprises and field experts in the spring of 1972 were based on the previous report and asked for further information
related to graphs and tables in the publication. Eleven useful replies were received.

The type of information asked for is not very well suited for questionnaires since the information must always be related to different work conditions. Some of the replies had to be disregarded for that reason.

LITERATURE

FAO reports with information on logging and transport have been scrutinized and relevant facts have been extracted. In general very little useful information for the specific purposes of this study was obtained through these reports. This is quite understandable since the reports were, in most cases, written for other purposes.

There are, however, a few external publications that prove the need for analyses like the one at hand. Most of these are published at the Centre technique forestier tropical.1 One of these reports by CTFT was compiled on a consultancy for FAO.

It should be noted here that the list of references is not extensive; although there are numerous publications on timber harvesting, few of them concern operations in tropical high forest.

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1 CTFT, 94 — Nogent-sur-Marne, France.
1. THEORETICAL FRAMEWORK

Input factors in logging and transport operations, that is, labour and machinery, must be combined in an effective way. In order to allow for generalizations, the different phases of work must be related to cost-determining conditions. In this analysis only gross production data and approximate figures on the cost-determining conditions are available. It follows that production and costs can only be related to a few factors that are known by experience to bear strongly on the production of the logging process.

The following two sets of information are used:

(a) cost per unit time for each input factor (i.e., cost per unit time worked or utilized);

(b) the production (output) for each phase of work per unit time.

In order to arrive at a final cost figure for the operations (the cost of delivered wood), this information is processed as shown in Figure 1.

The calculations start with the different phases of work related to local cost-determining conditions, and build up successively to the final figure. The influence of varying conditions is thus assessed for each work phase and should give the best possible estimate of the true costs.

Selection of factors affecting production

Factors affecting production and costs of logging operations might be grouped in the following way:

climate — which has influence on output and cost but cannot be manipulated;

socioeconomic conditions — which are interrelated with the operations and are thus possible to influence in the long run. These include labour, skill, motivation, employment situation, state of economy of region and nation, etc.;
forest conditions — tree, stand, topography, soil, which are significant to some degree; technique — working methods and equipment, of which a large number of choices exist.

Among conditions or factors that affect or could affect the output of logging are groups having varying degrees of significance. Some conditions have a major impact on output, others play a secondary role. In skidding, for instance, the transport distance is important while the distance between felled trees, when kept within reasonable limits, has little effect on the production.

Another grouping of the factors affecting production refers to their measurability. Some of them are easy to measure (e.g., diameters and distances); other are almost impossible to measure (workers’ skill, carrying capacity of the soil).

![Flowchart](image-url)

**Figure 1.** — Method of processing output and unit time costs to find cost per unit of output.
In order to estimate output per unit time (Figure 1), it is necessary to know how certain factors affect output. The selection of those factors is a compromise between availability of data, precision in results and simplicity.

The interaction between importance and measurability of the factors affecting production gives the following groupings:

1. Factors that are important and easily measured. Some of these are measured for other purposes, or can easily be measured for the purpose of production and cost analyses. They have the same principal impact on output all over the world and it is evident that factors of this nature (tree diameter, equipment used, transport distance, weight of logs) play a dominant role in production and that they will affect production in all localities. They are termed "main conditioning factors" and used as entries in the graphs and tables in this report.

2. Factors that are important but difficult or expensive to measure (e.g., terrain conditions, quality of the trees). Some of these factors are included in this report based on subjective estimates. In some cases auxiliary tables are included in the text.

3. Factors that are less important and/or difficult or expensive to measure. These factors are known from other studies to influence production only in a limited way. They would be considered only in refined analyses based on detailed work study and are excluded from this report.

Limitations of the study

Because tropical high forest logging takes place under a wide range of conditions the ensuing analysis is limited in that the information refers to the most commonly used operations, with data on manual operations being reported when available; to work carried out by trained workers (i.e., those who have surmounted the initial work difficulties and arrived at a stable rate of production); and to operations in which equipment and machinery get reasonable maintenance and service.

These apparently severe limitations may seem to lessen the value of the results, but estimates show that approximately three fourths of the total cut of tropical timber for industrial purposes are handled at least partly with mechanical equipment. This implies that the results are limited to output reached in relatively large enterprises — that is, those having regular management, regular working conditions and relatively well-trained and experienced labour working with relatively well-kept mechanical equipment.
The purpose of the following text is to give data for production and cost forecasts for various phases of logging and transport of wood. Generally, nomograms have been used to relate output or time consumption to the conditioning factors. As the number of observations do not allow regression analysis, the curves have been drawn "by hand" with the best possible fit to the observations, taking into account the reliability of each observation.

The production graphs generally indicate output per hour and/or per day or as time consumption per unit of production. The assessment of effective working time is an essential part of calculations and estimates of logging costs. It is clear that in small enterprises without proper management the number of hours effectively worked will be irregular and difficult to assess. This is less so in larger enterprises, particularly when mechanical equipment is employed and is in line with the limitations made in the previous chapter. It should be noted that the number of hours effectively worked per day generally does not exceed six, even when gross working hours run to eight or nine hours. In the following text, "effective working hours/day" is similar but not quite identical to Productive Machine Hours (PMH) as defined in the scheme in Appendix 1. This scheme is recommended for production control in logging operations.

Although the conditions under which the nomograms are valid are fairly well defined, the graphs do not reflect the deviations bound to occur in logging. There are several conditions not included in the production graphs or tables that may cause substantial deviation in certain cases between predicted and actual production. Such deviations should be considerably smaller for the cost of machines (see Chapter 4).

If graphs, tables, correction factors, etc. are properly used, production figures arrived at are estimated to fall within ± 15 percent of the corresponding "true" production.

Compared to conditions in man-made or otherwise homogeneous forests, logging in tropical high forest has some significant technical characteristics; these are outlined below.
1. The trees are large; the diameter of the logs is generally between 50 and 100 cm; certain species also have a butt swell or buttress.

2. The merchantable part of the tree (the bole) often represents only 30-50 percent of the total height of the tree; the first large branch will normally set the limit for what will be utilized; delimbing is seldom done.

3. The harvested volume per hectare is low; apart from dypterocarp forests and other exceptions, only 5-40 m$^3$/ha are normally extracted.

4. Since most logging operations take place in virgin stands, work is hampered by thick undergrowth, creepers and climbers, a comparatively high degree of damaged trees, and stands heterogeneous with respect to diameter and height of trees, etc.

Stump area operations

Cutting tools

During the 1960s there was a very rapid increase in the use of the power saw (used here as a synonym for motor chain-saw). There is no doubt that the power saw is a good piece of equipment for tropical high forest logging. Both one-man and two-man saws are in use but the two-man saw seems to be gradually losing ground. It is found today on bigger landings exclusively. The one-man power saw with a fairly long bar and motor-power of some 10-12 hp is the most suitable type. One of the advantages with this equipment is the possibility of making centre cuts through buttresses which in turn permits directed felling.

Axes and different types of hand saws are still found in several operations. When hand tools are used, wooden constructions (platforms) are built around the tree in order to make the felling cut above the buttress.

Production

Nomogram A (Figure 2) gives the estimated production per hour and per day in felling and crosscutting. The selected production factors are: tree diameter (DBH above possible buttress), number of logs per tree, and effective working time.

The diameter affects production in two ways: it determines the amount of work needed to fell a tree (i.e., the area to be cut through), and it reflects

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1 Nomogram A is based on the utilized volumes per tree shown in Figure 3.
the volume that might be utilized. A large tree will require more time to be felled and cut into log lengths but it will also give a higher volume of timber.

The number of hours effectively worked per day is one of the most significant factors affecting production. It is also one of the most difficult to establish. Lines for 4, 6 and 8 effective hours are drawn in Nomogram A. Experience shows that the level of six effective hours is seldom reached in felling mainly due to physical exhaustion in the hot climate. In this operation effective working time includes walking to the trees, handling of tools, preparation at stump site, sawing and minor items, but excludes long pauses and delay time.

Felling with axe, using a platform. (Centre technique forestier tropical, France)
Table 1 gives some condensed information on methods and production for stump area operations (typical volumes under normal high forest conditions).

**Table 1. — Felling and crosscutting production in the stump area**

<table>
<thead>
<tr>
<th>Method</th>
<th>Normal daily crew production (m³)</th>
<th>Number of workers in crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axe for felling and crosscutting</td>
<td>3-15</td>
<td>1</td>
</tr>
<tr>
<td>Axe for felling, two-man saw for crosscutting</td>
<td>25-30</td>
<td>2</td>
</tr>
<tr>
<td>Two-man crosscut saw for felling and crosscutting</td>
<td>15-30</td>
<td>2</td>
</tr>
<tr>
<td>Power saw</td>
<td>30-70</td>
<td>2</td>
</tr>
</tbody>
</table>

Regardless of the cutting tools used, there are remarkably small differences in costs per unit of production. The cost for stump operations could be forecast with a high degree of certainty to be US$0.30-0.50 per m³ regardless of method used. Even the influence of very low harvested volume per unit area on the cost of stump area operations is not significant.

**Figure 2. — Nomogram A — Felling and crosscutting with power saw (1 operator + 1 helper).** Hours/day refers to number of effective working hours per day.

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2 In this study “dollars” ($) always refers to United States dollars.
**Table 2. Correction factors for stand and terrain conditions**

<table>
<thead>
<tr>
<th>Terrain and vegetation on the felling site</th>
<th>Form and quality of trees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tall and well-formed trees and/or little damage</td>
</tr>
<tr>
<td>Steep terrain (more than 40%) or swampy ground and/or severe felling obstacles (underbrush, etc.)</td>
<td>0.9</td>
</tr>
<tr>
<td>Average - normal conditions</td>
<td>1.2</td>
</tr>
<tr>
<td>Smooth or undulating terrain, well-drained soils, no severe underbrush or other felling obstacles</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Comments and directions**

Nomogram A is read in a counter-clockwise direction, starting on the horizontal axis at the right. After determination of the expected number of logs (crosscuts) per tree the production per hour is read on the vertical axis. The expected production per day or shift is then read on the horizontal axis at the left after establishing the expected number of effective working hours.

There are a number of correction factors that may have to be applied to the production estimates obtained by applying Nomogram A:

1. For stand and terrain conditions the values given in Table 2 should be applied.
2. When platforms are built for felling above the buttress or buttswell, production should be reduced by 20 percent by multiplying the production figure by 0.80.
3. The nomogram is designed assuming the utilized volume per tree shown in Figure 3. These volumes are considered typical for today's practices and species used. If the expected volume should deviate from the volume assumed in designing Nomogram A, e.g., if an 80-cm DBH tree is expected to give 7 m³ of merchantable timber instead of 6 m³, a correction must be made. This is done by multiplying the production figure by the quotient between expected and assumed volumes — in the above case by 7/6.
4. It is assumed in the nomogram that the work is carried out with one-man power saws being used by one operator and one helper. This is not to say that two men per saw is always the case. A third worker may be attached to the crew to help with supplying fuel, etc. If so, the output will increase by 5-15 percent. This might be worth while in areas where the harvested volume is low. In such cases the second helper acts as scout and locates the trees to be felled, thus decreasing walking and preparation time for the saw operator.

5. It is assumed in the nomogram that crosscutting is made at the felling site before extraction (skidding). If additional crosscuts are made at roadside, this work operation can be assessed approximately by taking the balance between readings in the nomogram for the number of crosscuts at the felling site and at roadside respectively. Example:

- Reading for 3 crosscuts gives 25 m³/day, equals 0.040 man-day/m³
- Reading for 1 crosscut gives 40 m³/day, equals 0.025 man-day/m³
- Time consumption for 2 crosscuts at roadside is 0.015 man-day/m³ or a production of 67 m³/day.³

³ All of the above correction factors may be superimposed on one another if conditions require that all should be applied. The PMH (productive machine hours) of the power saw is about 50% of the effective working time.
**PRODUCTION EXAMPLES**

A number of examples of felling and crosscutting production in the stump area with the power saw are given in Table 3:

**Table 3. – Examples of felling and crosscutting production with power saw**

<table>
<thead>
<tr>
<th>Logging area</th>
<th>DBH</th>
<th>Used volume per tree</th>
<th>Number of cross-cuts (logs per tree)</th>
<th>Effective working hours per day</th>
<th>Production per day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Centimetres</td>
<td>Cubic metres</td>
<td></td>
<td></td>
<td>Cubic metres</td>
</tr>
<tr>
<td>Gabon, Zaire</td>
<td>90</td>
<td>8.5</td>
<td>1</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>Malaysia (West)</td>
<td>70-80</td>
<td>6.0</td>
<td>3</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>Surinam</td>
<td>50-55</td>
<td>2.5</td>
<td>1</td>
<td>6</td>
<td>140</td>
</tr>
<tr>
<td>Philippines</td>
<td>85</td>
<td>9.0</td>
<td>2</td>
<td>6</td>
<td>90</td>
</tr>
</tbody>
</table>

1 3-man crew.  2 Very well-organized operations.

