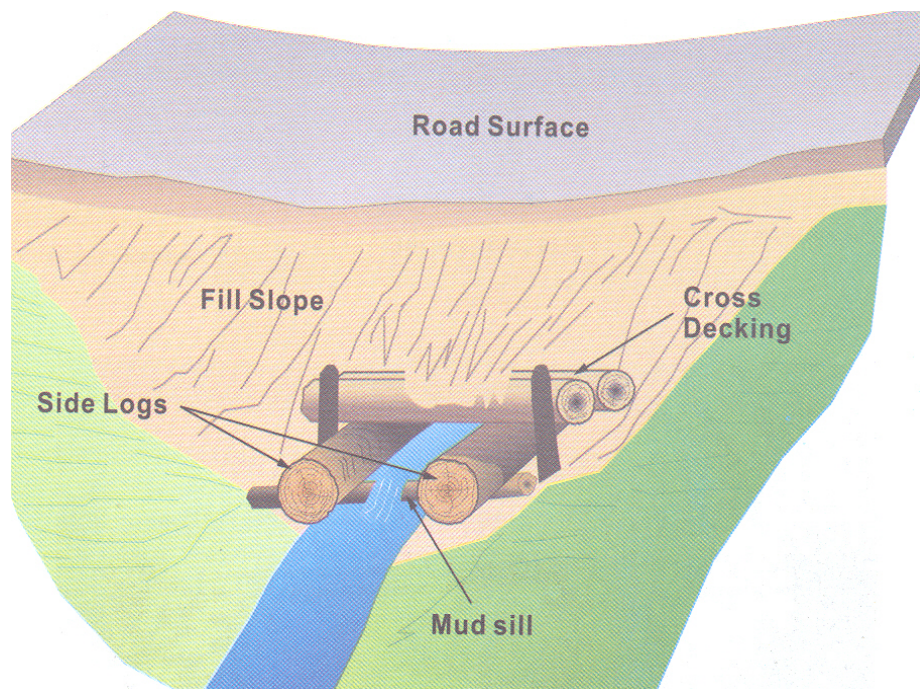


# FORESTRY TRAINING CENTRE INCORPORATED



## MANUAL ON INTRODUCTION TO FOREST ROADS *And Considerations for Reduced Impact Logging*



©Tropical Forest Foundation



TROPICAL  
FOREST  
FOUNDATION

IWOKRAMA

February 2010.

## Foreword

The renewable nature of forests can be conserved indefinitely provided stakeholders act responsibly their interventions in forest resources.

One vital and critical aspect of forest management, whatever the objective of management, is the construction of roads and trails. The harvesting of timber in particular leads to a higher density of roads (km/ha) and in addition skid trails at the rate of about 1-2.5km/100ha; roads are essential for conveying production inputs (machines, fuel, rations, logging rigs, personnel) to the areas targeted for harvesting, for the removal of logs from forest concessions to processing locations, and for concession monitoring purposes. Poor road design and road construction lead to higher truck maintenance costs and deterioration of logs in transit. Roads are therefore intrinsically linked to the viability of forest enterprises. Good roads also reflect environmental responsibility.

**This manual is for loggers.** Its intention is to sensitise loggers to the key considerations guiding road location, road construction and road maintenance within the context of reduced impact logging.

- a) It does not in any way attempt to replace the excellent manuals on roads available in stores and on the internet. This manual does not attempt in any way to detract from standard engineering criteria for road location and construction. The objectives of the manual are to: provide loggers with enough information in a simple format to encourage the logger into taking road construction and maintenance more seriously;
- b) help the logger identify any specific problems and to seek expert technical assistance as required;
- c) help logger articulate their road construction and road maintenance plans within their forest management plans and their annual plans of operations.

For the Guyanese forestry sector, it is anticipated that this manual will complement the prescriptions of the Code of Practice for Timber Harvesting. (In fact, much of the prescriptions on roads in the Code of Practice have been reproduced in this manual).

**Table of Contents**

Foreword	2
Acknowledgement	6
Glossary	7
Module 1: Introduction to Forest Roads	11
Module 2: Soil Properties & Forest Roads	13
2.1 Soil particles	13
2.2 Organic matter	14
2.3 Soil Moisture	14
2.4 Important soil characteristics	14
Module 3: Location of Forest Roads	16
3.1 Introduction	16
3.2 Basic considerations	16
3.2.1 The P-Line	16
3.2.2 Grade	16
3.2.3 Slopes	17
3.2.4 Obstructions	17
3.2.5 Distance from Waterways	17
3.2.6 Waterway crossings	17
3.3 Methods of Locating Roads	18
3.3.1 Introduction	18
3.3.2 Preliminary location of the road (P-Line) by a two man crew	18
3.3.3 Use of grade and slope stakes	19
Module 4: Road Construction	20
4.1 Basic Considerations	20
4.2 Clearing and Grubbing	20
4.3 Earthworks	20
4.4 Road Surfacing	21
4.5 Horizontal curves	22
4.6 Vertical curves	22
4.7 Erosion control	22
4.8 Drainage structures	22
4.8.1 Introduction	22
4.8.2 Culverts	23
4.8.3 Bridges	23
4.9 Other considerations	24
4.9.1 Choice of road construction equipment	24
4.9.2 Water management	24
4.9.3 Compaction	25
Module 5: Recommended design and drainage standards for Guyana	28

5.1 Road classification	28
5.2 Road Planning	29
5.2.1 Road location	29
5.2.2 Surveying requirements	30
5.3 Road Construction	30
5.3.1 Timing of construction	30
5.3.2 Roadway Development	30
5.3.3 Side slopes	31
5.3.4 Road grades	32
5.3.5 Road width	32
5.3.6 Curves	35
5.4 Drainage	36
5.4.1 General Considerations	36
5.4.2 Methods of Drainage	36
5.4.3 Additional requirements	37
5.4.4 Spacing between drains	37
5.4.5 Drain outflow	38
5.5 Water Crossings	40
5.5.1 Types of crossings	40
5.5.2 Construction of Crossings	41
5.5.2.1 Location of crossings	41
5.6 Earthworks	42
5.7 Bridges	42
5.8 Culverts	44
5.9 Low level watercourse crossings (fords)	46
Module 6: Road Maintenance	47
6.1 Introduction	47
6.2 Road surface failure	47
6.3 Road surface deformation	47
6.4 Road way drainage maintenance	48
6.5 Drain and culvert maintenance	48
6.6 Waterway crossing structures	48
Module 7: Swamps	49
7.1 Definition	49
7.2 Swamps and forest roads	49
7.3 Methods of crossing swamps	50
Module 8: Road Safety Practices	51

**Tables:**

Table 1: Introduction to basic soil particles	13
Table 2: Forest Road classification	28
Table 3 Maximum road grades	32
Table 4: Maximum road widths (meters) for loam, clay soils	33
Table 5: Maximum road widths (meters) for white sand soils	35
Table 6: Recommended minimum radius of curvature	35
Table 7: Maximum drain spacing	38
Table 8: Types of water crossings	40

**Figures:**

1: Diagram of a typical timber bridge on a logging road	24
2: Photograph of a road segment showing clayey soils	26
3: Photograph showing severe erosion near a bridge	27
4: Photograph showing degradation of a timber bridge	27
5: Road location and drainage	29
6: Half and full bench construction	31
7: Balance of cuts and fills	31
8: Road width limits and cross section	34
9: Turn out drains	36
10: Additional drainage requirements	35
11: Drain spacing	38
12: Drain diversion by turnouts and culverts	39
13: Log clusters with earth are not allowed	40
14: Cross water courses at right angles	41
15: Bridge construction	43
16: Stabilising bridge abutments and stream banks	44
17: Culverts should be set at the level of the stream bed	44
18: Culvert installation and outlet protection details with splash apron or rip rap lined plunge pool for energy dissipation and scour control	45
19: Provisions at culvert inlets (sumps) and outlets (energy dissipaters) to minimise erosion caused by flow entering or discharging.	45
20: Sediment traps of logs, rocks, etc. will be required in places where high water flows are expected.	46
References	53

**Annexes:**

Annex I: Selected Notes (from Unasyvla No. 70).
Annex II: Useful Notes on Equipment (taken from Unasyvla-No. 69: Forest Roads in the Tropics II)
Annex III: Additional Notes on Road maintenance (Taken from Unasyvla No. 69.)
Annex IV: Very useful notes on Timber Transport by truck, Tractor Trailer
Annex V: Recommended Safety signs for forest roads

## **Acknowledgement**

Several logging companies have, by their interest, supported the production of this manual and helped to field test its contents.

Barama Company Limited, Guyana and the Iwokrama International Centre for Rain Forest Conservation and Development, Guyana and E-Timber Industries, Suriname all of which have an interest in obtaining international certification of their forest management systems, have been requesting courses on forest roads, and FTCI acknowledges the interest of those companies in promoting the development of the Manual and in helping to determine the relevance and appropriateness of the contents.

FTCI also benefitted considerably from materials produced by the Guyana Forestry Commission and the US Forest Service.

## Glossary

**Aggregate:** crushed, angular rock used for road surfacing

**Alignment:** A general term referring to the physical location of the road. Vertical alignment refers to the vertical elements of a road location or constructed road, including vertical curves. Horizontal alignment refers to the horizontal elements of a road location including horizontal curves.

**Base course:** The bottom layer of road surface rock in a two-layer surfacing system. The base course is the layer between the sub grade and the surface layer of crushed rock.

**Borrow Pit:** An area where excavation of road construction or road surfacing material takes place.

**Catch basin:** The constructed basin at the inlet of a culvert, use to store water and direct it into the culvert.

**Centreline:** the field location of a road or the established centreline of the road.

**Clearing:** Removing standing and dead vegetation within a roadway clearing limits, as the first step in the construction of a forest road.

**Clearing limits:** The limits of clearing as designated on the ground.

**Compaction:** Mechanically compressed soil or rock, resulting in increased density in pounds per cubic foot.

**Construction slash:** All vegetative material not suitable for timber production, such as tops and limbs of trees, brush and removed stumps.

**Cross-drain:** Installed or constructed drainage structure such as a culvert or purposely constructed dip in the road which directs water from one side to another.

**Crowned:** A road surface that is sloped from the centre of the road to the inside and outer edges to effect road surface drainage.

**Culvert:** A drain pipe or wooden structure that channels water across and off a road.

**Cut slope:** The inside road cut into the face of the hill slope.

**Ditch (side drain):** A shallow channel constructed along the road intended to collect water from the road and adjacent land for transport to a suitable point of disposal.

**Embankment:** Soil, aggregate, or rock material placed on a prepared ground surface and constructed to grade. The embankment is the fill material on the downhill side of the road.

**Environmental impact:** An activity that has an effect on the surrounding environment, such as eroded soil from a road silting a nearby stream.

**Erosion:** For forest roads, the process of dislodging and transporting soil particles by wind, flowing water or rain along or across the road way. It is the wearing away of the surface of the earth

**Excavation:** Removing earth from an area.

**Filter or buffer strip:** A strip of land adjacent to a water body; its vegetative cover is used to filter the sediments out of surface run off water from roads.

**Fill:** Earth material used to build a structure above natural ground level, as with fill sections on the downhill side of a road.