Felling with power saw in UNDP/FAO project, Ivory Coast.
Ground skidding

**GENERAL CONDITIONS**

Ground skidding is the most commonly used method for short-distance transport and is normally performed by crawler tractors or articulated four-wheeled skidders. Sometimes both types are employed in the same operation. Both types will be dealt with in this section. It would seem that
the wheeled skidder, introduced in this type of work in the late 1960s, is gradually gaining ground and arousing increasing interest.

The crawler tractor is considered to be superior to the wheeled skidder because of its greater penetration capability and its use in road building. A skidding vehicle in tropical high forest logging must be able to push through the remaining stand and undergrowth, constructing a simple trail between every felled tree and the landing. For this penetration the wheeled skidder has not been found sufficiently powerful, but being both less expensive and two to three times faster than the crawler, it is a useful complement to that machine.

Estève et al. (1972) have shown that a 185 hp wheeled skidder will spend some 30 percent of the total round-trip time in opening up the skidding trail when this work is not carried out by a crawler. It is also noted that

![Nomogram B](image)

**Figure 4.** Nomogram B — Skidding with crawler tractor.
its hourly production will increase by some 50 percent when the trails are prepared prior to the skidding phase (Ivory Coast).

In addition to the particular conditions found in tropical high forest (large trees, low volume and thick undergrowth), skidding is often hampered by swampy or loamy soils and periodically flooded areas. After skidding a number of times along the same trail, the tractors might be considerably hampered by low carrying capacity of the soil.

Nomograms B (Figure 4) and C (Figure 5) refer to production per effective working day (shift) in favourable seasons. The long-run production will not always correspond to figures derived from the graphs. “Favourable season” refers to conditions during the dry period in tropical climates. The long-run production will be reduced by low output or shutdown during wet periods. Experience shows that during wet periods the production will often drop to 65-75 percent of the corresponding production during dry periods.
It is important to make realistic assessments of the length of the working period in different seasons. Besides the climate, machine maintenance and service facilities are significant aspects in this respect. Experience shows that only 50-70 percent of the available number of working days (some 250 annually) are effectively used for skidding (because of breakdowns, waiting, bad weather, other tasks for the equipment, etc.). Despite a high daily production, the annual output of a D7 crawler tractor is often found to be not more than 4000-5000 m³ (although the theoretical production might be three to four times higher).

The advantages of the wheeled skidder are high manoeuvrability, high speeds on suitable ground and smaller investment as compared to the crawler. Its drawbacks are limited drawbar pull and lower penetration capability. Owing to these characteristics the wheeled skidder is often used in combination with a crawler. In such operations the skidding work is divided between the two types of machines. The crawler works close to the stump site and the skidder operates on prepared trails, skidding logs to the landing.

Existing wheeled skidders have lower drawbar pull than the crawlers. For this reason it is sometimes found that the crawler skids the bigger logs and the wheeled skidder the smaller ones.

In some cases the wheeled skidder is also used in the complete skidding operations, that is, from stump to landing. In such cases the ground conditions should not be too rough.

Recent information on a large wheeled skidder (185 hp) shows that such a vehicle might be a very interesting alternative to the crawler. In 1973 a 300 hp wheeled skidder weighing over 25,000 kg and fitted with a heavy-duty full-width (407-cm) dozer blade was put on the market. It should have the required penetration capability to replace the heavy-duty crawler tractor now used for skidding in tropical high forests. It is priced at around $85,000.

**Assessment of Load Size**

In theory the output than can be achieved depends strongly on load size. In practice a small load size is sometimes compensated by reduced round-trip time.

Figure 6 shows the typical relationship between load size and net horsepower of the skidding machine. The graph seems to be reasonably valid for both crawler tractors and articulated wheeled skidders. However, exemptions from this this observation are not uncommon. In very big timber it is not unusual that crawlers log the biggest logs, whereas skidders
log the small and medium-sized ones. Also the range of load sizes seems to be wider for crawlers.

Figure 6 is based on average load sizes as recorded in available sources. The diagram is very simplified since the load size is sensitive to different conditions in the work environment (harvested volume per hectare, density of undergrowth, terrain). The load size depends also on the type of forest harvested and on the logging system design. It is not possible to elaborate this point much further. For instance, it sometimes happens that work conditions permit extra logs to be added to the load on the way down to the landing. Figure 6 refers to the normal case in which the log density permits a full load to be taken within a limited area, and in which, therefore, the total skidding distance is covered with full load.

![Figure 6. Typical load sizes for tracked and wheeled skidding machines.](image-url)
The following procedures are suggested for the assessment of load size for two situations.

1. Skidding machines already on hand:

   (a) read load size over net hp rating of the machine in Figure 6;

   (b) check that this load size is likely to be achieved with regard to terrain; skidding uphill on grades of more than 10-15 percent will reduce the practical load size; skidding downhill on grades of more than 35-40 percent will reduce actual load size;

   (c) check if soil conditions under "normal weather conditions" will permit the load size;

   (d) check if tree and log size will permit a full load; in tropical high forest skidding one log per load is normal and more than two logs per load is unusual;

   (e) check if harvested volume per hectare permits the estimated load size.

2. Choice of skidding machine to be made and roads to be constructed:

   (a) estimate average volume of merchantable bole and maximum log size, taking into account that the biggest boles may be cut into two or several logs;

   (b) decide whether ridge roads or valley roads will be constructed and thus if uphill or downhill skidding will dominate;

   (c) enter load size in Figure 6 and read the corresponding net hp rating on the horizontal axis, considering the aggregate influence of terrain, soil and climate as shown by the lines called "easy terrain" and "difficult terrain";

   (d) choose a skidding machine corresponding to the net hp arrived at.

Skidding with Crawler Tractor

Production forecasts in crawler tractor skidding are based on Nomogram B. Starting with the skidding distance (the horizontal axis in the nomogram) one of the nine numbered curves is selected in order to arrive
at the expected round-trip time (vertical axis). The curve selected is determined by Table 4, which gives a curve number after evaluating slope, harvested volume per hectare, type of soil and obstacles.

The production estimate is completed by establishing in Nomogram B the load size per trip (with the help of Figure 6 if no local information is available) and the effective working hours per day. The nomogram includes all phases of work: loading, unloading, skidding and return trip. There are, of course, very complicated relationships between time consump-

Table 4. – Table for selecting stand and terrain curve (for use Nomogram B)

<table>
<thead>
<tr>
<th>Slope % down grade loaded</th>
<th>0-15%</th>
<th>15-35%</th>
<th>Over 35%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvested volume, m³/ha</td>
<td>5</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>25</td>
<td>100</td>
</tr>
</tbody>
</table>

Firm, dry soil; little downtimber, rocks or undergrowth

<table>
<thead>
<tr>
<th></th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
</table>

Moderately wet or soft soil; some downtimber, rocks or undergrowth

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th>3</th>
<th>2</th>
</tr>
</thead>
</table>

Muddy or loose soil; much downtimber, rocks or undergrowth

<table>
<thead>
<tr>
<th></th>
<th>6</th>
<th>4</th>
<th>3</th>
</tr>
</thead>
</table>

Table 5. – Examples of skidding production using crawler tractors

<table>
<thead>
<tr>
<th>Logging area</th>
<th>Average distance</th>
<th>Type of tractor</th>
<th>Load size</th>
<th>Effective working hours/day</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metres</td>
<td>Cubic metres</td>
<td>Cubic metres/day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
<td>500</td>
<td>D7</td>
<td>7</td>
<td>6</td>
<td>1 70</td>
</tr>
<tr>
<td>Zaire</td>
<td>400</td>
<td>D7</td>
<td>7</td>
<td>8</td>
<td>2 45</td>
</tr>
<tr>
<td>Colombia</td>
<td>400</td>
<td>D7</td>
<td>15</td>
<td>9</td>
<td>3 150</td>
</tr>
<tr>
<td>Tanzania</td>
<td>200</td>
<td>D8</td>
<td>7</td>
<td>6</td>
<td>70</td>
</tr>
<tr>
<td>Rio Muni</td>
<td>1 000</td>
<td>D8</td>
<td>15</td>
<td>7</td>
<td>4 45</td>
</tr>
</tbody>
</table>

1 Slopes 15-30 percent. — 2 Rough terrain, 1 tree per hectare. — 3 15 trees per hectare, efficient management. — 4 Skidding trails prepared beforehand.
tion in these different phases and load size, type of tractors, terrain difficulty, log size, etc. The charts and table are designed to cut through all such interrelations.

If the skidding route varies regarding slope, soil conditions or any other characteristic, a mean value may be established. Should the variations be very significant, it is advisable to divide the area in two or three reasonably homogeneous parts and carry out the exercise for each part separately.

Table 5 gives some examples of skidding production with crawler tractors in several developing countries.
SKIDDING WITH ARTICULATED WHEELED SKIDDERS

There are two different situations for the use of wheeled skidders:

(a) work takes place on prepared skidding trails. In this case the skidder generally works along with a crawler tractor, one of the tasks of the crawler being to prepare the trails. This is "trail skidding";

(b) work takes place as "nontrail skidding," which means that the skidder works on the undisturbed forest floor.

Production forecasts for the two situations are based on Nomogram C, which in turn is based on production records from operations with the 130 hp skidder. Organized information on the 185 hp skidder so far has come from one country only. Compared to the production data summarized in Nomogram C the following preliminary conclusions on the productivity of the 185 hp skidder seem justified:

(a) trail skidding: no significant difference between the 130 and the 185 hp skidder as concerns round-trip time; due to greater load capacity the 185 hp skidder should, however, have a higher production rate;

(b) nontrail skidding: the 185 hp skidder should have a much higher production rate mainly due to its greater penetration capability and its greater horsepower. The estimated round-trip time appears to be some 60 percent of the corresponding "130 hp value."

Nomogram C (Figure 5) is read in the same manner as Nomogram B, i.e., starting with the skidding distance and reading counter-clockwise.

As in the case of crawler-tractor skidding, there are complicated relationships between load size, trail standard and other conditions. The assessment of trail standard in Nomogram C should be based on the following average speeds, excluding delay times, for skidding and return trips:

<table>
<thead>
<tr>
<th>Trail standard</th>
<th>Average speed in km/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>—8</td>
</tr>
<tr>
<td>Average</td>
<td>8—12</td>
</tr>
<tr>
<td>High</td>
<td>12+</td>
</tr>
</tbody>
</table>
Some examples of actual production in several developing countries are given in Table 6. It should be noted that these results were obtained when using 130 hp skidders, such as the Timberjack 360 and 404 and Clark 666 and 667, and that larger and more powerful skidders, developing 185 hp and even 300 hp, are now available.

**Table 6. — Examples of skidding production using 130 hp wheeled skidders**

<table>
<thead>
<tr>
<th>Logging area</th>
<th>Average skidding distance</th>
<th>Load size</th>
<th>Effective working hours per day</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gabon (operation a)</td>
<td>900</td>
<td>6.0</td>
<td>6</td>
<td>56</td>
</tr>
<tr>
<td>Gabon (operation b)</td>
<td>500</td>
<td>6.0</td>
<td>6</td>
<td>120</td>
</tr>
<tr>
<td>Ghana</td>
<td>3000</td>
<td>6.5</td>
<td>6</td>
<td>52</td>
</tr>
<tr>
<td>Ivory Coast</td>
<td>250</td>
<td>6.5</td>
<td>3</td>
<td>58</td>
</tr>
<tr>
<td>Guyana</td>
<td>400</td>
<td>4.3</td>
<td>6</td>
<td>75</td>
</tr>
</tbody>
</table>

**Comments and directions**

In Nomograms B and C production factors are skidding distance, load size and the number of effective hours per day. Work environment such as terrain and slopes is included to a certain extent.

The influence of the above conditions on output is obvious. They determine either the number of round trips per day or the production of each round trip.

Terrain conditions influence production in two ways. Primarily the terrain influences the travel speed of the machine and thus the round-trip time. Secondly, the load size has a direct but limited relationship to the terrain (see Figure 6). Unfavourable terrain conditions tend to result in smaller loads.

**Combined use of crawler and wheeled skidders**

It appears from the foregoing that there are certain basic differences between the two types of skidding machines that make them more or less well suited for different phases of work. The crawler is expensive, powerful and travels with limited speed whereas the wheeled skidder is cheaper, travels faster but has less traction than the crawler. In crawler skidding...
the tractor pushes its way to every felled tree through the remaining stand. It constructs a simple road between the landing and the tree. However, the closer to the landing, the more often the tractor can operate on trails prepared during previous trips. For this part of the route the crawler's penetration capability is no longer needed and this phase of the operation is taken over by the wheeled skidder. The result is that the wheeled skidder operates on prepared trails transporting logs to the landing and the crawler operates in the upper part of the transport system bringing the logs from stump site to the trail. With this organization the crawler can make use of its power and the wheeled skidder of its speed. The crawler handles the more difficult part of the skidding, which means that Nomogram B reflects this operation if curves with high numbers are used.

The use of crawler tractor and wheeled skidder in combination will mean lower costs for skidding and/or less truck road. Calculations indicate that when the two machines are used together as described earlier the optimum distance between truck roads will increase by 20-30 percent, that is, the optimum length of truck road (m/ha) in the logging area will be reduced by 15-25 percent.

Cable yarding

General comments

Cable yarding is a short-distance transportation method generally restricted to terrain conditions where crawler tractors and/or wheeled skidders cannot work satisfactorily, as in swamps and on very rough terrain and steep slopes (over 50 percent).

Slope profile influences most cable yarding systems. Concave slopes offer maximum advantages. Convex slopes will reduce uplift of the forward end of the load in conventional high lead yarding and may interfere with the free movement of the load in running and other skyline systems. Such situations will cause a reduction in yarding distance or relocation of the yarding trail. See below for further discussion of location of skyline yarding trails.

This report deals with the typical high lead system and variations of the system which have been developed during recent years. Outstanding among these developments has been the running skyline system (see below) for either grapple or choker yarding, made possible chiefly by development of the interlocking yarder and special types of skyline carriages.

Other cable yarding configurations have been developed from the high lead system, which operated with either a slack or a fixed skyline. Such
configurations have the advantage of longer yarding distances but have several disadvantages as well when compared to the high lead system: large cable sizes, heavy back rigging, high braking torque, a greater degree of planning, more costly yarding road changing and a higher degree of skill on the part of the operating crew. Only the slack skyline configuration among these heavy duty systems is used to any extent today.

The Norwegian radio-controlled cable crane system, described by Sam- set, employs a fixed skyline, a skyline carriage, a single drum winch and an endless line to move the carriage along the skyline. It has been developed to coordinate felling and yarding into a single operation on mountainous terrain. It employs a two-man crew (a cutter to fell, partly limb, top and choke the tree and start the carriage on its way down, and a second man at the landing to unload and return the empty carriage, complete the de-branching and buck the tree into assortments). Each worker is equipped with a radio transmitter to give command signals to the radio-controlled winch. Under typical Norwegian mountainous conditions average production is around 8 m³ per man-day over a cableway length of 540 m. This system is not discussed further in this report.

Multispan cableway or cable crane systems, although still used in some regions (e.g., Europe and Japan), are declining in use. For this reason (and because they are not high lead systems) they are considered to be beyond the scope of this report.

Cable yarding systems are described at length by Pearce and Stenzel (1972).

**The High Lead System**

*Characteristics and application*

The typical high lead system is the simplest of the cable yarding systems. It consists of a winch or yarder with two yarding drums and a smaller strawline drum, a guyed lead spar, main and haulback lines, and the necessary tail blocks, butt rigging and chokers.

The main characteristics of the typical high lead system are described below.

1. It requires a relatively low capital outlay; it is simplest to rig and operate; it requires least crew training and least set-up planning and engineering; it can be a stepping stone to more complex systems.
2. It is generally restricted to uphill yarding; when yarding downhill there is more soil disturbance and more hang-ups because there is no lifting effect beyond the altitude of the main line spar block.
3. Efficient yarding distance depends on the height of the spar, the slope of the ground and the size of the yarder relative to log size; it is greatest when yarding uphill, least when yarding downhill, and rarely exceeds 300 m under any conditions.

4. It requires a denser truck road network than any other yarding system or the alternative of swinging the yarded logs to established truck roads at a cost of around $0.50 per m³ per swing plus the cost of rigging the swing.

5. It creates more soil disturbance than any other cable yarding system by reason of both the relatively dense truck road network and the poor log lifting capability inherent in the system; on steep slopes, with a truck road density of 32 m/ha, side cut construction may disturb as much as 12 percent of the total surface area (Silen and Grakowski) and, along with high leading, may cause a soil loss of 31 t/ha (Fredericksen, 1970); in some regions of southeast Asia landslides caused in part by road construction are a particularly serious problem, not only because of soil loss and stream silting but because of the consequent high cost of road maintenance and lost hauling time.

6. It is the poorest system from the viewpoint of modern forest management. It cannot be used economically in partial cuts without greater damage to the residual stand and reproduction. On slopes it causes more soil erosion and stream pollution than any other system.

High lead yarding originated in mountainous terrain of western North America, where it is still the most commonly used cable yarding system. It is, however, being supplanted by ground skidding methods where slopes are less than 40-50 percent and site damage is not a problem, where selective logging is being practised or where low stand density makes cable yarding uneconomical; and by other cable yarding systems with longer yarding distances and skylines where site damage during yarding creates silvicultural problems and where the load may be suspended over delicate terrain.

The few high lead systems in use in southeast Asia are also giving way to ground skidding and other cable yarding methods under the same conditions and for the same reasons as in North America. However, whereas mobile or portable steel towers have for the most part replaced spar trees in North America, the high capital cost of the portable towers together with relatively low labour cost has contributed to continued use of spar trees in southeast Asia.
Crew and production

The operating crew of a high lead yarding system, while it may vary from place to place, normally consists of 6 or 7 men in big timber: foreman or hook tender, yarder operator, chaser, signalman or whistle punk and 2 or 3 chokermen. This does not include a truck loading crew which may be working simultaneously. In some southeast Asian countries the yarding crew may be larger and a special crew of 3 or 4 men per 4 or 5 yarders may be employed to select, top and guy spar trees ahead.

Production of a high lead yarding system depends on many factors: number of logs per hectare, log size, power and speed of the yarder, effective working time, topography, yarding distance, crew efficiency, etc. The degree to which each factor affects output may never be settled, making it difficult to forecast production with a high degree of accuracy. Nomogram D (Figure 7) shows estimated normal production for southeast Asian countries, including time allowances for changing the tail block but excluding time to move the yarder to new sites and set out the yarding lines. The chart is based on the first four condition factors named above; the others are inherent in the result.

The principal key to obtaining reasonably reliable results with the nomogram lies in evaluating the yarder size relative to log size. This evaluation must be done subjectively since no reference table is available. In the chart a solid "normal" line has been drawn to represent the normal relation of yarder size to average log size and two broken lines have been drawn to represent the extremes in this relationship. The nomogram is read in an anti-clockwise direction starting with the number of logs per hectare; for example, with a log density of 35 logs per hectare an hourly production of 4.5 logs may be expected when yarder size relative to log size is assumed to be normal; with an average log size of 3 m³ and a work day of 6 effective hours, production is estimated to be 80 m³ per day.

Swinging

Nomogram D refers to high lead yarding, that is, collecting the logs at a spar tree from the surrounding area. A logging operation often involves transporting the yarmed logs to a second spar tree. This operation is known as swinging and is used to move yarmed wood to an established truck road. While usually done with a skyline yarding system, swinging uphill by high leading is often economical if the yarding distance is well within the limits of such a system (having due regard to spar height, topography and power and speed of the yarder). Nomogram D may be used
to estimate swinging production by assuming "stand density" to be 50-60 logs per hectare and completing the estimate in the usual manner.

THE GRAVITY YARDING SYSTEM

Any typical high lead system may be converted into a gravity yarding system by using the same 2-drum yarder, the main line as a slack skyline to carry a light carriage, butt rigging and chokers, and the haulback to haul the carriage up the skyline and control its free descent.

Its general design is shown in Figure 8. The skyline is slacked to hook on the turn and raised before yarding it.

The weight of the turn and the yarding distance are limited by the relatively low capacity of the main line when compared with the regular skyline.
PRODUCTION ESTIMATES

FIGURE 8. — Gravity skyline system.

cable. Gravity yarding uphill is very effective on slopes over 35 percent. It is also possible to skid downhill with the gravity system, but steeper slopes would be required because of the additional drag of the haulback which the carriage must overcome.

THE RUNNING SKYLINE SYSTEM

Description

The most up-to-date high lead yarding system is the running skyline system. It has some of the attributes of a skyline system without the need for a large-diameter standing line. It uses a 3-drum interlocking yarder (with a strawline drum as well), the haulback as a running skyline, main and slack pulling lines, and a carriage riding on the haulback and carrying tong line and chokers. This arrangement is shown in Figure 9 with more carriage details in Figure 10. The main and slack pulling drums are identical in dimensions and interlocked by means of gears and chain drive; through clutches their relative rotation may be changed so that the two drums may inhaul or outhaul simultaneously or move in opposite directions at identical speeds.

The main and slack pulling lines have the same length and diameter and are connected near the carriage to form a single line as shown in Fig-
FIGURE 9. — Running skyline system.

FIGURE 10. — A simple slack-pulling carriage.
ures 9 and 10. The tong line is clevised to the connector joining the main and slack pulling lines and runs over a driven sheave in the carriage down through a box fair lead to the butt rigging carrying the chokers. The tong line may be as much as 15 metres in length.

The running skyline (haulback) drum assembly is fitted with an infinite ratio interlocking system so that the line may be tensed or slackened at any time without interfering with the movement of the main and slack pulling lines. The maximum permitted tension in the line is predetermined and set; it cannot be exceeded, thus minimizing rigging and tailhold damage and waste of power.

The system may be used to high lead the turn or to carry it suspended, depending on turn weight, available skyline deflection, yarding road profile and interlock tensions. Under the system the running skyline adjusts itself to the weight of the turn, i.e., deflection increases under heavier loads to provide lift to the suspended load without adding to line tension. Minimum line deflection should be 8 percent; 10 percent deflection is better; 6 percent deflection may be acceptable on flat ground; deflection may be reduced to 5 percent with use of the recently developed balloon tail spar.

The strength of the running skyline relative to the more conventional single-line derives from its multi-part lines between tailhold and carriage and between carriage and yarder. For example, a 19-mm haulback and a 16-mm main and slack pulling line are sufficient to provide the same skyline strength as a single 29-mm skyline.

The head spar may be a portable or mobile steel spar or a leaning A-frame type, integral with the yarder in most cases and properly guyed. The tail block may be attached to a spar tree, a stump or a heavy-duty tractor, properly anchored in all cases. Modern practice favours the use of the crawler tractor as a tailhold as its mobility greatly facilitates changing yarding roads.

An example of running skyline production

A running skyline system operating in the Pacific northwest of the United States used a 5-man crew (yarder operator, chaser, hook tender and two chockermen) and a 300 hp 3-drum interlocking yarder carrying 650 metres of 22-mm main line, 1 300 metres of 22-mm haulback line and 650 metres of 16-mm slack pulling line to yard uphill in a low-volume selective-cut area.

The area being yarded extended uphill from an undulating plain at an average slope of 40 percent. Maximum yarding distance was 500 metres but due to irregular topography average yarding road length was of the order of 300 metres. Yarding roads were parallel and about 75 metres
apart, so that lateral yarding distances exceeded 30 metres. The yarder was moved an average of 1.5 times per day in an average time of 1.25 hours.

The area harvested by each road averaged 2.3 hectares; log size averaged 1.5 m³; the harvested portion of the stand averaged about 45 m³ or 30 logs per hectare; the number of chokers used varied from 1 to 5 depending on log size. Daily production averaged around 150 m³.

Manual loading of logging truck, Andaman Islands.
The running skyline vs the high lead system

The running skyline has a number of advantages over the typical high lead system:

(a) it may be used with spans up to 600 m, and spans of 800 m are being studied (whereas the typical high lead is limited to 300 m), thereby reducing truck road density by 50 percent or reducing swinging operations; longer yarding roads means fewer yarding road changes and higher production (line speeds increase as lines build up drum diameters so that, from a practical point of view, constant yarding cycle times are maintained);

(b) it makes possible the practice of selective logging through the use of parallel yarding roads and lateral yarding; logs may be yarded laterally to the skyline efficiently from distances up to 30 metres, making practicable a yarding road spacing of 65-75 metres;

(c) yarding may be done either uphill or downhill with equal facility;

(d) all lines are suspended — there are no lines on the ground to create hazardous working conditions, permitting logs to be prechoked, thus speeding up the yarding cycle and increasing production;

(e) optimum payloads may be yarded because chokers may be pre-set for bunching in the same manner as for ground skidding machines;

(f) less environmental damage is done in that truck roads, the construction of which is the greatest cause of soil disturbance in logging, are spaced more widely; and turns of logs may be made to drag more lightly or at times be carried suspended (this will depend on line tensions, turn weight and yarding road profile);

(g) low density stands can be logged more economically.

The grapple yarding system

The grapple yarding system is a type of high lead, made practicable by the development of the running skyline and special log grapples. It works in the same manner as the choker system with one in-haul line opening the grapple and the other (the main line) closing it. The grapple yarding carriage is illustrated in Figure 11. When grapple yarding, the carriage sheave is free running and no fair lead is required. For efficient operation the system requires a mobile yarder of around 300 hp mounted on either tracks or wheels and fitted with a swinging boom; and a mobile tailhold, usually a heavy-duty crawler tractor.
The swinging boom is necessary to assist in placing the grapple on the log to be yarded and in arranging the log on the usually restricted roadside landing. The mobile tailhold is necessary because yarding road changes are frequent and the yarding crew is small (usually two men).

The system is limited to yarding one-log turns uphill in clear-cut areas, and to a yarding distance of around 300 metres. Since the system is restricted to single-log turns, there is a minimum log size for an economical operation as well as a break-even economical yarding distance. On the other hand, grapple yarding has a number of advantages which tend to offset the limitations noted above:

(a) it requires only a 2-man crew — a yarder operator and a signalman;
(b) it permits high man-day productivity — important in high-wage man-power-short regions but less so in developing countries;
(c) it is less hazardous than choker systems;
(d) it may be double-shifted by floodlighting the work area during darkness.