**Gradient:** The slope of a road along its alignment. This slope is usually expressed as a percent of rise in elevation over run in distance. For example a 10 meter rise in elevation over a distance of 100 meters of distance is expressed as a 10% grade.

**Grade (Adverse):** An uphill grade (+) in the direction of the haul.

**Grade (Favourable):** A downhill grade (-) in the direction of the haul.

**Grubbing:** The digging and the removal of stumps and roots and removal of litter within the clearing limits of the roadway.

**Horizontal curve:** A circular curve used to change the horizontal direction, left or right, of a road.

**Inslope:** A road surface sloped toward the ditched side or inside shoulder of the road.

**Landing:** A logging site where logs are collected and/or stored.

**Lead off ditch:** Excavations designed to divert water away from the road way at a point where this does not occur naturally, in order to reduce the volume and velocity of roadside ditch water.

**Native material:** Natural or 'in place' soil hat has formed on site and has not been artificially imported to the site.

**Off tracking:** The distance the rear wheel sets on a log truck, tractor-trailer, or other vehicle pull to the inside on a curve. Because of off-tracking, curves will need to be wider than straight sections of road. In general, the tighter the curve, the more a vehicle will off-track.



**Outslope:** A road surface sloped to the outside shoulder. In general, an outsloped road needs no ditch because the slope of the road itself shed run-off water away from the road.

**Parent material (native material):** The original material on which the road has been constructed.

**Pioneer road:** Temporary access roadway constructed within the clearing limits to provide for clearing, grubbing and timber removal activities.

**Profile:** A longitudinal cross section of the road used to design the road and calculate the anticipated grade of the constructed road.

**Relief Culverts:** A pipe that carries water from road drains across a road, discharging the water beyond a fill slope.

**Right-of-way:** The strip of land which is cleared to permit the construction of a road. This includes the road itself as well additional opening of the forest to permit better sun access.

**Road grade:** The slope of a road surface in the direction of travel, usually expressed in percent. For example, a 10% grade equals a change along the road of ten vertical feet in 100 horizontal feet.

**Roadbed:** A road sub-grade surface between the sub-grade shoulders.

**Roadway:** The portion of a road within the limits of excavation and embankment.

**Running surface (wearing surface):** The top layer of the road surface which is driven upon. It should be durable, have a good resistance to skidding, and be impervious to surface water. In forest roads, the running surface may consist of well compacted parent material or material brought in from a suitable borrow pit.

**Seasonal road:** A road that is used mainly during a specific season, such as a logging road used only during the dry season.

**Sediment (sedimentation):** Soil consisting of clay, silt and sand, which enters a stream due to the process of erosion and reduces the quality of water.

**Seepage (ground water seepage):** surface movement of water down a slope which surfaces along the cut bank of the road.

**Shoulder:** the strip along the edge of the travelled way of the road. An 'inside shoulder' is adjacent to the cut slope. An 'outside' shoulder is adjacent to the fill slope.

**Slope ratio:** The steepness of a slope expressed as a ratio of the slopes horizontal to vertical distance ratio. For example, a 1:1 slope changes 1 foot horizontal to every 1 foot vertical (45°).

**Slope stability:** natural or artificial slopes resistance to movement or failure.

**Standards:** The definitive dimensions or specific materials incorporated in a road.

**Sub-grade:** The layers of road bed on which the base or surface course are placed. On an unsurfaced road, the finished sub-grade is the wearing surface (the top layer of the surface of the road).

**Surface course:** The top layer of the road surface.

**Tangent:** A straight section between two horizontal curves.

**Through cut:** A roadway sub-section cut through a ridge: it will have cut slopes above both sides of the road.

**Through fill:** An elevated roadway section with fill slopes below both sides of the road.

**Traffic volume:** The number of vehicles passing per day over a given section of road. In general, the more the traffic volume, the more road surfacing needed.

**Turnout:** A widening in the road to allow for trucks to pass each other.

**Vertical curve:** A curve that makes a transition between two road grades (such as between uphill and downhill grades). Unlike horizontal curves, which are designed as portions of a whole circle, vertical curves are designed with flatter parabolic or non-circular curves.

**Water bar:** A structure installed in the road surface to divert road surface water off the road. Water bars are constructed from sub-grade soil or other materials such as rubber strips and timber.

**Wearing surface:** The road surface on which vehicle wheels run.

## **MODULE 1: INTRODUCTION TO FOREST ROADS**

Roads are essential for logging activities and are generally the forest manager's first major intervention in the forest resources. Roads facilitate forest inventories and allow the conveyance of production inputs (chainsaws, fuel, and rations for example), to forward areas within the forest concession while at the same time facilitating the flow of production outputs (logs, piles, posts, and sawn lumber) to timber depots or points of sale or sawmills generally outside the concession area. Roads are a major cost centre in logging budgets, costing between US\$3,000 to \$8,000 per km. Roads are also a major source of environmental impacts. In addition, road use by various parties may lead to many negative social impacts.

Roads are frequently necessary in forestry because other timber harvesting options have major restrictions. Manual methods of timber extraction are generally not feasible over distances exceeding one km. Animal use for logging purposes is not feasible over distances exceeding one kilometre and the monitoring of animals in the face of prevalence of large jaguars and pumas within forest areas is a major consideration. The use of sleigh winches is not feasible for large and medium scale operators, and even sleigh winches require some form of road. Aerial logging in Guyana appears impractical at this time, due to very challenging conditions (fog, frequent rainfall, hilly terrain, and selective harvest practices).

Roads constructed by loggers create opportunities for other forest resource based activities. Miners, hunters and fishermen, eco-tourists, farmers, and persons engaged in the harvesting of non-timber forest products frequently use roads constructed by loggers almost as soon as these have been constructed. In many instances, forest roads are eventually integrated with the national road net-work: for example the Anarika-Arawai forest road built by Toolsie Persaud Limited and the Wineperu - Allsopp Point forest road (at 19 miles Bartica-Potaro Road) now form part of the Linden-Bartica Road.

The value and utility of good forest roads for forestry purposes is frequently underrated or misunderstood. Conway (1982) contends that transportation costs consume up to 60% of total operating costs and asserts that poorly aligned roads and adverse steep grades slow down the haul cycle, reduces payloads, and lead to higher truck maintenance costs. One may argue that bad roads also lead to higher incidences of driver fatigue, which in turn impairs driver judgement and contribute to road accidents. Vieira (1980) opines that improperly located, constructed and maintained logging roads continue to be the cause of more wasted finance than any other single factor in the logging operations in Guyana.

Loggers must consider all the variables associated with road use if the entire logging operation is to be feasible. These variables include:

- a) topographic conditions (favourable versus adverse grades and soil conditions);
- b) soil conditions (this has an influence on traction and lead to decisions to remove or add various earth materials);

- c) volume of timber to be extracted (which leads to decisions the size of trucks used, how often a road will be used and how much money will be invested in its design, construction, and maintenance);
- d) the timber product being hauled: for example local loggers have a preference for extracting full length logs which impacts on the kind and power of logging trucks and 6x6 or 6x4 trucks with pole trailers are frequently used in Guyana); and
- e) hauling distance (this affects the haul cycle, number of trips per day).

Road construction is therefore serious business. The viability of many local enterprises is closely linked to the quality of roads used.

Module 2 provides some introductory information on soils and its relevance for road construction and Module 3 provides basic information on considerations for road location. Module 4 addresses issues of road construction, while Module 5 reproduces standards proposed in the Code of Practice for Timber Harvesting. Module 6 addresses issues of road maintenance while Module 7 deals with roads through swamps. Finally Module 8 deals with a number of recommended safety practices for the use of logging roads.

Annexes I through IV contain a number of articles selected from various sources; FTCI hopes that loggers may find the additional reading useful. Annex V contains recommended signage for forest roads

## **MODULE 2. SOIL PROPERTIES AND FOREST ROADS**

### **2.1 Soil particles**

Soils are a mixture of natural materials derived primarily from the weathering of rock and through chemical reactions between soil components. Soil is not normally uniform in texture and structure because any given sample comprises solid particles of various types, shapes and sizes. The four main particles identified in soil are gravel, sand, silt, and clay.

The solid particles do not always fit closely together or may be pushed apart by roots, leaving spaces that contain water or gas.

Gravel, sand, silt and clay have basic properties that affect their suitability as road building materials. Soils with a high percentage of silt and clay make poor roads, while soils with a combination of types, including silt and clay, in lower proportions can make a suitable road surface. More specific properties of the various types are set out in Table 1.

Table 1: Introduction to the properties of soil particles.

<b>#</b>	<b>Rock type</b>	<b>Properties</b>
1	Gravel >2mm in diameter	Gravel and rock can make a strong, all weather roads that are fairly resistant to erosion and wear.
2	Sand 0.5 to 2mm in diameter	Whether coarse or fine, sands feel grainy and its strength is not affected by wetting. Sand does not make good roads because it has very little cohesive strength. Sand does support substantial weight, it is not affected by wetting, and it drains well. Sand can become compact when its grains are vibrated or pressured by compaction into their most dense arrangement; this gives sand, and other granular material, internal friction from a 'stacking' action of the particles. When sandy soil is mixed with silt or clay (to produce loam), a good road structure is created by combining the positive qualities of each.
3	Silt 0.002 to 0.05 mm in diameter	When dry, silt is a very fine material, floury in appearance. If pure, silt will settle out of water and make it clear. It is also granular and therefore permeable. Soil with a high percentage of silt is not suitable for road fills because it compacts poorly. Like sand, silt has no cohesive strength. Silt is also easily pulverized when dry. Soils with high silt content should be excavated and replaced, or the road relocated.
4	Clay< 0.002mm in diameter	Clay is the finest soil particle and it consists of microscopic scale-like particles that allow it to be rolled or kneaded when moist. Clay has several positive characteristics: it is cohesive because its particles have a high attraction for each other; it has a high dry strength and good workability, compacts rapidly, it has low permeability; and it withstands the erosive forces of running water. On the other hand, clay has no internal friction and will slide or slough off in large sections; it shrinks and swells, which tends to break apart road surfaces; and its low permeability means it does not drain well. Soil with a high percentage of clay should be removed from the road bed; it could however be mixed with sand to improve its qualities for road foundation.

Soil is the foundation of any road; different soil types exhibit various performance characteristics as road foundation material and therefore affect the strength and

durability of the road in terms of wear under traffic, erosion, slump and landslides. For example, some soils support wheel loads well and drain well, while others provide little strength and do not drain well; soils that do not drain well may swell and shrink with variations in moisture content until they finally break apart.

In summary, *stone fragments, gravel, and sand, or silty or clayey gravel and sand* are good for road sub-grade. Silty soils or clayey soils are not recommended for road-sub-grade. One must take this into consideration when locating roads. Soil type is therefore a major consideration in the location of roads

## 2.2 Organic Matter

Organic matter is partly decomposed vegetable or animal matter. In soils it appears as a fibrous, black or brown organic silts, peat or organic clays, all of which are generally soft. Organic matter should not be considered for road fill material because it is unstable and will continue to decompose and lose its shape, and therefore provide little strength to the sub grade.

## 2.3 Soil Moisture

In addition to the type, size and shape of soil particles, the amount of moisture in any soil determines when it can be properly compacted.