TENSION SKIDDING

More complex running skyline systems have been developed than those described above. For example, the Madill 052 Tension Skidder is a heavy-duty unit using a 500 hp 3-drum (plus strawline drum) interlocking yarder with special controls and an integral telescoping steel spar, large diameter lines (up to 32 mm), 61-cm sheaves and drum cores and a special carriage. It is capable of yarding wide parallel roads for distances up to 600 metres.

The carriage carries a drum divided into three segments, each designed to hold 150 m of main line, tong line or slack pulling line respectively. The main line from the yarder is overwound and tailheld to one outside segment of the drum; the slack pulling line is underwound and tailheld to the other outside segment; thus the drum may be made to rotate in one direction by pulling on the main line and in the opposite direction by pulling on the slack pulling line. The tong line is wound on the centre segment and made to extend through a fair lead by pulling on the slack pulling line and to retract by pulling on the main line.

The yarder is operated by means of a highly developed, yet simple set of controls. These consist of four pneumatic pilot-actuated valves with overriding manual controls and a transmission selection lever. The four valve control levers are:
FIGURE 11. — Slack-pulling carriage with grapple.

(a) a directional control and throttle lever to move the logs toward the carriage, to interlock the winch drums and to move the carriage on the skyline;

(b) a tong line and throttle lever to control the up-down movement of the tong line when the carriage is stationary;

(c) a tension control lever to regulate the tension in the skyline and therefore the height at which the carriage travels;

(d) a log level control lever to regulate the long line tension in order to high lead the turn or to carry it suspended.

The control system is described in Paper No. 710660 published by the Society of Automotive Engineers.
Unloading with A-frame at a river. (Centre technique forestier tropical, France)
System load-carrying capability

The capability of a running skyline system may be defined as the safe working load calculated when the lines are standing still, the load is suspended directly below the carriage and the carriage is at midspan. A practical method of calculating the capability is described by Mann for both uphill and downhill yarding using coefficients given in the "Skyline Tension and Deflection Handbook," by Lysons and Mann (1967).

The capability is considered to be the sum of skyline tensions due to the weight of the cable itself and to the load on the cable (carriage, rigging and payload). The two are calculated separately. The tension due to cable weight is a function of unit cable weight and span length and deflection. It may be found by the method described in Lysons and Mann's handbook. The payload capability of the system may be found by using the coefficients and other data in the handbook and the work sheets given in Mann's Research Paper PNW-75.

Planning running skyline yarding roads

The network of running yarding roads must be planned and checked for each area before logging begins to ensure that skyline deflections will fit the topography at each proposed road. This applies equally well to standing skylines. The time-consuming and costly work involved in doing this in the field has led to development of a new procedure involving the following steps:

1. Orthographic distortion-free aerial photographs are taken.
2. Topographic contour lines are added by photogrammetrical methods.
3. Proposed yarding roads are selected and marked on the aerial map.
4. The contour (profile) points along each road are plotted with a digital analyser, thus providing profile data.
5. The profile data, along with spar height, difference in elevation of head spar and tail blocks, span distance, acceptable deflection and maximum turn weight are fed into a computing calculator.
6. From this input data, the calculator, when properly programmed, writes a linear equation which outputs as a diagram showing two lines: the ground profile along the proposed yarding road and the acceptable skyline deflection line.

If the two lines in the diagram do not cross, the proposed location is satisfactory; if they cross, either the yarding road must be relocated or less skyline deflection and lighter turn loads will have to be accepted.
Estimating production

A method of estimating production of running skyline systems for variations in yarding distance, average log size and yield per unit area has been presented by Penn A. Peters in the form of a research paper. It considers also the dependent variables of volume per turn, yarding cycle time and road changing time. The production estimate is presented in equation and graphical form.

It is generally accepted that all sound production formulae must be based on field study data, the collection of which is normally time-consuming and costly. Peters' method uses a relatively small data base and includes some features often neglected:

(a) the load curve concept (log size distribution in the population and logs per turn in relation to log size);

(b) a breakdown of yarding cycle time into outhaul, hook, inhaul and unhook components together with delay factors;

(c) yarding road change time related to yarding road spacing and skyline span;

(d) downtime expressed as a percentage correction applied to the production estimate.

The method has some limitations. While some of Peters' formulae may be applied regardless of the yarding system or condition, others must be developed from field data for each different situation. In regard to the latter, for example, new field data would have to be taken for each yarding system as well as for different yarding road spacings; nor could formulae developed for clear-cutting operations be applied to selective logging. Peters' paper may be considered as a progress report on research to develop an improved method of estimating cable yarding production.

Stump anchors

There is no definite method of predicting the load-bearing capacity of stumps anchoring spans and skylines. It is widely accepted that holding power increases with soil depth and density and approximately as the square of stump diameter; and that stumps have greater holding capacity on uphill pulls than on downhill pulls because of the greater root structure on the lower side.
There are also some rigging rules in general use:

1. Anchor stumps should be notched or other means taken to prevent lines from slipping off.

2. When making multi-stump anchors, stumps should be aligned as closely as possible with the skyline, i.e., the angles between tieback lines and skyline should be as small as possible; and a block or blocks should be used with tieback lines for better load distribution.

3. At least one tieback line should be used on each main anchor stump; such a line will absorb from one third to one half of the skyline tension depending on how it is applied.

The subject of skyline anchors has been discussed in a detailed report entitled “Mechanics of Skyline Anchoring,” prepared by Chas. O. Campbell of the Seattle, Washington branch of the Pacific Northwest Forest and Experiment Station.

**Long-distance transport**

**General conditions**

Once logs are brought out of the forest there is not much difference in handling principles between tropical timber and timber from other types of forests. The most significant differences stem from the size (weight) of the logs and reduced storing possibilities due to climatic conditions.

Long-distance transport includes floating, rafting and hauling with trucks or railway. Truck hauling is the most commonly used method, whereas water or rail transport can take place only under special conditions which, by the way, often require truck hauling for part of the total transport.

It is difficult to generalize about river transport. Output and costs must be established for each particular case depending upon distance and the physical characteristics of the waterway. The logs might either be towed by tugboats in rafts or on barges or floated one by one according to the prevailing situation. Tropical timber generally has limited floatability, some species are “sinkers,” and often up to 50 percent of the harvested volume must be considered as “nonfloatable.” This obstacle may be overcome either by the use of barges or by fastening the logs together in rafts in a suitable mixture of floatable and nonfloatable species.

When public railway transport is available, production and cost must be established in each instance. Terminal equipment and rolling stock
may differ considerably as may the tonnage to be transported and thus the bargaining position of the enterprise.

Freight rates are often set by governments, and sometimes are based on political commitments. They do not necessarily reflect the true transportation costs, thus making technical forecasts impossible.

Truck hauling is the major means of long-distance transport for which production and costs are predictable in technical terms. Below are the factors selected as being the most important ones in establishing estimates of cost and production.

Hauling distance

The most economical size of transport vehicle is found to vary with the length of haul and the loading and unloading methods used. Usually it is found that the longer the haul the larger the optimum vehicle. However, the relationship is rather insensitive and requires specific analysis in each case. On short hauls, loading becomes a major element of round-trip time and, with very large vehicles in particular, too great a portion of the cycle time is spent being loaded and unloaded, waiting on other trucks and being otherwise delayed. Again, on very short hauls, a greater portion
of the haul is likely to be on roads with steeper grades, sharper curves and narrower widths than on large hauls on main roads. As hauling distance increases, a greater portion of the round-trip time is spent in motion and consideration should be given to the use of diesel power instead of gasoline power engines.

Road standards

The standards of design and construction have a great effect upon hauling speed. The optimum condition is a near level road with a wide right of way, good drainage ditches, a smooth surface and tangent curves which permit long-sight distances. Short rolling or momentous grades have little effect upon average hauling speed. Long adverse grades, even if minimal,
seriously affect the speed of heavily loaded logging trucks. Care should be taken in locating roads initially because once a road is constructed it is difficult to justify its relocation; bad curves and adverse grades resulting from poor location practices will be a physical nuisance and bring increased costs over the life of a hauling operation. Truck operating costs per hour are almost constant, for a given size of vehicle, and hauling production and therefore cost per unit of timber hauled vary according to the quantity of timber the truck can haul per hour. This production in turn depends upon speed of travel, light and load.
Loading and unloading equipment

The terminal functions of loading and unloading have a direct influence on hauling productivity. Minimum turn-around time is the desired goal. When the hauling distance is short, the terminal times should be short; otherwise they will constitute too large a part of the total round-trip time. A major factor is the choice of loading method and equipment in relation to the volume or weight of timber to be moved. Small volumes of timber can only support low capital-cost loading equipment and vice versa. Speed of loading is critical and this may depend more upon the layout and organization of the terminal than upon the cost of the equipment.

Load capacity

Hauling costs tend to decrease with increase in payload capacity. It is difficult to generalize on the choice of engine power for a truck. In North America, the controlling factor in engine power is that trucks must maintain a speed on hills that will eliminate traffic congestion and safety hazards resulting from very slow-moving vehicles. The commonly accepted requirement is 32 km/hr on a 3 percent grade. This is roughly the equivalent to a weight/horsepower ratio of 180/1 hp.

As usual, all four parameters (hauling distance, road standard, loading and unloading equipment, and load capacity) are determined by other conditions and could be broken down further. Travel speed, for instance, is determined by road standard, type of vehicle, size of payload, the driver's experience, etc.

Given the four parameters, the estimate of production per day can be limited to an estimate of the number of round trips per day or shift. Nomogram E (Figure 12) demonstrates the interrelation between the parameters and gives estimates of truck hauling productivity.

Terminal operations

Loading and unloading of trucks is carried out in a number of different ways. For loading one will find the whole range between pure manual work and the most sophisticated loading tractors or winch systems. Due to the limited volume harvested per hectare, the tonnage handled on each landing might be comparatively small. Mobility of the loading equipment is therefore essential. Such mobility can be attained by using wheeled loaders (heavy front-end loaders or grapple loaders), or by attaching load-
Figure 12. — Nomogram E — Truck hauling.

ing equipment to the truck itself (for example, bunks with built-in wires for winch loading).

Wheeled skidding machines may also be used for loading by employing an extended arch to give sufficient height to lift one or possibly two tiers of logs onto a hauling vehicle. If a loading deck is provided or the whole truck is backed into a hole dug for the purpose, the logs may be pushed onto the truck with the bulldozer blade. Whenever possible, advantage should be taken of gravity when moving or loading logs.

It would serve no purpose to give a complete list of all technical solutions used in loading. This is an operation in which imagination and ingenuity give the most rewarding results.

The most commonly used method of unloading is side dumping (often into a river or water storage) by pushing the load of logs sideways off the truck with a tractor or by driving the truck onto a side slope, unfastening the binders and letting the logs roll off the deck of the truck. Cranes, mobile and stationary, winches and loading tractors are also used.

The technical capacity of various equipment used for loading and unloading is not difficult to assess. This information is, however, of minor interest for this purpose because other circumstances have a wider impact. For instance, it is rather seldom that capacity is a limiting factor in loading or unloading; overcapacity seems a normal phenomenon.

Field data have revealed that loading and unloading time normally averages 30-60 minutes per load, but may reach 2 hours when both operations are manually performed.

Loading method and equipment affect daily production as is shown in
Nomogram E. The nomogram shows what may be expected — that terminal (loading and unloading) times have little influence on round-trip time and the number of trips per day on the longer hauls but that on short hauls they may cause a reduction of one or two trips per day. For example, on a 100-km haul at an average speed of 35 km/hr, the average number of round trips per 9-hour day would be 1.2-1.4 regardless of the time spent loading and unloading. On the other hand, on a 20-km haul at the same speed, terminal times could make a difference of two trips per 9-hour day.

Hauling

Apart from terminal work, the number of round trips per day depends on travel speed, travel distance and effective working time. Travel speed varies, among other things, according to road quality and driver ability. The last factor plays a more dominant role than might be expected. Attempts to relate travel speed to road quality will often fail because of differences in skill and motivation among drivers.

One factor affecting the cost of log hauling that does not apply to public truck transport is that the hauling units, with few exceptions, are loaded
Loading with A-frame mobile crane mounted at the rear of a truck and supported by two wooden poles.

Side loading of logging truck by truck-mounted double-drum winch (the two wire ropes run through each bunk to a pulley on top of the stake), west Africa.

(Centre technique forestier tropical, France)
Loading with elephants, Sri Lanka.
LOGGING AND LOG TRANSPORT IN TROPICAL HIGH FOREST

for only one half of the round trip. They almost invariably return empty. The total costs of the round trip must be applied to the load hauled one way only.

The working day is normally limited to eight or nine gross hours but the trucks are often employed for a longer or shorter time. The drivers normally want to complete the (last) round trip. It is considered in Nomogram E that the working day does not exceed nine hours.

Comments and directions

Production in truck hauling is estimated in the following steps:

1. Estimate or measure average hauling distance.

2. Estimate dimensioning speed of the roads. Dimensioning speed of the road is a general expression of road standard. It is determined primarily by road alignment in plane and profile, road width, road surface, etc. In this analysis, dimensioning speed refers to average travel speed for both hauling and return trips. Average round-trip speed is determined by the following equation:

\[ \text{average Speed} = \frac{2(SL \times SE)}{SL + SE} \]

where \( SL \) = speed loaded, and \( SE \) = speed empty, both expressed in linear units per unit of time, viz., km/hr.

If there is no experience available, estimates can be based on the following indicative data:

- (a) branch roads (or the outer parts of the forest road network) = 10–20 km/hr
- (b) main forest roads = 30–40 km/hr
- (c) good public roads = 40–50 km/hr

A weighted average covering the total hauling distance must then be established.

3. Determine the number of round trips per day (Nomogram E).

4. Estimate effective payload (m³) per trip and multiply by the number of round trips to find production in m³/day.
It is a common misunderstanding that the travel speed is much higher for the return trip than for the hauling trip. In most cases there seems to be no significant difference. When the vehicle is empty, high speed is often limited by poor vehicle control owing to condition of the road. Trucks and trailers incur more damage from high speed travel over rough roads than from any other source. A loaded truck seems to "float" much better, even when heavily burdened.

Roads

Present-day forest can hardly be managed or harvested without roads; they are needed for transport of labour and material and for the extraction of the timber crop. Road construction and road maintenance are important cost items, especially in tropical forestry with a low yield of merchantable wood per unit area. By proper planning of the road system, an optimum input of road investment can be achieved and the long-term use of the road can be properly recognized.

Roads in forestry may be classified in two broad categories with regard to their function: access roads and feeder roads.

Access roads

Access roads are roads needed for transportation to and from the forest area. They have no "crosswise function" as logs are not extracted from the surrounding area but logs, labour and equipment are carried on the road (a "lengthwise function") between, for example, a mill, a town or village and the forests. Some of the main roads within the forests may also be classed as access roads. Access roads are generally used many years, they carry considerable traffic and are often built to a standard corresponding to parts of the public road network. Bridges and culverts are, as a rule, permanent constructions. Road costs (i.e., construction and maintenance) for the public roads of similar standards may serve as guidelines for cost estimates. The construction cost for access roads may often be in the range of $8-12 per metre in easy up to fairly steep country. In very mountainous regions with frequent rock outcrops, in regions with extreme wet seasons and in cases when ballast or other road material must be brought long distances, road construction cost may easily double.

Access roads with a "lengthwise function" can be of high standard. If they service a forest on a sustained yield basis, the volume of wood to be hauled over the road becomes infinite and construction cost approaches
O per unit transported over the road. Road maintenance costs will be the major cost item per unit. If such roads penetrate a forest concession, they may have a decreasing standard as less wood becomes tributary to the road as it penetrates to the rear of the concession.

**FEEDER ROADS**

Feeder roads are located within the forest area. They have a dual function. Their main purpose is to penetrate the forest and shorten the skidding distance. Feeder roads have also a "lengthwise function," more accentuated in the lower parts of the road network.

As a rule, feeder roads should be built to a low standard, the outer parts of the roads to the lowest acceptable standard. Normally the feeder roads are built for temporary use only. Culverts may not be needed or may be primitive, for example, built of logging debris or unmerchantable species. A road is considered to be temporary when built only for the purpose of logging an area and to be abandoned when logging has been completed.

The construction cost for feeder roads may vary widely, from less than $0.50 to $10 or more per metre (see below).

**CORRELATION BETWEEN ROAD SPACING, ROAD DENSITY AND SKIDDING DISTANCE**

The extension of a forest road network is usually quantified by road spacing or road density. They are inversely related to each other and may be arbitrarily used.

Average skidding distance is one fourth of the spacing between the roads, provided logs are transported to the road from both sides and the roads are approximately equally spaced in the area. If the roads serve only one side, the average skidding distance is one half of the spacing. It is common to add an allowance for winding roads and other differences between this pure mathematical correlation and practical conditions. Road density — road length per unit area — can be readily estimated by measuring the roads (on maps or in the field) and the corresponding forest area they serve. If one wants a figure of road density relevant to skidding problems, only roads within the forests should be included and parts without "crosswise functions" should be excluded. Similarly, larger unproductive areas within the forests should, as a rule, be excluded.

The feeder road density may be correlated to skidding distance by applying the following formula:
\[
D = \frac{a}{s}
\]

where \( D \) = feeder road density in metres per hectare;

\( a \) = "road efficiency" factor, normally varying between 5 and 9:
- 4-5 for flat undulating terrain,
- 5-7 for hilly terrain;
- 7-9 for steep terrain;
- 9 or more for very steep irregular terrain;

\( s \) = average skidding distance in kilometres.

The formula \( D = \frac{a}{s} \) can be used for either estimating average skidding distance when road density is known; or estimating road density when average skidding distance is known.

**Example 1:** Road density is measured at 15 m per ha in undulating to hilly terrain, where the factor \( a = 5 \). Average skidding distance may then be calculated as below:

\[
s = \frac{5}{15} = 0.33 \text{ km}
\]

**Example 2:** Given an average skidding distance of 0.3 km with crawler tractor in rather hilly terrain where the "road efficiency" factor \( a \) is estimated to be 6.5, the feeder road density may be calculated as below:

\[
D = \frac{6.5}{0.3} = 22 \text{ m per ha}
\]

If feeder road construction cost is $1.50 per metre and harvested volume per hectare is 20 m³, the cost of feeder roads will be:

\[
\frac{1.50 \times 22}{20} = $1.65 \text{ per m}^3
\]

The unit cost of feeder roads should normally lie within 60-80 percent of the total skidding cost when both costs are expressed on the same basis (e.g., as a cost per m³). If in the road planning it is higher, \( D \) should be
decreased; if it is lower, $D$ should be increased; the calculation should be repeated until the ratio of 60-80 percent is obtained.

Sometimes skidding distances $(s)$ are determined technically by the logging system (e.g., in cable yarding). In such a situation this calculation cannot be applied.

**Cost of road construction**

As the cost of road construction varies widely with terrain and soil conditions, local experience from current forest operations is very useful. Cost figures from public works or highway departments should be used with a considerable care as the public roads are often much more expensive than forest roads because of higher safety and traffic standards.

The working techniques in road construction are very much the same all over the world, bulldozers and graders being most commonly employed. Exceptions are roads being built exclusively with manpower and increasing use of excavators in combination with bulldozers in some countries.

Mechanized road construction is a labour-extensive work. The labour cost usually accounts only for about 20 percent of the direct road construction cost, materials for 5-10 percent, and the balance, cost of equipment. Labour wages have, therefore, only a minor influence on the total cost. Records from many countries indicate that road construction costs are fairly uniform throughout the world. Where labour is cheap, less skill or experience and higher machine cost seem to offset the influence of cheap labour.

An example of road construction in tropical forests in west Africa (Ivory Coast and Gabon) has recently been published by Esteve and Lepitre (1972). The costs are specified for four road standards and, in the case of Gabon, for three terrain conditions, and are broken down to the different work elements (Tables 7 and 8). The road widths were the following:

- Access roads: 10-12 m
- Primary roads: 8 m
- Secondary roads: 6 m
- Skidding trails: 4.5 m

The type of terrain in the different zones is exemplified on the maps in Figures 13 and 14 for Ivory Coast and Gabon respectively.

On the basis of these data and other available records, an attempt is made below to assess road construction cost. The following work elements are chosen: (a) staking, felling, forming, clearing, grading and miscel-
FIGURE 13. — Typical topography in Ivory Coast (Daloa region).

Scale 1:50 000  Contour interval 20 m
Figure 14. — Typical topography in Gabon.

Scale 1:50 000

Contour interval 20 m

1 Mitzic region. — 2 Monts de Cristal region.
Table 7. Total direct cost of forest roads: Ivory Coast

<table>
<thead>
<tr>
<th>Work element</th>
<th>Access roads</th>
<th>Primary roads</th>
<th>Secondary roads in laterite</th>
<th>Secondary roads in nonlaterite</th>
<th>Skidding trails</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staking of the alignment</td>
<td>60</td>
<td>60</td>
<td>40</td>
<td>40</td>
<td>—</td>
</tr>
<tr>
<td>Felling and formation</td>
<td>2417</td>
<td>1156</td>
<td>735</td>
<td>735</td>
<td>315</td>
</tr>
<tr>
<td>Clearing</td>
<td>200</td>
<td>200</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Grading, surfacing</td>
<td>294</td>
<td>204</td>
<td>102</td>
<td>102</td>
<td>—</td>
</tr>
<tr>
<td>Gravelling</td>
<td>532</td>
<td>399</td>
<td>266</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>400</td>
<td>280</td>
<td>200</td>
<td>200</td>
<td>—</td>
</tr>
<tr>
<td>Total cost per km</td>
<td>3813</td>
<td>2299</td>
<td>1343</td>
<td>1077</td>
<td>315</td>
</tr>
<tr>
<td>Rounded to</td>
<td>3800</td>
<td>2300</td>
<td>1350</td>
<td>1100</td>
<td>320</td>
</tr>
</tbody>
</table>

The most important cost item is the felling and formation of the road subgrade with the bulldozer. The relative productivity of the Caterpillar crawler tractors for this work is shown in Table 9. The approximate influence of the terrain is shown in Figure 15, but it should be borne in mind that the influence of slope may vary widely depending on soil and rock outcrops.

The following formula may be applied:

\[
C_i = 230 + 17 \times SL + 660 \times ST_i + 30 \times SL \times ST_i
\]

where \( C_i \) is the direct cost in dollars per km for road standard \( i \) (supervision and overheads excluded);

\( SL \) is the inclination in percent of the major slopes (>50 m) of the hillsides;

\( ST_i \) is the road standard, which takes the following values:
- 0 for trails for wheeled skidders and jeeps;
- 1 for secondary feeder roads;
- 2 for primary feeder roads;
- 3 for main and access roads.
FIGURE 15. — Direct construction cost of forest roads.
### Table 8. Total direct cost of forest roads: Gabon

<table>
<thead>
<tr>
<th>Work element</th>
<th>Access roads</th>
<th>Primary roads</th>
<th>Secondary roads in laterite</th>
<th>Secondary roads in nonlaterite</th>
<th>Skidding trails</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staking of the alignment</td>
<td>100</td>
<td>190</td>
<td>60</td>
<td>60</td>
<td>—</td>
</tr>
<tr>
<td>Felling and formation:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) easy terrain</td>
<td>4492</td>
<td>2807</td>
<td>1572</td>
<td>1572</td>
<td>449</td>
</tr>
<tr>
<td>(b) average terrain</td>
<td>5615</td>
<td>3369</td>
<td>2470</td>
<td>2470</td>
<td>898</td>
</tr>
<tr>
<td>(c) difficult terrain</td>
<td>6738</td>
<td>4941</td>
<td>3369</td>
<td>3369</td>
<td>1123</td>
</tr>
<tr>
<td>Clearing</td>
<td>356</td>
<td>356</td>
<td>356</td>
<td>356</td>
<td>—</td>
</tr>
<tr>
<td>Grading, surfacing</td>
<td>459</td>
<td>459</td>
<td>287</td>
<td>287</td>
<td>—</td>
</tr>
<tr>
<td>Gravelling</td>
<td>1820</td>
<td>1365</td>
<td>910</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Miscellaneous:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) easy terrain</td>
<td>600</td>
<td>400</td>
<td>280</td>
<td>280</td>
<td>—</td>
</tr>
<tr>
<td>(b) average terrain</td>
<td>680</td>
<td>480</td>
<td>320</td>
<td>320</td>
<td>—</td>
</tr>
<tr>
<td>(c) difficult terrain</td>
<td>800</td>
<td>600</td>
<td>360</td>
<td>360</td>
<td>—</td>
</tr>
<tr>
<td>Total cost per km:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) easy terrain</td>
<td>7827</td>
<td>5487</td>
<td>3465</td>
<td>2555</td>
<td>449</td>
</tr>
<tr>
<td>(b) average terrain</td>
<td>9030</td>
<td>6129</td>
<td>4403</td>
<td>3493</td>
<td>898</td>
</tr>
<tr>
<td>(c) difficult terrain</td>
<td>10273</td>
<td>7821</td>
<td>5342</td>
<td>4432</td>
<td>1123</td>
</tr>
<tr>
<td>Rounded to:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) easy terrain</td>
<td>7850</td>
<td>5500</td>
<td>3500</td>
<td>2550</td>
<td>450</td>
</tr>
<tr>
<td>(b) average terrain</td>
<td>9050</td>
<td>6150</td>
<td>4400</td>
<td>3500</td>
<td>900</td>
</tr>
<tr>
<td>(c) difficult terrain</td>
<td>10300</td>
<td>7850</td>
<td>5350</td>
<td>4450</td>
<td>1150</td>
</tr>
</tbody>
</table>

In tropical high forests roads are usually built wider than in temperate forests, because of poor soil conditions, heavy rain, etc. Often a rather wide strip on both sides of the road is cleared to allow a rapid evaporation after heavy rains. The formula applies to the following road widths which include both travel surface and shoulders:
In very steep terrain or other severe terrain conditions, these road widths are often substantially reduced. The travel surface to be gravelled is obtained by deducting about 1 metre from the width of the shoulders on each side. For roads of high standard on poor soil, the shoulder width is often increased.