Moisture is generally present in three forms:

- a) *Gravitation moisture* or water that is free to move downward or laterally and drain from the soil
- b) *Capillary water*, held in the capillaries or pores between soil particles
- c) *Hydroscopic water or moisture* that remains after capillary and gravitational waters are removed. It is held as a thin film on the surface of soil grains. Hydroscopic water creates a chemical affinity between neighbouring soil particles, providing a tight bond between them. Hydroscopic water will be in balance with the humidity of the surrounding air; the lower the humidity, the lower the hydroscopic water volume.

## 2.4 Important soil properties

A few other soil properties, resulting from the mixture of various soil particles, organic matter and moisture content should be noted:

***Shear resistance*** refers to soils particles *resisting* separation from each other, or to *friction* between granular particles. Shear resistance is a positive soil quality for roads.

**Elasticity** refers to the soils ability to return to its original shape after load is removed. Elasticity is a negative quality for roads, because the rebounding and flexing of the soil mass eventually causes the road surface to rupture and break apart.

**Swelling and Shrinking** refers to the movement of soil particles with variation in moisture content, such as when water is added by rainfall or lost by evaporation. Swelling and shrinking (normally in soils with fine grain clay materials) are negative characteristics because it causes the soil surface to rupture and break up.

**Soil permeability** refers to the capacity of a soil to give up moisture without excess swelling or shrinkage. Soil permeability is a positive quality.

**Compressibility** refers to the ability of a soil to take on progressively less volume under a load; compressibility is a desirable, positive soil property providing the soil does not shrink and swell excessively and if it drains well.

## **MODULE 3: THE LOCATION OF FOREST ROADS**

### **3.1 Introduction**

A number of variables should be taken into consideration in planning and locating roads since these affect road quality and total road costs. In order of priority, the forest surveyor or technician should opt first for locations devoid of obstacles, ridges, areas with gently sloping grades and slopes, areas devoid of large trees, areas with suitable soils.

All personnel engaged in road construction or all personnel at locations where road construction is ongoing should be equipped with safety helmets, high visibility vests, goggles and safety (steel toed) boots.

Suitable aids should be used at road construction sites to warn anyone in the vicinity that road construction is in progress.

### **3.2 Basic Considerations**

#### ***3.2.1 The P-line***

Road location is the 'foundation' of any road. The goal in road construction is to get from one point to another in the most efficient manner, with the least amount of earth movement, the least amount of follow up maintenance and environmental damage given the prevailing terrain, ground stability and conditions that facilitate the operating parameters of the vehicles, such as turning radius and grade.

The direct location method is frequently used by small loggers, where no maps or formal surveying data is used to plan or design the road 'in office'. In applying the direct location method, most road design work is accomplished in the field. Direct location methods requires considerable experience if it is to be done properly.

Large scale logging operations using capital intensive technologies base their work on topographic maps or aerial photographs or even satellite images and ground surveys: there is the 'L-Line' which is placed on maps using topographic criteria (stream pattern, terrain and the location of major stocks of commercial timber) and then there is the 'P-Line', the Preliminary surveyed line set out on the site, considering grade, slope, obstacles, distance from streams, and soil type.

It is strongly recommended that all loggers must set out a P-Line as they undertake road development.

#### ***3.2.2 Grade***

Road grade is the difference in elevation between two points along a road surface. The grade is positive (+) uphill and negative (-) downhill. Grade is frequently expressed in percent (%), the vertical change of a road elevation for a given horizontal distance along the



road. For example the change of a grade uphill (+) 5 % would be a change in elevation of 5 vertical meters in a distance of 100 horizontal meters.

*A negative road grade in the direction or along the route in which a loaded truck is called a favourable grade. A positive grade in the direction of a loaded truck is called an adverse grade. The grade on any road should be a minimum of  $\pm 2\%$ . Grades less than that do not drain well and small ruts can cause standing water to collect. Under normal road surface conditions, the ability of a loaded truck to negotiate adverse (uphill) grades must also be considered.*

Road grades should be kept below 10% except for *short distances* where this limit may be exceeded to a maximum of 15% to 20%.

Excessive grades increase maintenance and trucking costs and frequently make it too expensive to keep roads intact. Long, steady grades permit the build-up of drainage water and increase the erosion potential of the running water unless adequate drainage structures are installed.

### ***3.2.3 Slopes***

Hill side locations permit good cross drainage and also provide the construction advantage of balanced cross sections which involve a minimum of earth moving.

### ***3.2.4 Obstacles***

Rock outcrops, ledges, swampy places and other features which are apt to present difficulties in construction should be avoided. The exact location of such obstacles must be known because they constitute control points that will influence the final location of the road.

### ***3.2.5 Distance from waterways***

Stream beds do not make good roads and should not be used for that purpose. Road surface drainage should be kept out of streams and located far enough from a stream to provide sufficient filtering area.

### ***3.2.6 Waterway crossings***

Stream crossings should be made at right angles wherever possible regardless of whether the crossing is a bridge, culvert or ford

### 3.3 Methods of locating roads

#### 3.3.1 Introduction

Sufficient reconnaissance work via a management level inventory should normally inform forest road location to ensure that timber stocks are hauled over the shortest distance possible and via the better grades possible. A decision is then taken as to whether the road will be used permanently or temporarily. Permanent roads must take into account long term considerations, including blocks that may not be logged in the short term.

The tools required for marking road location are as follows:

- a) Topographic map or aerial photographs and pocket stereoscope;
- b) Clinometer;
- c) Measuring tape or chain;
- d) Flagging tapes;
- e) Hatchet, axe or brush hook;
- f) Compass, notebook, and rain proof pouch.

Once a good stock map or large scale aerial photograph is at hand, the next steps are as follows:

- a) Plot the road alignment: two methods are usually used to plot the road: either topographic maps or aerial photographs.
- b) Ground of the road alignment: via a *sirih* walk the road alignment, checking ground conditions for grades, slope, obstacles and water ways. Ground control points should be established and the minimum of marking is done on this first occasion.

#### 3.3.2 Preliminary location of the road (P-Line) by a two man crew:

The following procedures are recommended for the establishment of the 'P-Line'

- a) The crew leader, armed with a clinometer, directs the flag man in the direction of the *Recce* line, and checking the grade. If the grade is excessive, the flagman moves to his right or left until the desired grade is achieved.
- b) The starting point and the forward point where the flag is are marked with flagging orange coloured flagging tape.
- c) The team leader then moves to the forward marked point and the flagman moves forward to the next station. In this manner, the road location process proceeds until the entire alignment is marked. This marked line constitutes the centre of the right-of-way.
- d) Curves must be of sufficient radius for trucks to negotiate easily. The radius should not be less than 35 feet and on flat a grade as possible.

### ***3.3.3 Use of grade and slope stakes***

In very rugged terrain, a road with more stringent engineering applications is required and this should include the use of grade and slope stakes are necessary.

Grade stakes are normally placed along the location survey line at 20 m intervals, but this depends on the uniformity of the terrain. At sharp turns and in very hilly terrain, stakes may be set at 8 m intervals. A grade stake marks that point on the ground and represents that point in the cross section of the road where the 'cut' and 'fill' sections meet and are reduced to zero.

Slope stakes mark those points in the cross section which represent the outer limits of construction, namely, the top of the cut bank and the toe of the fill bank. Some technicians choose to put slope stakes only on the cut side of the slope. The setting of slope stakes follows the 'grade' survey as a separate operation. Slope stakes are placed on the upper side of every grade stake.

## MODULE 4: ROAD CONSTRUCTION

### 4.1 Basic considerations

Road construction machines are very expensive to acquire and maintain and it is important to plan their use at all times. Before the heavy equipment is engaged and put to work, the road location/alignment should be well marked on the ground and all preparatory work within the right of way should be completed. This will permit immediate and steady use of the machine, prompt completion of construction and minimum construction costs.

### 4.2 Clearing and grubbing

The first step in the road construction process is the clearing of trees and brush from the road right of way. The clearing limit is the width that the trees, stumps and organic debris should be cleared along the future road way. A pioneer road allows the removal of vegetation and merchantable timber prior to major roadway excavation; this preliminary access road is constructed within the clearing limits of the future road way to provide for machine access and the removal of commercial timber.

Commercial species along the right of way should be felled and bucked into logs, ahead of construction. Takubas lying across the right of way should be junked. Stumps should be about one meter high to facilitate their removal by bulldozer. The least costly method to dispose of stumps and non-commercial species is to scatter it along the down hill side of slopes.

Stumps and organic debris must be removed from the road surface prior to filling because organic debris does not compact well: it tends to settle, causing slumps in fill sub-grade. Stumps that will be covered with a depth of earth fill exceeding 0.5 meters may be left as they are. All other stumps and roots over 75mm should be dug out of the ground.

All snags, leaning trees, defective or dead trees, and large lianas in the vicinity of the *right of way* must be removed.

The ideal equipment for grubbing the road is a D6 or D7 or equivalent Bulldozer for road clearings up to 4 meters and a larger machine (D8) for wider roadways.

### 4.3 Earthworks

Earthworks refer to the movement of soil or materials through excavation or fills during road construction. Before material from a borrow pit is extracted, it would have been compacted; after it is excavated, the material swells due to the accumulation of air voids. Once the material is used for filling, it **must be compacted again** by some mechanical means. Generally road sub-grades are compacted to higher densities than the natural state of the soil.

On site, earthworks are carried out with a tractor or hydraulic excavator. Dump trucks haul materials that needs to be moved farther than is economical for a tractor or hydraulic excavator. Excavators may be used to create borrow pits while front-end loaders are used to load stockpiled materials into dump trucks.

Road fill material, soil or soil mixed with rock should be placed in approximately 30cm layers and **compacted** before adding the next layer. The amount of compaction achieved depends on the moisture content and the energy expended on compacting. The more the soil is compacted, the tighter the bonding of the soil particles and the smaller the air voids.

Various types of compaction equipment are used such as smooth wheeled vibratory rollers or sheep foot rollers. When the projections on the sheep feet roller no longer sink into the soil, that soil is compact.

Many loggers depend on the repeated passage of loaded trucks to compact the road bed; this method can achieve up to 80% of optimal compaction.

Materials such as wet clay pockets, or subsurface water that enters the sub-grade, can cause serious and continual maintenance problems. Ground water in a cut bank or under the sub-grade must be cut off from entering the sub-grade.

#### **4.4 Road Surfacing**

The two most common types of road surfacing in forestry are native soil surfacing and lateritic earths Surfacing with lateritic earths provides more strength and long term wear to the road surface for vehicle passage than do natural soil surfaces

##### *Native soil surfacing*

Native soil surfacing is used when timber harvesting operations are carried out primarily in the dry season. Compacted and well drained native 'in situ' soils help avoid road damage. The use of such roads in the wet season creates road surface ruts, subsequent erosion and erosion damage; the use of such roads during the wet season should be restricted.

##### *Rock surfacing, laterite surfacing*

Aggregate rock or lateritic earth is either excavated with a tractor or excavator or produced at stone quarries. Rock aggregate is placed on a road sub grade to add strength to support vehicular traffic, provide wheel traction, provide a relatively smooth travelling surface, and reduce road surface erosion. When compacted, the rock particles bind together for added strength. *In Guyana, natural deposits of lateritic earths are generally an appropriate substitute for aggregate rock (which is quite costly).*

Sub-grades within forested areas vary in texture and structure and therefore the requirements for aggregate rock or lateritic earths vary considerably. Where the sub grade is laterite earth, no surfacing is required, while where weaker sub-grade occurs, a sub base and surface layer of lateritic earth (most times referred to simply as laterite) is employed for an **all weather haul**.