It should be emphasized that this formula is an approximation. It covers the cost of alignment, felling, clearing, formation and grading, but does not include rock blasting, surfacing (gravelling), culverts (other than those built with logging debris) and bridges. Neither does it apply to a road

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
<th>Road width</th>
<th>Value (STₙ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Usually access roads and main primary roads</td>
<td>10-12 m</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Usually primary feeder roads</td>
<td>8-10 m</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Usually secondary feeder roads</td>
<td>5-7 m</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Skidding trails</td>
<td>3.5-4.5 m</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 9. - Approximate productivity ratios for Caterpillar tractors¹ of various sizes, transmissions and year of manufacture, when used in road construction

<table>
<thead>
<tr>
<th>Model number</th>
<th>Year of manufacture</th>
<th>Flywheel horsepower</th>
<th>Transmission type ²</th>
<th>Production ratio³</th>
</tr>
</thead>
<tbody>
<tr>
<td>D8H</td>
<td>1958-66</td>
<td>235</td>
<td>D.D.</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>1960-66</td>
<td>235</td>
<td>P.S.</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>1966</td>
<td>270</td>
<td>D.D.</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>1966</td>
<td>270</td>
<td>P.S.</td>
<td>1.70</td>
</tr>
<tr>
<td>D7E</td>
<td>1961-66</td>
<td>160</td>
<td>D.D.</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>1961-66</td>
<td>160</td>
<td>P.S.</td>
<td>1.00</td>
</tr>
<tr>
<td>D7F</td>
<td>1967</td>
<td>180</td>
<td>D.D.</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>1967</td>
<td>180</td>
<td>P.S.</td>
<td>1.10</td>
</tr>
<tr>
<td>D7D</td>
<td>1959-62</td>
<td>140</td>
<td>D.D.</td>
<td>0.75</td>
</tr>
<tr>
<td>D7C</td>
<td>1955-59</td>
<td>128</td>
<td>D.D.</td>
<td>0.60</td>
</tr>
<tr>
<td>D6C</td>
<td>1963-67</td>
<td>120</td>
<td>D.D.</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>1963-67</td>
<td>120</td>
<td>P.S.</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>1968</td>
<td>140</td>
<td>D.D.</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>1968</td>
<td>140</td>
<td>P.S.</td>
<td>0.85</td>
</tr>
</tbody>
</table>

¹ Other makes and sizes can possibly be calculated on the basis of this table. — ² D.D. = Direct Drive; P.S. = Power Shift. — ³ Using the 160 hp Power Shift D7E as 1.00.
system which consists entirely of ridge roads. Nevertheless, the formula provides a rather good fit for a considerable number of observations both in developed and developing countries and can therefore serve as a guide when local cost data are not at hand.

Rock blasting

In developing countries rocky terrain is often avoided because of lack of trained workers for rock blasting. However, when needed, drilling holes into the rocks is now generally mechanized. For larger quantities of rock, very often drilling machines powered by a compressor mounted on or pulled by a wheeled or crawler tractor are utilized. However, for small quantities of rocks, drilling performed with hand-carried machines is more economical. Even manual drilling may be considered.

Nowadays, the technique of electrical ignition with milli-second detonation is applied to rock blasting over longer distances. Detonating with fuse is limited to small blastings (individual rocks, stumps, etc.).

An average cost per m³ solid rock of $1.70-3.40 should be allowed depending on the hardness of the rock, scale of the blasting operation and equipment used. The cost of uncovering the rock and cleaning the surfaces may add another $0.80-1.60 per m³. It is recommended that these unit costs be checked locally as usually there is, in most countries, a market price for rock blasting.

### TABLE 10. ESTIMATED COST OF GRAVELLING ROADS WITH NATURAL GRAVEL

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost in dollars/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gravel at the pit</td>
<td>0.10 - 0.40</td>
</tr>
<tr>
<td>Loading:</td>
<td></td>
</tr>
<tr>
<td>of small quantities</td>
<td>0.65 - 1.30</td>
</tr>
<tr>
<td>of large quantities</td>
<td>0.15 - 0.25</td>
</tr>
<tr>
<td>Transportation¹</td>
<td></td>
</tr>
<tr>
<td>a) 0-5 km</td>
<td>1.20</td>
</tr>
<tr>
<td>b) 5-10 km</td>
<td>1.50</td>
</tr>
<tr>
<td>c) 10-20 km</td>
<td>1.80</td>
</tr>
<tr>
<td>Grading and rolling</td>
<td>0.35 - 0.40</td>
</tr>
</tbody>
</table>

¹ This cost amounts to around $1.00 per m³ plus $0.05 per m³/km.

Surfacing (gravelling)

Forest roads on soils of clay and silt have to be gravelled in order to make them permanently open to traffic; otherwise roads would be open
only in the dry season. Also, roads with a sub-base of sand often need to be gravelled. Normally an average thickness of 25-35 cm of gravel will meet the requirements for heavy log transport, which corresponds to an approximately 20 to 30-cm compacted gravel layer. Thus, for a running surface width of 3.5 m, about 1 m$^3$ of gravel would be needed per metre of road. On swampy ground, the gravel layer has to be thicker, up to 60 cm for main roads. It should be noted that many forest roads of low standard need to be gravelled only on especially weak sections so that often
only 0.2 m\(^3\) or even less is needed per metre of road. In the afforestation of bare land, roads needed for planting and tending purposes do not carry heavy traffic and gravelling may be considerably restricted. The cost items of gravel material, quarrying or gathering from the pit, loading, truck transport, grading and rolling may be involved.

A breakdown of average costs in dollars/m\(^3\) of gravel in place on the road, when natural gravel is available, should be about as shown in Table 10.

If the natural gravel is so coarse that it must be crushed before being placed on the road, the cost in stockpile at the pit will be between $0.50 and $2.00 per m\(^3\) depending on the size of material produced. If the crushed material is run directly from crusher to truck, the loading cost given in Table 10 may be eliminated.

In developing countries with low labour wages, the crushing may often be done manually. One man may crush around half a cubic metre per day. Usually the rock is dumped on the subgrade and the workers spread out the gravel as it is being crushed. This work can provide a considerable number of work opportunities at a cost comparable with or even lower than mechanical crushing.

If natural gravel is not available and surfacing material must be processed from rock by blasting and crushing, a normal cost in stockpile at the quarry will be around $3.00-$3.50 per m\(^3\). If the rock is so loose that it can be excavated with bulldozer or ripper, this cost can be considerably lowered.

**Culverts and bridges**

When logging in tropical high forests, culverts are not usually installed on the primitive branch roads. Passage of water is often provided by pushing down big unmerchantable trees or boles in gullies and covering this debris with soil. Roads used for longer than one season will require culverts. The cost of culverts and bridges varies widely and the cost figures given below are only indicative.

Depending on terrain, soil and layout of the road, on average one to five culverts/km of main forest road may be required, and in steep terrain additional drain-offs with a spacing of 15-20 m. In flat, moist terrain, drain pits are often needed to keep erosion to a minimum on the road surface and base. If the drainage of the soil is very good, these requirements may decrease considerably.

Nowadays, concrete culverts are commonly used; wooden culverts have become less important because of their high maintenance costs.

The material, transportation and installation costs per metre of culvert are likely to be more or less as follows: 
Cost per metre of culvert in dollars:

a) Corrugated steel culvert Ø 0.60 m–Ø 1.75 m 20–90
b) Concrete culvert Ø 0.30 m–Ø 0.60 m 6–16

These costs do not include import duties on the material, nor do they cover the work of excavating for placement of the culvert, backfilling with soil after placement and constructing abutments, as these are already included in the roadbed construction cost.
The cost of constructing bridges depends on their dimensions and the material used. Table 11 shows representative cost estimates, which may be used for forest roads in developing countries.

**Table 11. – Representative cost of constructing forest road bridges**

<table>
<thead>
<tr>
<th>Construction material</th>
<th>Width to be spanned</th>
<th>Height above water level</th>
<th>Estimated cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metres</td>
<td>Dollars</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>3–5</td>
<td>1.5</td>
<td>2 900</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>1.5</td>
<td>4 300</td>
</tr>
<tr>
<td>Wood</td>
<td>6–12</td>
<td>0.5–2</td>
<td>700–1 700</td>
</tr>
</tbody>
</table>

Concrete bridges of high standard will often cost $200-$300 per m², depending on soil conditions and use of engineering works to prevent erosion.
Manual road construction supplying employment to local workers, Sri Lanka.

ROAD MAINTENANCE

Logging in tropical high forest has often an exploitation character: the merchantable timber is extracted and the roads are then abandoned. A considerable part of the road system is therefore used for only a very short time, often only one logging season, after which no road maintenance is done. The forest yield is often low — in most cases around 10-20 m$^3$ per ha — and the traffic intensity is not very high on the terminal parts of the road system.
Road maintenance is consequently almost confined to the access and main roads and it is frequently difficult to distinguish maintenance from construction of the feeder roads.

As a rule of thumb, maintenance cost for roads per annum amounts to a fixed cost of $50-100 per kilometre plus 1-2 percent of construction cost. The lower figure applies to conditions with moderate weather conditions and well-built roads, whereas the higher figure should be used in regions with heavy seasonal rainfall. In very mountainous regions with severe rain, the annual road maintenance cost may, in exceptional cases, go up to as much as 10 percent of construction cost during the first few years when excessive maintenance may be required, and then decrease as the roadbed and slope surfaces stabilize.

**OPTIMIZING THE ROAD SYSTEM**

Roads are built to facilitate the transport of wood, labour and material. The road density should be extended and road standards improved to the extent that the aggregate costs of roads and transport are minimized. This can also be expressed so that marginal input in roads will balance the subsequent marginal reduction in transport cost.

Mathematical models are developed for optimizing road systems with regard to both spacing (density) and standard. In Appendix 2 some of the basic formulae of optimum spacing are included and a few comments on their use are made. It is of course imperative not only that the costs fed into such models are realistic but also that the model itself is a rather good representation of the real life situation. One particular problem in using such models requiring careful analysis is the "planning period" or "time horizon" of the calculations, especially in forests under sustained yield. In tropical logging it is often the question of paying off the road investment during a rather short period of one or a few years. Consequently the use of these models is considerably simpler and can be recommended even for staff with little experience of such analysis.

With regard to optimum road standard, roads should be improved as long as such improvements bring about a reduction of hauling cost that is greater than the cost of the improvement. However, when the cost of upgrading such haul roads shall be amortized over several years, it may be required not only to recover the cost, but also to make a profit on the investment. This can be a realistic requirement when other profitable investment opportunities are available.

On the other hand, it is often advisable to build a haul road to its ultimate standard at once, rather than go through one or more upgrading processes,
in order to get the early advantage of lower road maintenance cost and lower hauling cost while the timber adjacent to the road is being logged. Experiences in North America indicate that the following savings in cost may be possible in upgrading ordinary unstabilized gravel to a paved surface:

(a) decrease in road maintenance costs 75 – 80 percent
(b) decrease in tire costs 60 – 75 percent
(c) decrease in vehicle cost, principally fuel and vehicle maintenance up to 30 percent

Bulldozing with crawler tractor. (Centre technique forestier tropical, France)
3. ORGANIZATION AND SUPERVISION

An assumption which underlies the production estimates given in previous chapters is that the work is well planned and administered. One of the main reasons for variations in efficiency found among different enterprises is the quality of organization.

Another important reason for variations in production efficiency is the difference in degree of experience and skill among the workers.

Each operation will require a certain staff for planning, organization and instruction, and, obviously, the number of planners, administrators and supervisors depends on the size of the operation.

The number of functions, however, is similar in different enterprises, and in small operations one person may perform several functions.

Judging by the experience of several successful operations, the kind and number of functions, listed below, have been found adequate.

1. Management — to set goals, to coordinate the work and ensure that the work is performed as set out in instructions and policy.

2. Administration — to be responsible for administrative work, including a wide field of aspects from housing, personnel and economic transactions to clerical work.

3. Planning — to allocate resources in an optimal fashion and to advise field personnel (and the general manager) on working standards.

4. Operations — to manage felling, skidding (yarding) and transport in a direct line position and be responsible for the fulfilment of goals set by the general manager.

5. Workshop — to be responsible for the efficient operation of the
workshop and to furnish field operations with quick repair and maintenance groups and keep on hand an adequate stock of spare parts.

6. Supervision — to supervise felling crews, tractors and trucks, and group work in various places.

These six jobs are found to be necessary in every operation. In very small operations all six may be held by one person, whereas in larger operations each function may include several persons. The number included in each function may be derived from the following list, which is based on experience in well-planned and organized operations:

(a) General manager — there should always be a general manager, whatever the size of operation.

(b) Administrative manager — the administrative manager is assisted by clerks and typists. If the total number of workers is less than 20 the general manager will normally also be the administrative manager. If the number of workers is 20 to 60, the administrative group is two or three men. If the number of workers is 60 to 100, the administrative group is enlarged to five or six men. If the workers are more than 100, the group increases by one man per 50 workers.

(c) General planner — with less than two managers for felling, skidding and trucking, the general manager will also do the planning. If the felling, skidding and trucking managers are two or three, a general planner is employed, sometimes with an assistant.