The thickness of lateritic earths added to a sub-grade depends on the strength of the sub-grade relative to the vehicle wheel loads, road grade, the number of vehicles using the road, the availability of the aggregate, and the cost of hauling it to the road construction site.

As with soil compaction, lateritic earths should be compacted when moist to attain optimum compaction and the greatest performance from the surfacing.

Specific mechanical action is required to compress the surface aggregate. Dump trucks, logging trucks and motor-graders are generally used by loggers to compact aggregate. Better results may be achieved with a self propelled smooth wheel vibratory roller.

#### **4.5 Horizontal Curves**

Horizontal curves are used to change direction of a road to the left or to the right. The radius of a curve depends on topography, vehicle speed and vehicle type.

On short single lane roads, speeds do not normally exceed 32km/hr. At the lowest vehicle speeds, 20 meters is often considered the absolute minimum turning radius. (In Guyana, where loggers prefer logging trucks with pole trailers, the trailer's wheels follow the wheel tracks of the truck directly and virtually no 'off tracking' occurs. (However, fuel tankers and trucks used to carry lumber and other supplies have trailers hitched to the fifth wheel and with such vehicles, 'off tracking' occurs).

#### **4.6 Vertical curves**

Vertical curves are used to make transitions between changes in the road grade, such as changing from an uphill to downhill grade, and vice versa. Vertical curves must be constructed with a curve length long enough to permit a truck to pass without bottoming out and also for safe sight distance.

On forest roads, the length of a vertical curve is designed to accommodate truck passage.

#### **4.7 Erosion Control**

Erosion control is important for two reasons: to protect the road and to minimise or eliminate sediment transport into streams.

### **4. 8 Drainage Structures**

#### **4.8.1 Introduction**

Drainage structures are built specifically to permit the road to cross a waterway or to divert water across or under a road.

The following measures should be considered:

- a) Install culverts during road construction and as close to the natural ground line as possible.
- b) Avoid installing culverts on elevated fill
- c) Cross drains should be put on long sloping sections of road where side diversion of the rainwater or seepage from the cut bank cannot be diverted off the road.
- d) Avoid the use of hollow logs or multiple logs in the fill, because this type of cross drain gets blocked easily leading to water ponding and flooding of the road way.
- e) Culverts are best installed with an excavator

#### **4.8.2 Open cross drains**

Open cross drains refer to constructed dips in the roadway designed to allow (seasonal) water to cross the road. The material in the open cross drain should be resistant to erosion such as coarse gravel or bedrock.

#### **4.8.3 Culverts**

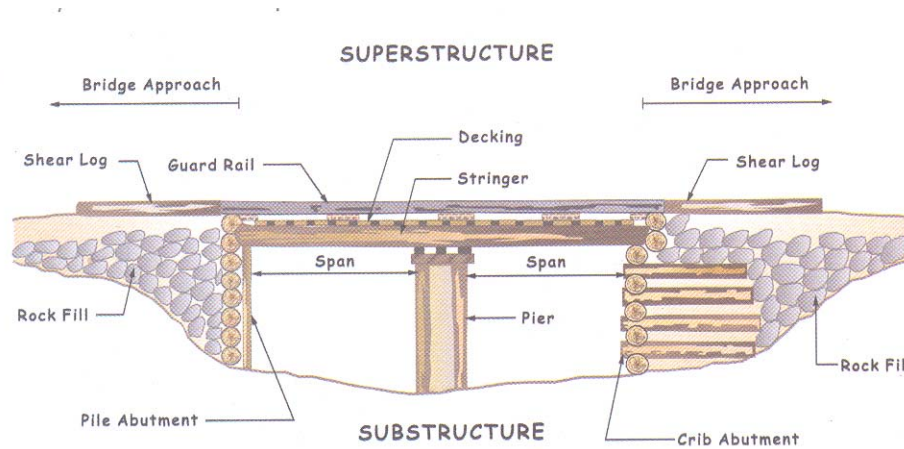
The most common form of drainage structure on forest roads are culverts. Log culverts are easy to install using locally available materials. A simple but effective box culvert consists of two parallel logs resting on mud sills which distribute the weight of the logs; the top of the culvert consists of cross-cut logs laid side by side.

Box culverts should be installed along the original ground line on ground that sustains the weight of the culvert and covering fill.

#### **4.8.4. Bridges**

Bridges vary considerably in shape and size to match local conditions. Logs near the location of the bridge are used.

A bridge consists of an abutment on either end which can be constructed using a log rib, piling or a concrete foundation. The span of bridge consists of logs referred to as stringers which can be covered in gravel or covered in a sawn timber decking. Various other components may be added to the bridge including guard rail logs and shear logs to protect the approaches to the bridge.



*©Tropical Forest Foundation, 2006*

Figure 1: Diagram of a typical timber bridge on a logging road

## 4.9 Other considerations

### 4.9.1 Choice of road construction equipment

The Caterpillar D6, D7 or D8 or the Komatsu D85-SS are effective machines when it comes to moving the large volumes of material required for forest road construction. If used incorrectly, they can also cause a great deal of destructions and excessive impacts.

Excavators excel over bulldozers as primary construction equipment in the following conditions:

- a) Steep terrain requiring careful positioning of excavated material
- b) In crossings of streams and gullies and in the installation of drainage structures.
- c) When crossing seepage sites or wet terrain with clay soils where drainage is often a problem
- d) In excavating material for road surfacing.

Frequently, in well planned situations, optimum results could be obtained from using both machines at the same time

### 4.9.2 Water Management

Water management is a priority during sub-grade construction. As far as possible, drainage structures should be installed as soon as possible during the construction of the subgrade. Seepage water should be controlled during through the establishment of a strong ditch line



and directed off the road as soon as possible. The subgrade should be constructed so that water does not accumulate or run along the surface of the road.

#### **4.9.3 Compaction**

A subgrade compacted immediately after formation will minimize surface erosion during a rainfall event. Compaction eliminates surface irregularities and accelerates drying of the subgrade. A compacted subgrade is less likely to produce surface erosion during rainfall and will largely eliminate the ponding of rainwater on surface irregularities, which prolongs the drying off period. A stabilized and compacted subgrade requires less additional surfacing material, thus saving costs. Before compaction a subgrade should be graded to create a clean ditch line and to smooth out any irregularities.



Figure 2: Photograph of a road segment showing clayey soils



Figure 3: Photograph showing severe erosion near a bridge



Figure 4: Photograph showing degradation of a bridge

Exercise 1: Discuss, on the basis of your knowledge so far what factors led to the state of the road (Figure 2 and 3) and bridge Figure 4

## 5. 0 RECOMMEND DESIGN AND STANDARDS FOR GUYANA

(Taken from GFC's Code of Practice for Timber Harvesting, 2<sup>nd</sup> Ed. 2002).

### 5.1 Road classification

Roads may be classified or graded in various ways. Table 2 shows criteria acceptable to local forestry authorities.

**Table 2: Forest Road Classification-Guyana**

Main or primary roads	Permanent, all-weather roads that make up the basic forest road network. They will carry log volumes of 2,000 m <sup>3</sup> (≈ c. 60 truck loads) or more per week and will be in service during the entire logging operation.
Secondary roads	All-weather roads that provide access to a logging compartment, connecting feeder roads and log markets to main roads. They will carry log volumes of 1,000 to 2,000 m <sup>3</sup> per week and will be in service for a (small) number of years only.
Feeder or spur roads	Temporary roads or tracks that provide access to a (small) number of 100-ha blocks. They will carry log volumes of less than 1,000 m <sup>3</sup> per week and will be in service for a short period only.

## 5.2 Road Planning

### 5.2.1 Location

- a) Avoid protected/exclusion areas and buffer strips
- b) Locate roads on well-drained soils and slopes where drainage will move away from the road
- c) Locate roads to follow the natural terrain by conforming to the contour, rolling the grade and
- d) minimizing cut and fills

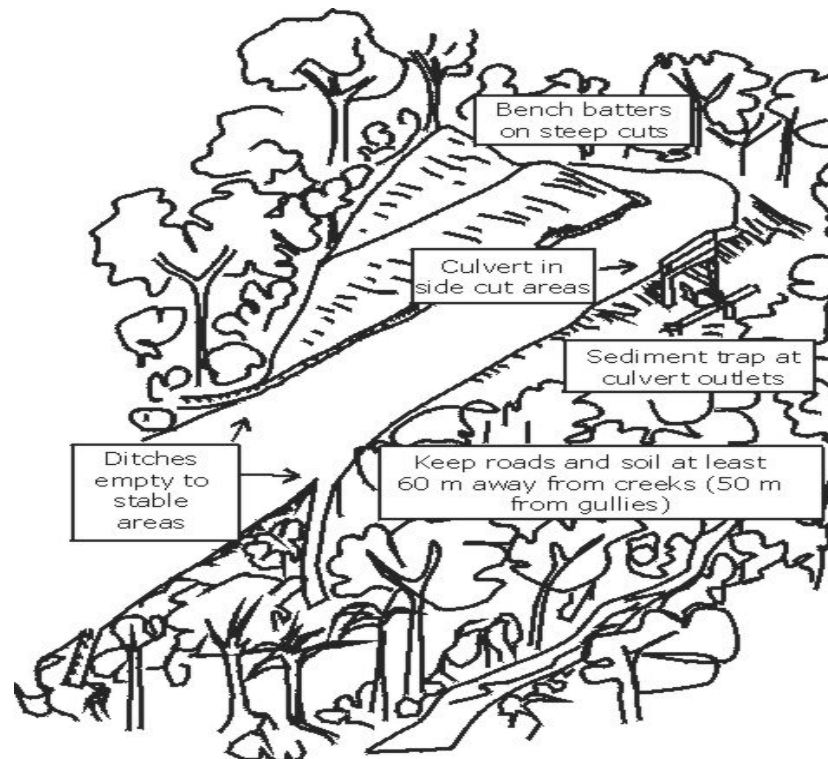


Figure 5: Road location and drainage

- e) Avoid locations that require box cuts
- f) Avoid steep and very flat terrain where drainage is difficult to control
- g) Avoid unstable and problematic locations such as swamps, marshes, landslides, steep slopes, massive rock outcrops, flood plains, and highly erosive soils
- h) Keep roads at least 40 m away from the edge of buffer strips (e.g. 60 m from the banks of creeks, 50 m from the edges of a gullies), except at designated watercourse crossing points
- i) Locate roads on ridges as much as possible
- j) Minimise the number of watercourse crossings



### **5.2.2 Survey requirements**

- a) Inspect, survey and mark the centre line of roads on the ground
- b) Locate and mark all watercourse crossings and culverts clearly
- c) Mark the total road clearing using the defined specifications
- d) Locate and mark log markets

### **5.3 Road Construction**

Road construction costs are mostly influenced by the standard of road built particularly road width, type of surfacing, and the steepness of the terrain. A road with cuts and fills on steep cross slopes greatly increases the time of construction, amount of earthwork, the areas of clearing, and adds length to cross-drains and other drainage structures

#### **5.3.1 Timing of construction**

- a) Primary and secondary roads should be completed 3 months before logging
- b) Construction should commence within 12 months before logging
- c) Preliminary roadway clearing should take place within 1 month of final construction to reduce sedimentation from undrained sites
- d) Construction should take place in the dry seasons only
- e) Wet weather restrictions apply

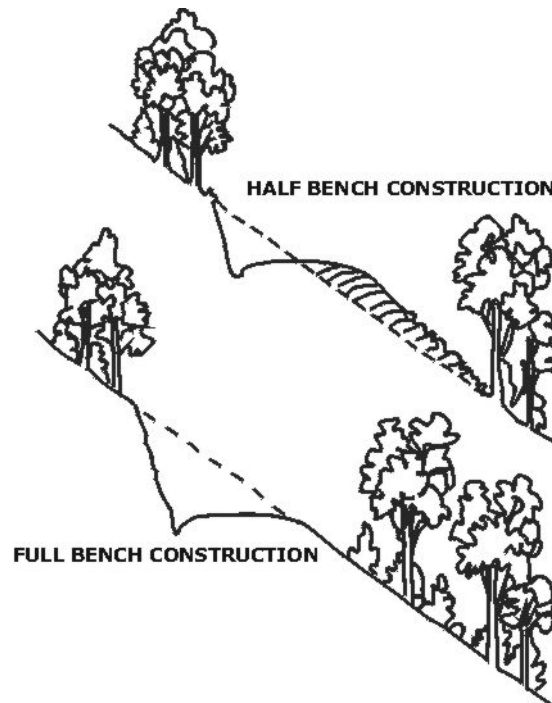
#### **5.3.2 Roadway development**

- a) Merchantable stems along the road reserve should be felled and preferably extracted before clearing
- b) While clearing, trees should be pushed into the road reserve and not into the adjacent forest
- c) Soil heaps, berm and debris stockpiling along the roadway are not permitted; instead topsoil should be stockpiled for use in cut and fill batters and/or in borrow pits
- d) Organic debris should not be used as fill
- e) Gravelling is recommended for primary and secondary roads, especially of bridge approaches and culverts
- f) All road fill and paving material shall be compacted
- g) Minimum compacted gravel thickness is 15 cm
- h) All road drainage works shall be completed before gravelling work commences

- i) Hazardous trees, which have a significant probability of falling onto the roadway, should be removed during construction

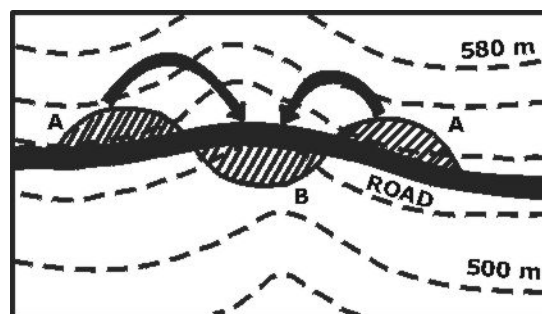
### **5.3.3 Side slopes**

- a) Side cut roads shall not be located on slopes greater than 50% (27°)
- b) Full bench construction should be adopted instead of half bench construction (see Figure 6) on slopes steeper than 25%



**Figure 6** Half and full bench construction

- c) Cuts and fills should be balanced in gentle terrain (see Figure 7) so that as much of the excavated material as is practical can be deposited in the roadbed fill sections



**Figure 7: Balance cuts and fills**

- d) Maximum fill batter slope 50% (27°)
- e) Cut batter slopes should be benched at 3 m vertical intervals

- f) Trees at the top of steep cut batters should be cleared where erosion or wind-blow is liable to occur

#### **5.3.4 Road grades (see Table 3)**

- a) Construct roads as much as possible with grades of 12% or less. On steep roads, drainage is difficult to control
- b) Steeper grades (up to 20%) for short sections (maximum 200 m) would be acceptable, once this shortens construction significantly or reduces earthworks, provided that adequate drainage is installed
- c) Any two sections of road at maximum gradient should be separated by 100 m of level gradient

**Table 3: Maximum road grades**

Road class	Favourable grade (%)	Adverse grade (%)
Main road	10	8
Secondary road	15	10
Feeder road	18	12

#### **5.3.5 Road widths (see Table 4, 5 Figure 8)**

- a) Where side cutting is not necessary, earthworks should be limited to the width for the roadbed plus ditches (table drains) on either side
- b) Feeder roads shall be located on ridges wherever possible to minimise side casting
- c) Primary and secondary roads on clay and loam soils should have trees removed alongside the road to allow sunlight onto the road to dry the surface quickly after rain. Roads on white sand soils should be protected from rain and direct sunlight by limiting clearing to the roadbed and ditches to maintain a functional road surface.
- d) On primary and secondary roads, tree stumps should be grubbed on at least one side of the road to allow for movement of tractors and other heavy machinery that would damage the road surface
- e) Passing spots shall be provided on roads with a roadbed narrower than 7 m, at least every 500 m and at bridge approaches and hillcrests.



Table 4: Maximum road widths in metres for loam/clay soils

Road class	Limit of Clearing	Limit of Roadway	Limit of Road Bed	Limit of Travel Way
Main road	25	20	9	6
Secondary road	20	15	8	5
Feeder road	15	10	7	4

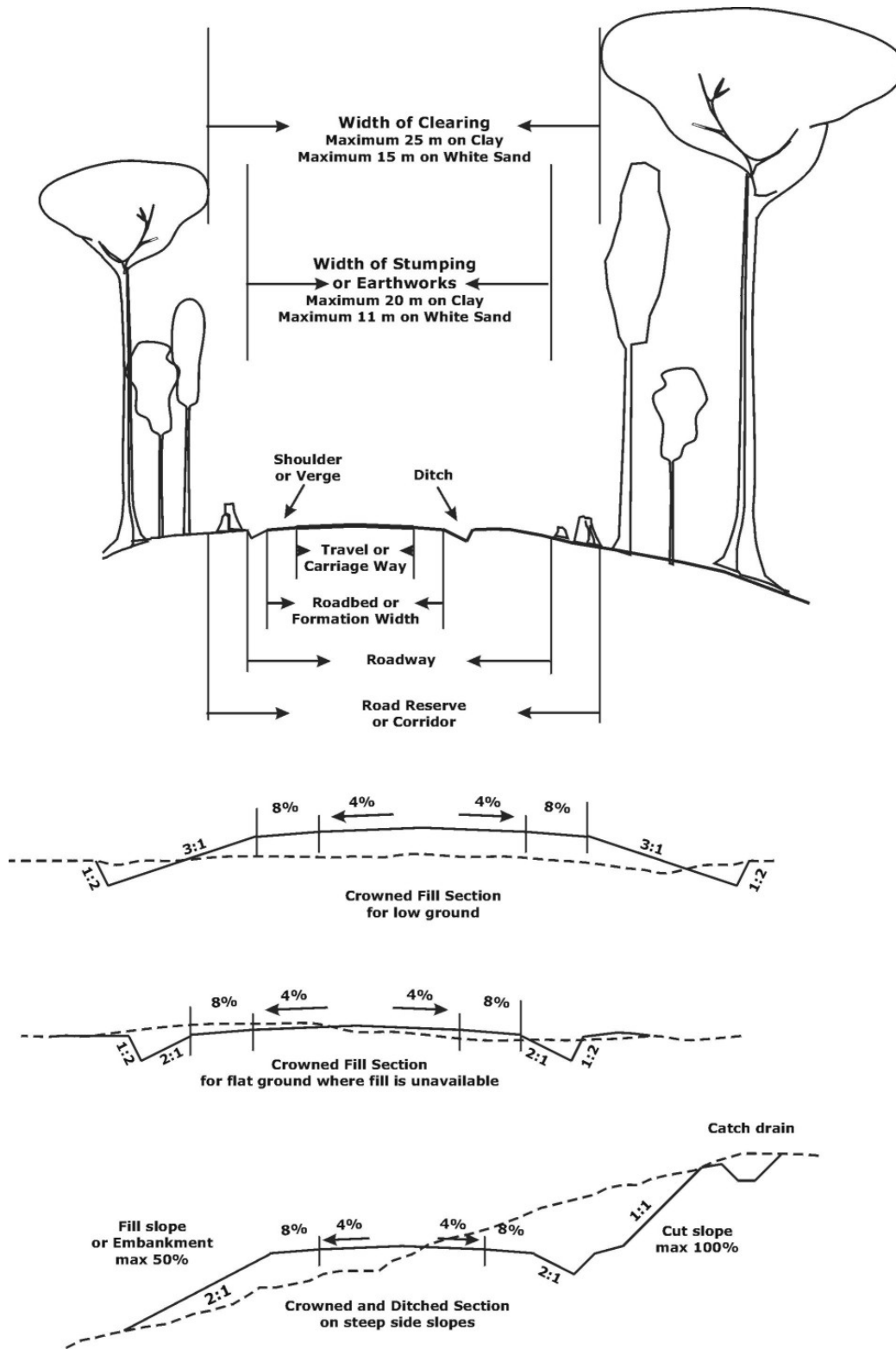


Figure 8: Road width limits and cross sections

Table 5: Maximum road widths in metres for white sand soils

Road class	Limit of Clearing	Limit of Roadway	Limit of Road Bed	Limit of Travel Way
Main road	15	11	9	6
Secondary road	15	10	8	5
Feeder road	10	9	7	4

- f) Widths of roads on laterite and brown sand should be intermediate between the limits given in the tables above

### **5.3.6 Curves**

- a) Fit curves to the topography; i.e. along the contour
- b) Curve widening is required on corners to allow for off-tracking of trailers
- c) To increase vehicle stability on a bend, banking (raising) the outer part of the curve is recommended below a radius of 50 m. (On a banked curve the roadway is not crowned but in-sloping = constant side slope)
- d) Shoulders may need to be cleared on the inside of the curve to obtain the required sight distance
- e) Minimum radius of curves should be related to visibility and the speed the vehicles will be travelling on the road:

Table 6: Recommended Minimum radius of curves

Road class	Design speed (km/h)	Minimum sight distance (m)	Minimum radius (m)
Main road	70	100	50
Secondary road	50	60	30
Feeder road	30	30	25

## 5.4 Drainage

Drainage problems often cause the largest impacts from roads with regard to erosion, sedimentation, and degradation of water quality. Poor drainage will also lead to rutting, scouring and gulying, while standing water and seepage under the roadbed may lead to road failure; in all cases necessitating extensive maintenance or even expensive repairs or diversions. These aspects make road drainage the single most important aspect of road construction and maintenance.

### 5.4.1 General Considerations

- a) In all phases of construction, adequate drainage will be provided to achieve the stability of the road formation.
- b) Wherever practicable, permanent drainage should be installed in advance of other construction to keep works as dry as possible. Temporary drainage shall be provided where there is likely to be a significant delay in installing permanent drainage

### 5.4.2 Methods of drainage

- a) A crowned road surface with a cross-fall of 4%, especially on clay/loam soils
- b) Ditches (table drains) alongside all roads, constructed to a minimum depth of 30 cm below the level of the crown of the road. Ditch grade (longitudinal) 1-5%.
- c) Turnout drains (side drains/outlets at grade 1-3%) at specified spacing Crossroad drainage (pipes or culverts) should be used where turnout drains are not possible.