(d) Managers for felling, skidding and trucking — there should never be more than one for each phase, i.e., not more than three in all. If there is only one group leader, he will also be manager. If there are two group leaders, it might be necessary to have a separate manager. If there are three group leaders, there should be at least one manager. If the group leaders are more than four, the number of managers should be three.

(e) Group leader-supervisor — a good average is one group leader per 10-20 workers.
Examples:

*Operation 1*: 300 workers

1 general manager
1 general planner
10 administrators — clerks, etc.
3 managers
20 group leaders

*Operation 2*: 50 workers

1 general manager
0 (or 1) general planner
3 administrators — clerks, etc.
1 or 2 managers
3 group leaders

Convoy of logging trucks travelling between Alembe and N'Djobe, Gabon.
4. TIME COSTS

Costs per unit volume are calculated as the quotient between unit time costs for resources (labour and machines) employed in the operations and the production per unit time. The production in different phases of work has been dealt with in previous paragraphs. In this chapter the time costs, that is, total costs per time unit worked or utilized, will be elaborated. The exposition will be divided into two parts: time costs for equipment and manpower respectively.

Equipment

The assessment of the time costs for machinery is a significant part of all calculations concerning mechanized forestry operations. This is particularly true in developing regions where machines are often extremely expensive and, due to low labour costs, the machine cost component will be very high, sometimes up to 80 percent of the total direct logging cost.

Information on various machine time elements forms a basis for control and improvements of machine operations and for determining the operating cost of a machine. Appendix 1 gives a method of breaking down machine time into detailed elements for the purpose of studying such machine characteristics as utilization and maintainability. However, such a detailed breakdown is not necessary for costing purposes. It is sufficient for such a purpose to know the following elements:

(a) shift hours
(b) downtime hours
(c) machine hours, divided, if required, into:
   i. productive machine hours
   ii. nonproductive machine hours.

The easiest way to obtain such information is by means of a tachograph installed on the machine.

No machine time distribution should be attempted which cannot be derived from an analysis of the tachograph chart or which is not going
to be used. The type of chart which should be used will depend on the
information desired. For example, in the case of a hauling truck, a tacho­
graph such as the Kienzle TCO-14 will show distance travelled, speeds,
beginning and end of shift, standing time, travelling time, and engine
revolutions per minute, and provide the time distribution required for
production control as well as for costing the hauling truck itself and the
hauling operation.

There are numerous textbooks on engineering economics with detailed
explanations of theories and methods for costing equipment. Therefore,
there is no reason to include in this report a thorough treatment on this
subject. Only simplified methods of the "ready reckoner" type will be
presented. As the estimates of output are subject to a considerable un­
certainty it may be argued that the simplifications and approximations
of such simplified methods are acceptable and will fall within the range
of precision of the complete exercise. None of the methods includes the cost
of the operating crew.

**METHOD 1**

The first simplified method uses the following cost components and gives
the costs, excluding operating crew, of owning and operating a machine:

(a) depreciation; (b) interest; (c) insurance and miscellaneous fixed charges;
(d) repairs and maintenance (excluding downtime costs); (e) gas, oil and
lubricants.

(a) *Depreciation* depends on the economic lifetime of the equipment which
in turn is set by wear (deterioration) and technical/economical develop­
ment (which causes obsolescence). There is no clear way to determine
this span of time beforehand. It follows that this question can be
made normative and that appropriate time periods can be proposed.
In this paper the following depreciation periods are used:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Normal conditions</th>
<th>Severe conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power saws</td>
<td>1 500 h or 2 years</td>
<td>1 000 h or 1 year</td>
</tr>
<tr>
<td>Tractors</td>
<td>10 000 h or 4 years</td>
<td>8 000 h or 4 years</td>
</tr>
<tr>
<td>Trucks</td>
<td>400 000 km or 4 years</td>
<td>300 000 km or 4 years</td>
</tr>
</tbody>
</table>

Of the alternatives (hours-years), the one considered to be reached first
should be adhered to because of the effect on machine life of climatic
conditions and the inexperience of operating and maintenance personnel.
For tractors and trucks a salvage value of 10 percent of the acquisition cost is considered normal.

(b) **Interest**: calculated on average investment or tied-up capital at the interest rate for which money may be borrowed.

(c) **Insurance**: calculated at the rate percent per year of acquisition cost independent of annual depreciation.

(d) **Repairs and maintenance**: a certain part of this cost is more or less unaffected by the degree of utilization. This part is estimated at 40 percent of the annual depreciation. The remaining part depends on the degree of utilization and is assumed to be as follows:

   for tractors, trucks and other heavy machinery — 3 percent of the annual depreciation per 100 hours worked;

   for power saws and similar equipment — 6 percent of the annual depreciation per 100 hours worked.

(e) **Fuel, oil and lubricants**: the cost of these items will account for a relatively small part of the total time cost — at least for heavy equipment. Based on normal oil and fuel prices, the following expressions are derived (“p” being the acquisition cost in thousands of dollars):

   for tractors, trucks and other heavy equipment $25 + 1.25 \times p$ cents per hour worked;

   for power saws and similar equipment: 20-30 cents per hour worked.

When fuel and oil prices are abnormally high or low these figures should be adjusted.

*Calculation example*

Calculate the annual cost of a crawler tractor, CIF price $30\,000$, importation tax \(^1\) 10 percent on CIF price, cost for delivery at logging site $500$, expected working time 1 500 hours per year under “normal” conditions.

\(^1\) In many developing countries the importation tax may be considerably higher, sometimes up to 40-50 percent.
(a) 
*Depreciation:*

The total cost at the logging site is $33,500. Since the total working hours are only 1,500 per year, the tractor will be used 6,000 hours during 4 years. Thus the 4-year depreciation period is reached before the 10,000-hour period. Considering the normal salvage value allowance of 10 percent, the annual depreciation is consequently

\[
\frac{33,500 \times 0.90}{4} = $7,540 \text{ per year}
\]

(b) 
*Interest:*

To avoid using the often misunderstood formula to find average annual investment, the annual interest may be approximated by considering 60 percent of the acquisition cost to be the average tied-up capital. Thus the annual interest cost at the rate of 10 percent is

\[
33,500 \times 0.60 \times 0.10 = $2,010 \text{ per year}
\]

(c) 
*Insurance, etc.:*

The cost of insurance at 3 percent of the acquisition cost is

\[
33,500 \times 0.03 = $1,005 \text{ per year}
\]

(d) 
*Repairs and maintenance:*

The fixed part will be 0.40 \times 7,540 = $3,015, and the work dependent part is 0.03 \times 7,540 \times 15 (since the tractor will work 15 periods of 100 hours each) = $3,390. The total expected repair and maintenance cost is

\[
(3,015 + 3,390) = $6,405 \text{ per year}
\]

(It may be noted that an annual working time of 2,000 hours would make this cost item equal to the annual depreciation.)

(e) 
*Fuel, oil and lubricants:*

Following the formula the cost will be (25 + 1.25 \times 30) cents \times 1,500 hours (30 since cost of customs and transport to work site do not influence the fuel consumption)

\[
= $940 \text{ per year}
\]
(f) **Total time costs**

By adding the cost components the total unit time cost is arrived at. The cost is $17,900 per year, which equals around $12 per hour worked. Vehicle taxes are one cost item that is impossible to forecast. This amount should be added to the above sum to arrive at a more accurate cost estimate.

**METHOD 2**

The second simplified method has been used by Samset (1972). His formula reads:

\[ y = 2A + 40 \]

where

- \( y \) = machine operating cost per day in NKr (Norwegian crowns), assuming 7.5 effective work hours per day;
- \( A \) = acquisition cost of machine in thousands of NKr.

Converted to dollars per effective hour, the formula will read:

\[ y = 0.27A + 0.82 \]

where

- \( y \) = machine operating cost in dollars per effective hour
- \( A \) = machine acquisition cost in thousand of dollars

\[ 0.27 = \frac{2}{7.5} \]

\[ 0.82 = \frac{40}{6.5 \times 7.5} \text{ when } 1.00 = 6.5 \text{ NKr}. \]

The machine operating cost obtained by this method agrees quite well with that obtained using Method 1 when, as is the case in most developing countries, the effective work day is 6 hours. The formula then becomes.

\[ y = 0.33A + 1.03 \]

and machine operating cost per hour, using the data in the example set out in Method 1, will be

\[ 0.33 \times 33.5 + 1.03 = $12.08 \]
METHOD 3

The third simplified method is based on data developed by the Caterpillar Tractor Company and published in its Performance Handbook. The data have been adapted for conditions existing in developing countries. The method develops cost values per effective hour for:

(a) depreciation;
(b) interest, insurance and taxes;
(c) fuel consumption;
(d) oils and lubricants, and
(e) repairs and maintenance

using the following formulae or cost estimates, with all cost values expressed in dollars:

(a) Depreciation

\[ = \frac{\text{acquisition cost} \times 0.90}{\text{estimated life in effective hours}} \]

(b) Interest, insurance and taxes

\[ = \frac{\text{acquisition cost} \times \text{MF}}{1000} \]

where MF is a multiplier factor read from Table 12, interpolated when necessary.

(c) Fuel consumption

\[ = 0.14 \times \text{engine hp} \times \text{fuel cost per litre} \]

(d) Oils and lubricants

\[ = \frac{\text{acquisition cost} \times 0.005}{1000} \]

(e) Repairs and maintenance

\[ = \frac{\text{acquisition cost} \times 0.10}{1000} \]

The machine cost per effective hour obtained by using this method will agree reasonably well with those obtained by using methods 1 and 2.

Comments and directions

Many logging enterprises use more refined and accurate methods for calculating the cost of owning and operating machines; for example, it is
possible to use true (local) fuel, insurance and interest costs. On the other hand, many enterprises do not calculate machine costs at all. There are instances in which the manager has no idea at all of the cost of operating the machinery in his enterprise.

There are certain advantages in costing equipment by a "ready reckoner" method as described above. The primary thing is that it is quick and easy. Another advantage is that by using such methods calculated differences between logging systems will not depend on differences in the method of calculation. A third advantage is that the result of calculations can be illustrated. All cost components depend on one or more of the basic values:

(a) acquisition costs;
(b) annual working hours;
(c) machine gross horsepower.

This makes it possible to calculate and illustrate the time cost for different combinations of the two as shown in Figure 16, drawn for Simplified Method 1. The bands covering different rates of utilization indicate the ranges between severe (upper) and normal (lower) work conditions.

To summarize, the following approximations of the time costs can be made:

(a) power saws: under "normal conditions," total annual costs (including repairs) are equal to 50 percent of the acquisition
cost plus the cost for fuel and oil. Under “severe conditions,” the total annual costs equal the acquisition cost plus the cost for fuel and oil. To arrive at the cost per hour, the total annual cost is divided into the number of running hours per year (normally 300-500);

(b) tractors, trucks and other heavy equipment: the cost per hour may be read in the graph.

![Time costs for tractors, trucks and other heavy machinery.](image)
Manpower

Direct Costs

The range of salary and wages for manpower in logging activities is generally far wider in developing countries than in developed ones. The direct wage for ordinary labour is usually in the range of $0.50 to $3.00 per day with a rather strong increase for skilled labour. As in developed countries, labour working by contract (piece rates) may earn considerably more than hourly paid workers. The structure of the salary and wage system is naturally different in every country, and needs to be surveyed for each particular study. The schedule given below should be seen merely as a list of different categories to be included in such a survey which can then be used for assessing the labour cost in the operation.

An Example of Ratios for Salary and Wage Rates – Logging Activities

Note: These rates are examples from one developing country and do not necessarily apply to other countries. The schedule should be seen as a checklist on the type of labour employed in logging to be used when establishing rates in the country of the study. For monthly and yearly paid labour the ratio 1.0 applies to the category “foreman.” For labour paid by the hour or by contract the ratio 1.0 applies to “labour” (ordinary workers).