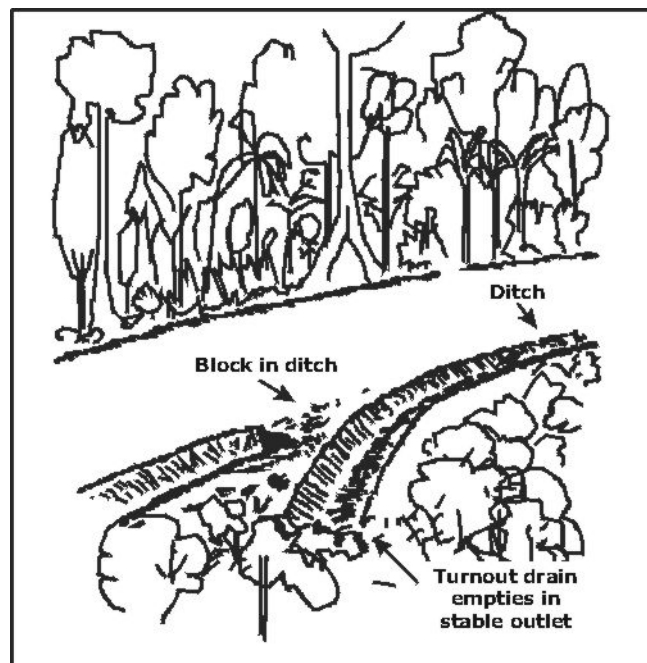


Figure -9: Turnout drains

### **5.4.3 Additional requirements**

- a) In highly erodable soils on slopes  $> 5\%$ , drains require special treatment such as lining with gravel or stones; log or rock bars; stepping and frequent outlets to reduce scouring
- b) Earth fills are to have adequate drainage through the fill (culverts) to prevent water build up and ponding behind the fill
- c) Side cuts are to be provided with catch drains along the top side to collect surface runoff

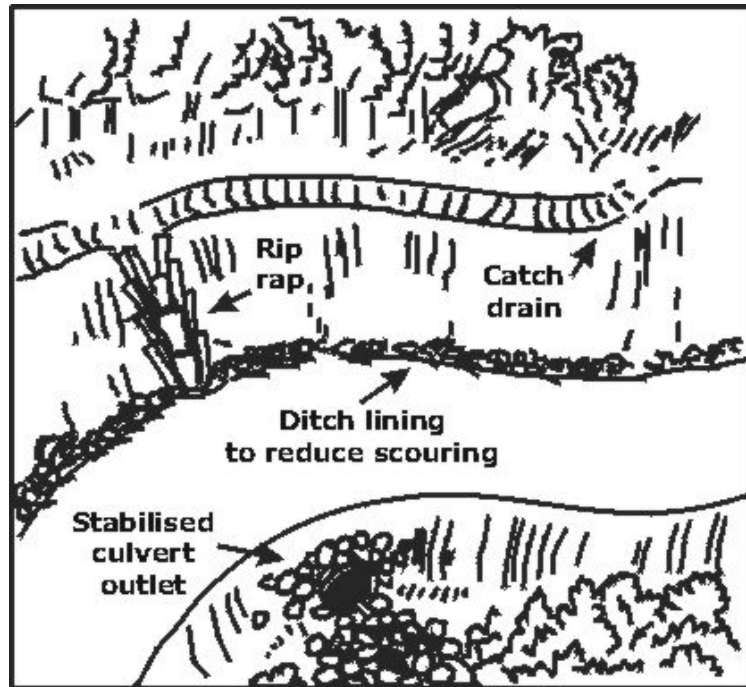


Figure: Error! No text of specified style in document. Additional drainage requirements

### **5.4.4 Spacing between drains**

Turnout drains or culverts shall be constructed:

- a) at changes of slope
- b) within 50 m of watercourse crossings
- c) additional drains to meet the maximum spacing requirements

Table 7: Maximum drain spacing†

Gradient (%)‡	Drain spacing (metres)
0-5	80
5-10	40
10-20	30

† Ditches adjacent to roads that have been box cut should be stepped or provided with rock or log bars at half the maximum drain spacing

‡ Roads should not be built with grades exceeding 20% (max unloaded truck grade is about 23%)

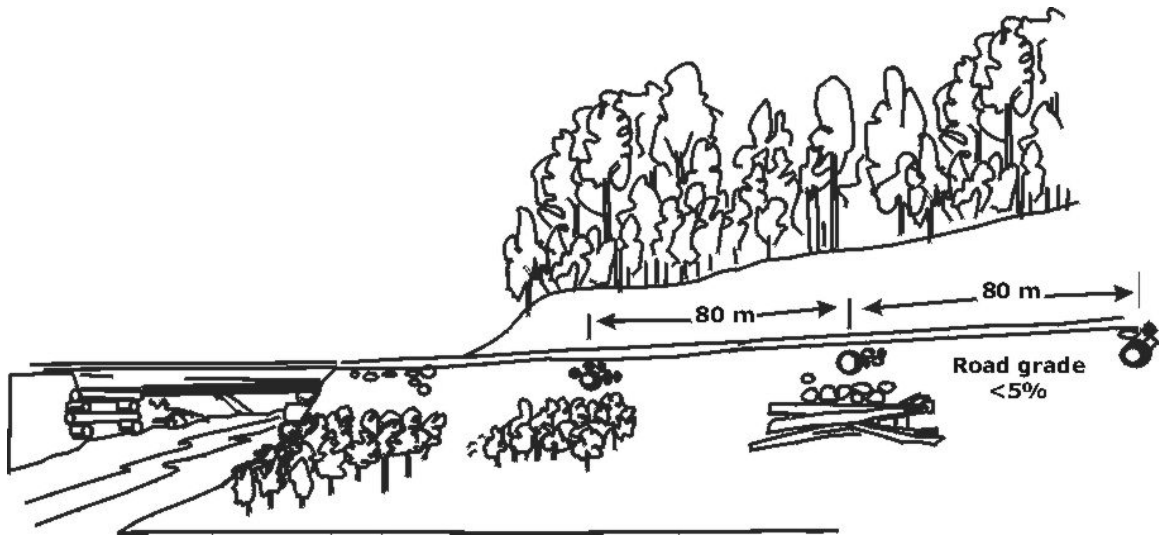


Figure 11: Drain spacing

#### **5.4.5 Drain out-flow**

- a) Ditches shall not drain directly into watercourses. Turnout drains (outlets) shall be installed at least 50 m before meeting a watercourse to divert water into surrounding vegetation. Where turnout drains are not practicable, drainage diversion by means of a culvert should be considered

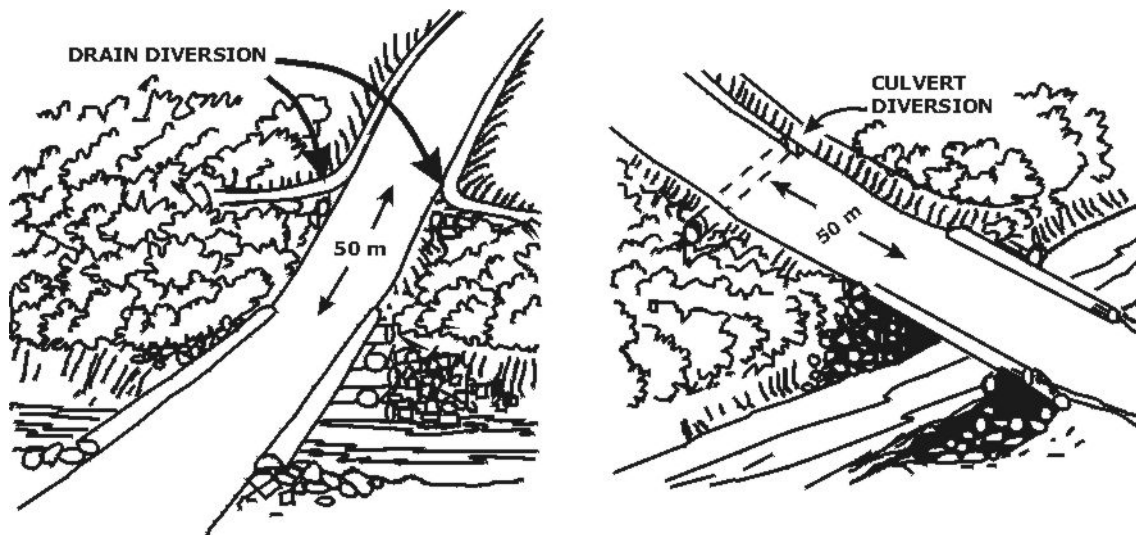


Figure-12: Drain diversion by turnouts or culvert

- b) All drains shall have stable outlets, protected by vegetation or rock or log barriers, particularly in fill areas and shall never directly enter watercourses.
- c) In steep terrain silt traps should be constructed at the end of turnout drains
- d) Sumps or silt traps shall be constructed in ditches at all four corners of watercourse crossings

## 5.5 Watercourse Crossings

### 5.5.1 Types of Crossings

Table 8: Types of waterway crossings

Bridges	Bridges shall be used for road crossings of all creeks. They may also be used to cross other watercourses
Culverts or pipes	Culvert or pipes should be used for crossing gullies and waterways (if bridges are not used)
Fords/low-level crossings	Fords are only permitted on feeder roads. They are only acceptable if: <ul style="list-style-type: none"> <li>– Bank height is less than 1 metre</li> <li>– Approaches to the watercourse are less than 10%</li> <li>– Depth of normal water flow is less than 0.5 m</li> <li>– The bed is stable (gravel or sand)</li> </ul> It is always desirable to corduroy fords
Corduroy with earth fill	Corduroy with earth fill is not allowed for crossing any watercourse in any situation because this would effectively block the water flow and may divert the course

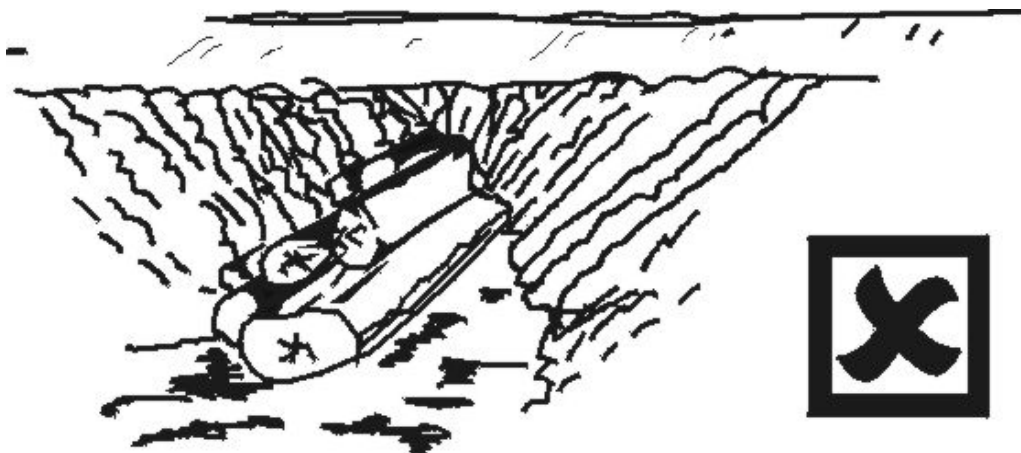


Figure 13: Log clusters with earth fill are not allowed



## 5.5.2 Construction of Watercourse Crossings

### 5.5.2.1 Location of crossings

- a) Select crossing points which
  - i. are immediately downstream of straight and stable watercourse sections
  - ii. have easy high bank access
  - iii. do not require deep box cuts
  - iv. require minimum alteration to the high bank
- b) Cross watercourses at right angles (see Figure 14)