<table>
<thead>
<tr>
<th>Labour paid by month or year</th>
<th>Salary ratios</th>
<th>Labour paid by hour or contract</th>
<th>Wage ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest manager</td>
<td>5.0</td>
<td>Powersaw operator</td>
<td>1.5</td>
</tr>
<tr>
<td>Logging superintendent</td>
<td>3.3</td>
<td>Tractor operator</td>
<td>2.4</td>
</tr>
<tr>
<td>Mechanical superintendent</td>
<td>2.5</td>
<td>Chockerman/Assistant</td>
<td>1.0</td>
</tr>
<tr>
<td>Forest engineer</td>
<td>2.5</td>
<td>Loader operator</td>
<td>2.4</td>
</tr>
<tr>
<td>Accountant</td>
<td>2.1</td>
<td>Assistant</td>
<td>1.0</td>
</tr>
<tr>
<td>Forester</td>
<td>1.25</td>
<td>Log-truck driver</td>
<td>2.4</td>
</tr>
<tr>
<td>Logging foreman</td>
<td>1.0</td>
<td>Gravel-truck driver</td>
<td>1.6</td>
</tr>
<tr>
<td>Road foreman</td>
<td>1.0</td>
<td>Powerman/Driller</td>
<td>3.0</td>
</tr>
<tr>
<td>Bull bucker</td>
<td>0.83</td>
<td>Driller</td>
<td>1.6</td>
</tr>
<tr>
<td>Shop foreman</td>
<td>0.83</td>
<td>Crusher charge hand</td>
<td>3.2</td>
</tr>
<tr>
<td>Technician/Assistant forester</td>
<td>0.6-0.7</td>
<td>Crusher operator</td>
<td>2.4</td>
</tr>
</tbody>
</table>


### TIME COSTS

<table>
<thead>
<tr>
<th>Position</th>
<th>Time Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assistant accountant</td>
<td>0.6</td>
</tr>
<tr>
<td>Medical/Safety</td>
<td>0.5</td>
</tr>
<tr>
<td>Survey and forest assistant</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>Scalers</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>Scaler helper</td>
<td>0.2</td>
</tr>
<tr>
<td>Clerks</td>
<td>0.35</td>
</tr>
<tr>
<td>Stores assistant</td>
<td>0.2-0.4</td>
</tr>
<tr>
<td>Mechanic/Electrician/</td>
<td></td>
</tr>
<tr>
<td>Welder</td>
<td>0.5</td>
</tr>
<tr>
<td>Apprentice helper</td>
<td>0.5</td>
</tr>
<tr>
<td>Delivery driver</td>
<td>0.3</td>
</tr>
<tr>
<td>Crew transport</td>
<td>0.3</td>
</tr>
<tr>
<td>Driver</td>
<td>0.3</td>
</tr>
<tr>
<td>Bridge charge hand</td>
<td>3.2</td>
</tr>
<tr>
<td>Bridge assistant/Machine operator</td>
<td>2.4</td>
</tr>
<tr>
<td>Helpers</td>
<td>1.6</td>
</tr>
<tr>
<td>Tiremen/Cleaners</td>
<td>1.6</td>
</tr>
<tr>
<td>Labour</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### INDIRECT COSTS

To the direct cost of manpower should be added the indirect costs. They consist of various fringe benefits, some of them given by labour laws and regulations, others negotiated in labour agreements and still others provided by the employer as a bonus addition to the direct wage. It is necessary to make a survey as well for each particular study as such indirect costs may vary widely from country to country and also within each country in different sectors of the economy. Usually the indirect costs of labour will amount to something between 20 and 100 percent of the direct wage. Indirect costs can be composed of a variety of items of which the following may be mentioned: annual leave; pension; health and accident insurance; medical care; family allowances; housing; transportation to and from work sites; clothing, including safety equipment; food, training and education grants.
APPENDIX 1.

Repair statistics and performance of new logging machines

Koehring Short-Wood Harvester/Report 1
S.A. Axelsson, October 1972

Definitions of machine time elements
used in Project No. 189 on logging-machine failure avoidance

The Canadian Pulp and Paper Association's standard definitions for machine availability and utilization, Woodland Section Index 2428 (B-1), have been used as a basis.

However, the CPPA Machine Availability, by definition, is influenced not only by the manufactured quality of the machine, but also by operational factors, mainly the efficiency of the maintenance support organization, the number of shifts and hours scheduled per day, and the amount of repair and service performed out-of-shift.

In addition to CPPA in-shift time characteristics, Total Machine time characteristics have been developed and introduced for this study, in order to present a more correct measurement of machine manufacturing parameters, independent of operational factors, and for calculation of maintenance costs.

The machine time elements used are outlined in Figure 17 and are defined in section A (below) in the "Extracts from Collection and Reporting of Field Data". Calculations of in-shift time and total machine time characteristics are defined in section B.

List of abbreviations (Figure 17):

- SMH = scheduled machine hours
- PMH = productive machine hours
- NMD = nonmechanical delay
- Maint.in = maintenance in-shift
- Maint.out = maintenance out-of-shift
- WM = waiting for mechanic (s)
- WP = waiting for part(s)
- Act.rep. = active repair
- Serv. = service

---

1 Reprinted with permission of the Pulp and Paper Research Institute of Canada, St. John's Road, Point Claire, Montreal 720, Quebec.
A. Extracts from collection and reporting of field data — Koehring Harvester Study

RECORDING OF TIMES

Check the individual time elements by reading the Servis Recorder chart. Note all times on the form rounded off to the nearest half hour, recorded as 0.5, 1.0, 1.5 etc. Delays of less than 15 minutes are disregarded and are not to be accumulated. Example:
Definitions of machine time elements

**Scheduled in-shift time (or scheduled machine hours, SMH)**

The time during which the machine is regularly scheduled to do productive work (e.g., 8 or 9 hours per shift, with one, two or three shifts per day). It should be noted that the scheduling refers to machine time, not operator's time. For example, an operator's regular half-an-hour break for lunch is not to be included in SMH.

The scheduled in-shift time is divided into:

- productive machine time;
- machine downtime due to maintenance (i.e., repair and service);
- machine downtime due to nonmechanical delays.

**Scheduled out-of-shift time**

The time during which no production is regularly scheduled for the machine. Time for active repair and service only is to be recorded on the daily report form regarding out-of-shift time.

**Productive machine time (or productive machine hours, PMH)**

That part of scheduled in-shift time during which the machine is performing a function for which it was scheduled.

**Repair**

Repair is mending or replacement of part(s) due to failure or malfunction. It also includes *modifications* and *improvements* of the machine. The total downtime for reasons of repair is subdivided into three time elements: *active repair; waiting for mechanic(s); waiting for part(s).*
Active repair

That part of total repair downtime during which the machine is actually undergoing repair, i.e., when the operator(s), mechanic(s) or other persons are working on the machine (at operating site, garage or elsewhere) in order to carry out one or several of the following actions:

- localization of failure or malfunction (trouble-shooting);
- disassembling of part(s);
- mending or replacing part(s);
- changing item, or installing new item (for modification and improvements);
- testing of part(s) or machine.

"Active repair" time is to be recorded on the daily report regarding both in-shift and out-of-shift.

Waiting for mechanic(s)

That part of total repair downtime during which the machine is waiting for mechanic(s) or repair facilities. It includes the following elements:

- operator contacting supervisor and/or mechanic(s);
- waiting for mechanic(s) to arrive to the machine;
- moving or transport of the machine (or part of the machine) to repair facilities, and return to operating site;
- transport of repair facilities to the machine (e.g., tools or welding set).

"Waiting for mechanic(s)" time is to be recorded on the daily report only as it pertains to in-shift time, not out-of-shift.

Waiting for part(s)

That part of total repair downtime during which the machine is waiting for spare part(s).

"Waiting for part(s)" time is to be recorded on the daily report only as it pertains to in-shift, not out-of-shift time, and only when the downtime cannot be classified as "active repair" or "waiting for mechanic(s)."
SERVICE

Service is fuelling, etc. and preventive maintenance performed to retain the machine in satisfactory operational condition. It includes:

- fuelling, lubricating, adding hydraulic oil, cleaning, etc.;
- routine inspection and checking;
- all work specified in a preventive maintenance programme (overhaul, replacement of oil filters and spark plugs, etc.).

If the machine is serviced while under repair, the time involved is to be classified as repair, not service.

For service, in-shift and total downtime is to be recorded on the daily report, i.e., no separation is done into “active service” and “waiting service” (e.g., waiting for oil).

For service out-of-shift, however, only active service is to be recorded.

NONMECHANICAL DELAY

That part of scheduled in-shift time during which the machine is not doing productive work for reasons other than maintenance. The various reasons for nonmechanical delay may be subdivided into:

- operational loss, such as weather or terrain conditions (e.g., warm-up, machine stuck); waiting for other phases of an integrated operation; waiting for superior’s instructions; aiding other machines; visitors, etc.
- personnel (e.g. operator late, sick, etc.)
- in-shift moving (i.e., moving or transport of the machine between operating sites, or between site and camp, assuming the machine is not under repair or service).

Only the total downtime for reasons of nonmechanical delays (in-shift) is to be recorded on the daily report (i.e., no separation into subheadings is done).

B. Calculations of in-shift time and total machine time characteristics

**IN-SHIFT TIME CHARACTERISTICS**

\[
\text{Utilization, \%} = \frac{\text{CPPA machine utilization}}{\text{SMH}} \times 100
\]
Operational availability, \( \% = \text{CPPA availability} = \frac{\text{SMH} - \text{Maint. in}}{\text{SMH}} \times 100 \)

Logistics delay, \( \% = \frac{\text{WM} + \text{WP}}{\text{SMH}} \times 100 \)

Shift-level = number of shifts per 24-hour day

**Total machine time characteristics**

Active repair time = Act. rep. in. + Act. rep. out, expressed in h/100 PMH

Service time = Serv. in + Serv. out, expressed in h/100 PMH

Mechanical nonavailability = Active repair time + Service time = Total Act. maint. in h/100 PMH

Mechanical nonavailability \( \% \) and Mechanical availability \( \% \) give the same information as Mechanical nonavailability, but expressed in \( \% \) instead of h/100 PMH

Mechanical availability, \( \% = \frac{\text{PMH}}{\text{PMH} + \text{Mechanical nonavailability}} \times 100 \)

\[ = \frac{\text{Total PMH}}{\text{Total PMH} + \text{Total Act. maint.}} \times 100 \]

Mechanical nonavailability, \( \% = \frac{\text{Mechanical nonavailability}}{\text{PMH} + \text{Mechanical nonavailability}} \times 100 \)

\[ = \frac{\text{Total Act. maint.}}{\text{Total PMH} + \text{Total Act. maint.}} \times 100 \]

Mechanical availability \( \% \) + nonavailability \( \% \) = 100\%, by definition

Number of repairs, expressed as total number or repairs (in- and out-of-shift) per 100 or 1000 PMH

\( \text{MTBF} = \text{Mean time between failures} = \frac{\text{Total PMH}}{\text{Total number of repairs}} \) in hours

\( \text{MTTR} = \text{Mean time to repair} = \frac{\text{Act. rep. in} + \text{Act. rep. out}}{\text{Total number of repairs}} \) in hours
APPENDIX 2.

Optimum feeder road spacing and density formulae

Examples are given below of formulae for calculations on optimum extension of forest road networks. The formulae are mathematically identical and give under identical sets of conditions the same results. In the first example the answer is given in optimum spacing between the feeder roads. It may be used under conditions where the road network consists mainly of parallel, relatively straight roads and where road junctions are few. In the second example the answer is given in optimum road density, and may be given preference under conditions of irregular or herringbone-like road systems.

These formulae are exact only when applied to extensive areas with uniform stand and terrain conditions. However, such conditions rarely occur in practice. Therefore, the results obtained by applying the formulae should be used with caution and the calculated spacing considered as a guide only when laying out the feeder road system. Application of the formulae has not been sufficiently developed in irregular steep terrain where, for example, grades may dictate both feeder road location and skidding or forwarding direction and distance.

A. Optimum feeder road spacing

Formula I

\[
\text{ORS} = k \sqrt{\frac{40 \, RL}{qct \, (1+p)}}
\]

where \( \text{ORS} \) = optimum spacing in metres;
\( R \) = road cost in dollars per km;
\( L \) = load in m³ in skidding or forwarding;
\( q \) = harvested volume in m³/ha;
\( c \) = operating cost of skidder or forwarder in dollars per minute;
\( t \) = time in minutes to travel 1 metre loaded and return light.
p = a factor, usually between 0.10 and 0.50 depending on terrain difficulties, designed to cover delay times regardless of the reason for such delays;

k = a factor varying between 1, when skidding or forwarding can be done equidistantly on both sides of the road, and 0.71 when skidding or forwarding can be done from one side only because of terrain or other limitations.

B. Optimum feeder road density

Formula II

\[ \text{ORD} = 50 \sqrt{\frac{c t v q}{r}} \]

where

\( \text{ORD} \) = optimum road density in metre/hectare;
\( c \) = variable skidding or forwarding cost in dollars per m\(^3\)/km;
\( T \) = factor allowing for the cases where skidding roads are winding and do not always end at the nearest point of the road;
\( v \) = factor allowing for the cases where the haul roads are winding, meet in junctions, terminate as dead-end roads, and are not equally spaced in the forest area;
\( r \) = road cost in dollars per km;
\( q \) = harvested volume in m\(^3\)/ha.

Note: For detailed explanation of the factors \( T \) and \( v \) see von Segebaden, 1964.

C. Comments and directions

1. The following relationships exist between the factors in Formula I and Formula II:

   in Formula I \[ (a) \quad \frac{c t 1 000}{L} = c \]

   in Formula II \[ (b) \quad \frac{1}{k \sqrt{1+p}} = \sqrt{\frac{v}{T}} \]
2. \( 2.5 \, TV = \) the factor "a" in the formula \( D = \frac{a}{s} \) in Chapter 2.

3. When assessing the road cost (the factor \( R \)), the average cost per unit length of the haul roads shall not be used but rather the normal cost per kilometre of the feeder roads of the lowest standard.

4. If the planning period extends over several years (as often in forests under sustained yield) \( R \) and \( q \) should represent the present worth of all road costs and harvested volumes during the period. More complex planning situations, related to the model's extension in time, are not uncommon. To analyse such situations goes beyond the scope of this paper.
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