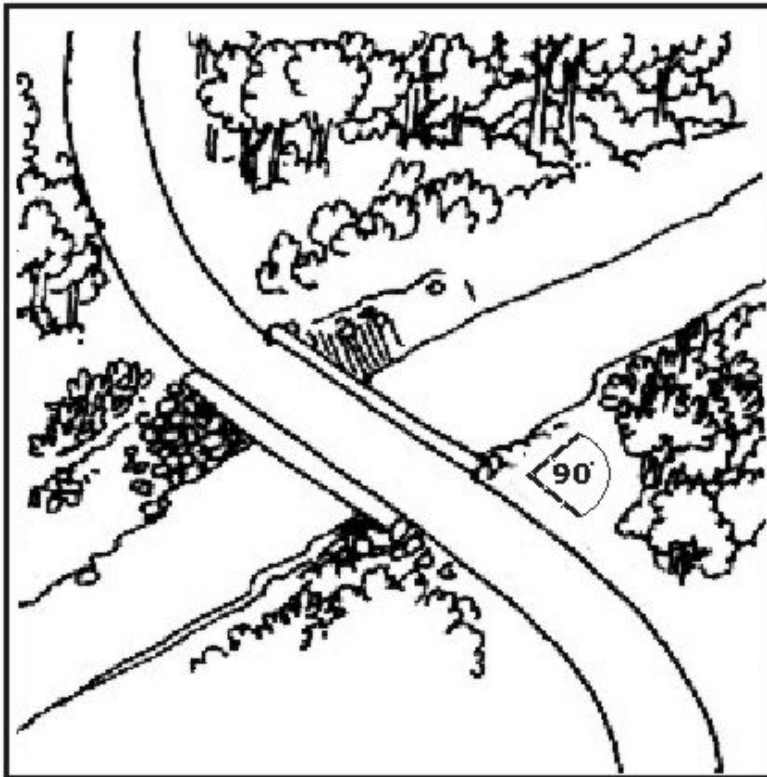


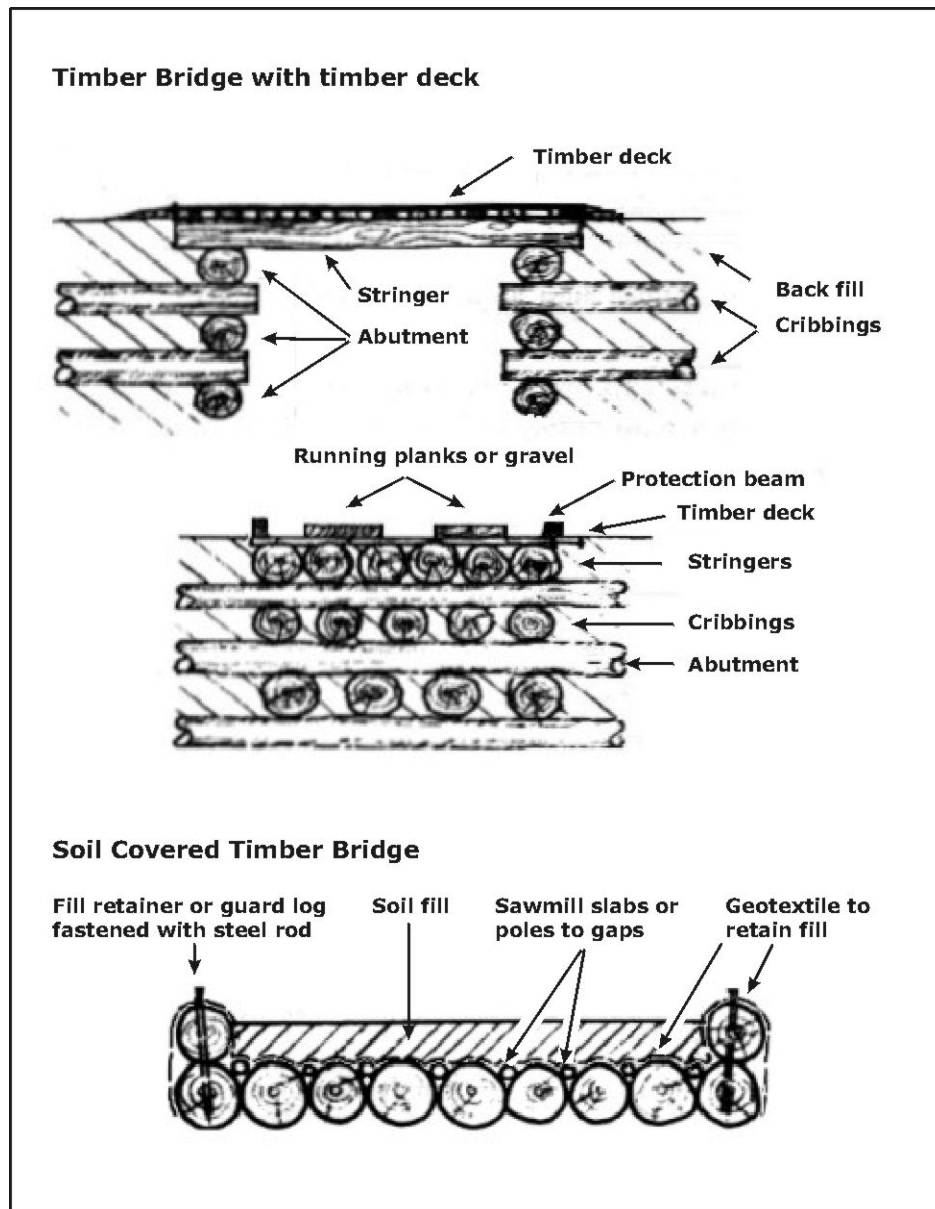
Figure 14: Cross watercourses at right angles

## 5.6 Earthworks

- a) In the construction of roads and bridges creek beds shall not be filled in
- b) During bridge construction oil, chemicals, excess concrete and other waste shall not enter the creek
- c) All earthworks shall be carried out so as to prevent soil from entering the watercourse
- d) All spoil should be removed to outside the buffer strip or placed in road fills where possible
- e) Watercourse buffer strip vegetation should be retained to the edge of the crossing
- f) Temporary crossings are permitted to allow equipment involved with the construction of the crossing to be moved to the other side, provided that:
  - i. the width of the temporary crossing is limited to 4 metres; and
  - ii. the temporary crossing is made on the final crossing alignment, so as to reduce disturbance to watercourse banks and buffer strip vegetation
- g) Wet weather restrictions apply

## 5.7 Bridges (see Figures 1, 15)

- a) Bridges should be sufficiently elevated to allow wet season flood flows to pass without damage to the crossing or its foundation
- b) The bridge should span at least 120% of the width of the watercourse measured from bank to bank; i.e. extend beyond the creek channel by 10% on either side
- c) Approaches should have a straight and level alignment for a minimum of 20 metres on either side



**Figure 15: Bridge construction**

- d) Foundations should be excavated to a solid base and not formed by pushed material
- e) All parts of the bridge shall be well anchored to prevent their washing away
- f) Decks should be constructed of durable sawn timber. Soil fill or covering is not allowed unless the stringers are completely covered with a material such as geotextile and have guard logs on both sides
- g) The stream banks adjacent to the bridge should be stabilised using wing walls of durable logs or other equivalent construction
- h) Silt traps shall be provided at the four corners of bridges

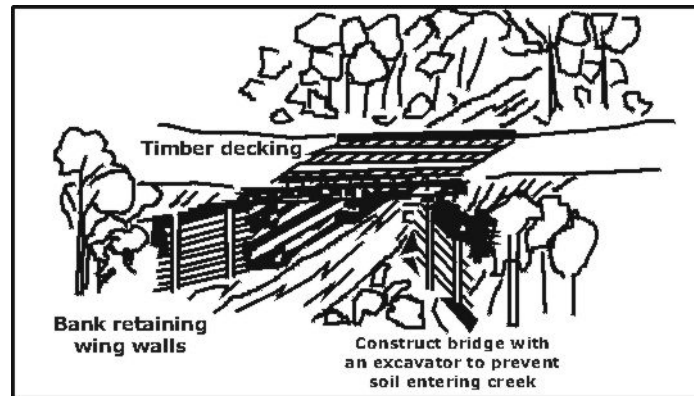


Figure 16: Stabilising bridge abutments and stream banks

### 5.8 Culverts

- a) Culverts should be set at or marginally below the level of the natural watercourse bed

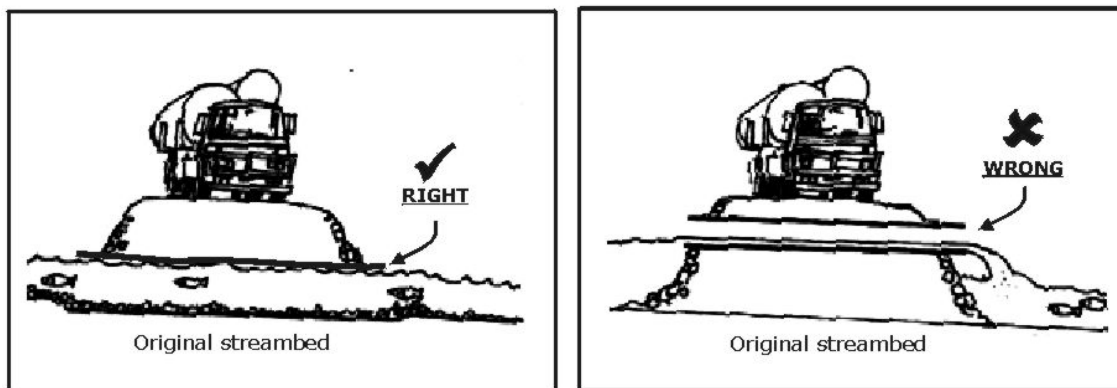


Figure 17: Culvert should be set at the level of the streambed

- b) may have an earth fill but are to have stable abutments to the level of the running surface to prevent soil entering the watercourse
- c) should be laid at a grade of 1-3% to minimize silting up and excessive scouring at the discharge end
- d) should have a headwall to prevent erosion under the pipe
- e) should have an opening with a diameter of 45 cm or larger depending on the wet-season flood-flow level. In case of log culverts it is recommended to use more than one log culvert if high flood flows are expected
- f) should have a earth fill of 30-60 cm to prevent pipe breakage
- g) Provisions shall be made at culvert inlets and outlets to minimise erosion caused by flow entering or discharging; sediment traps of logs, rocks, straw bales, etc. will be required in place where high water flows are expected

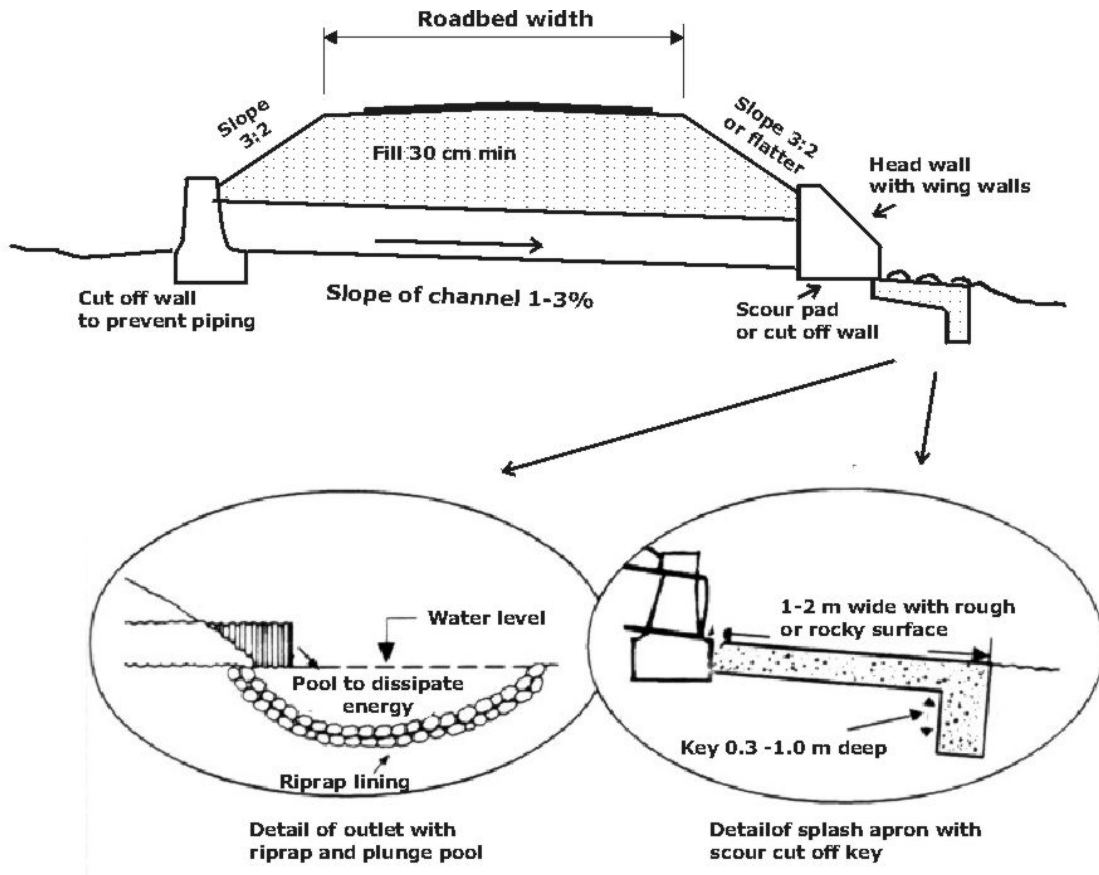


Figure 18: 1Culvert installation and outlet protection details with splash apron or riprap lined plunge pool for energy dissipation and scour control

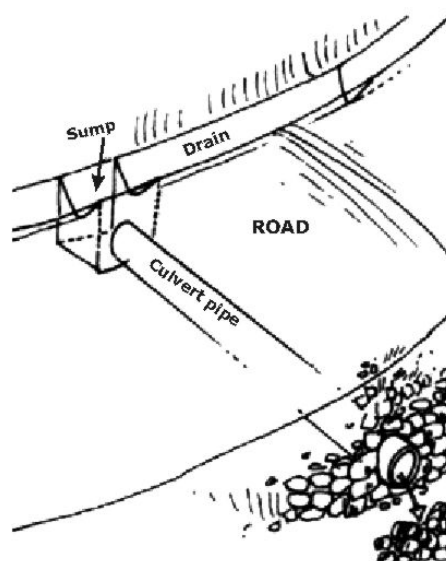


Figure 19 Provisions at culvert inlets (sumps) and outlets (energy dissipaters) to minimise erosion caused by flow entering or discharging

- h) Culverts shall not discharge over fills without adequate protection (e.g. rip rap, geotextile)
- i) Sumps or silt traps shall be constructed in ditches at all four corners of culverts to prevent siltation and blocking
- j) Log culverts require geotextile or another retaining mechanism to retain backfill

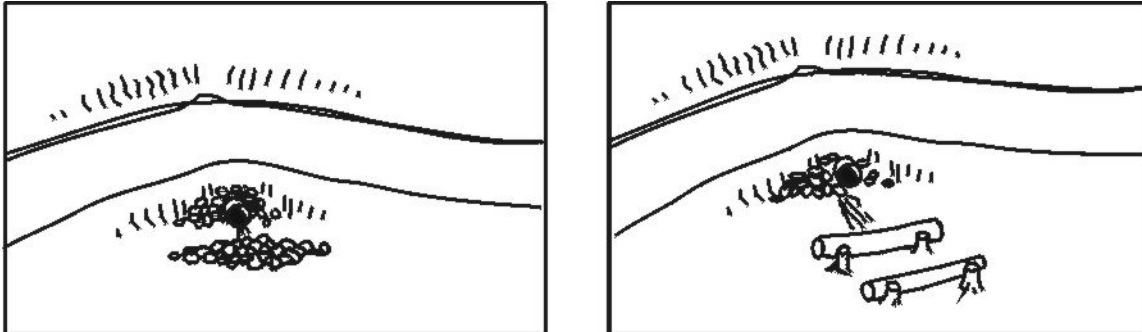


Figure 20 Sediment traps of logs; rocks, etc. will be required in places where high water flows are expected

### 5.9 Low-level watercourse crossings (fords)

- a) Construction shall minimise earthworks and impact on streambed
- b) Shall be built to allow water to flow
- c) Should provide protection against scouring below crossing unless the bed is solid gravel or stone
- d) Should be corduroyed to minimise impact on creek bed; corduroy is to be removed after use

Road design and road standards have a major impact on the feasibility of the timber harvesting operations. Construction costs and trucking costs respectively are the fundamental economic considerations that inform road design and road standard. Compliance with national environmental requirements also impact on road costs.

The following considerations should be noted:

- a) The size of the load is determined by the size of the trucks
- b) Total hauling costs are proportional to the time the loaded truck spends on the road (or the ease with which the road is traversed).
- c) Excessive road maintenance and trucking expenses may more than offset savings in construction.

Road banks may be cut just as steep as the stability of the material will permit. Bank slopes may be 1:4 on stable material to 1: 1 on erosive soils such as sand.

*Note: The construction cost for a 4 meter width road may be as much as one third higher than a 2.5 meter road on the same location, the difference being represented by the high volume of earth to be moved out of the additional two feet.*

## Module 6: Road Maintenance

### 6.1 Introduction

A managed road has a well maintained surface, clear and well maintained drainage, and effective erosion control; ditch and culverts are kept clear of debris; and there is little evidence of erosion.

A road causes an unnatural change on the natural landscape; over time, nature will continuously work toward re-establishing a natural landscape. In addition to natural damage, traffic damage not quickly repaired can seriously erode a road. Wheel rutting causes serious erosion damage during heavy rainfall, damaging both the road and the environment because surface run-off is channelled down the wheel ruts, which increases the erosive power of the water, which in turn carried sediment into waterways. On the other hand water standing in wheel ruts can saturate the subsurface, leading the road to fail or sections to slough off.

### 6.2 Road surface failure

The vehicle wheels of logging trucks depress road surfaces over time and where there has been little compaction, ruts develop after a while. Rut formation occurs much faster where wheel loads are too heavy for existing road surface conditions. Where there is no maintenance the rut formation process intensifies. Frequently, when signs of distress are very noticeable, the sub-grade, base and surface courses have already failed (from invisible damage under the road).

One mode of failure is called shear failure, where the wheel load is too heavy for the road surface to support, and thus the surface material punctures into the sub-grade. This type of damage is difficult to detect, but frequently small wheel ruts appear in the road surface. (Overloading vehicles is the primary cause of sheer failure).

Another common mode of road surface failure is called '*pumping*'. The problem begins when the sub-grade becomes saturated from standing water that seeps in horizontally from a blocked ditch, or vertically from wheel ruts. Moisture in the saturated sub-grade is pumped up onto the road surface, whenever the sub-grade is squashed from a wheel load and saturated soil particles migrate into the more porous aggregate surfacing. The moisture and fine particles act as a lubricant, destroying the strength of the sub-grade and surfacing. (To avoid this type of damage, loggers should prevent standing water by keeping ditches free of obstructions or regarding to eliminate ruts. Under extremely wet conditions, the logger should desist from using the road).

### 6.3 Road Surface Deformation

Some types of road surface deformation affect only the surface layer. Shallow rutting and wash boarding (corrugations) are limited to the surfacing material and do not penetrate the base course. Wash boarding is caused by the forward and downward motion of a vehicles

wheel or bouncing on the road surface, which initiates the formation of small corrugations on the surface layer, perpendicular to the road.

In Guyana, wash boarding is frequent along saddles straddling creek sources (creek heads)

Wash boarding is easy to detect and can easily corrected with the use of a moulding board of a motor-grader.

#### **6.4 Roadway Drainage Maintenance**

Drainage is a major consideration in road design, construction and maintenance. Poor drainage is frequently is frequently the main challenge in road construction.

The moisture impacting on road condition originates from four main sources: road surface run-off, blocked drains, blocked culverts and horizontal subsurface water flows. Improperly shaped road surfaces contribute to the retention of water on the road surface by causing the ponding of water which in turn infiltrates the road surface, weakening the sub-grade and causing potholes and ruts.

Road surface shape (crowned, inslope/outslope, and the corresponding drains) is frequently designed and maintained to divert run-off as quickly as possible.

#### **6.5 Drain and Culvert Maintenance**

Relief culverts are designed allow water to flow between drains; therefore any blockage of culverts causes water to back-up with catastrophic results.

Ditches may be kept free by hand, with a shovel, or a backhoe.

#### **6.6 Waterway crossing structures**

Bridges and culverts represent huge investments and it is therefore important to maintain these structures in a fully functional state.

Timber bridges should be inspected periodically for damage caused by vehicles, insects, rot or flooding.

Culverts should be inspected periodically, and frequently during the rainy season, kept free of any blockage. A blocked culvert can lead to massive removal of fill from the sides and top of the fill around the pipes



## 7. Forest Roads through swamps

### 7.1 Definition

Swamps are areas where there is water logging for most of the year. Swamps indicate some sort of impeded drainage, either because the area is flat and does not force the water to move quickly, or there may be an elevated water table that keeps water near or on the surface. Many rivers overflow their banks and where this happens frequently, water logged conditions persist. Marshes differ from swamps because these dry out during the dry season, becoming water-logged again after heavy rainfall.

The presence of Ité palm (*Mauritia flexuosa*) and Mora (*Mora excelsa*) are good indicators of swampy conditions.

### 7.2 Swamps and forest roads

Swamps and marshes are major hazards in forest road construction **and ideally should be avoided at all costs**. It is very difficult to maintain a firm road foundation in swampy terrain and a loaded truck or bulldozer would probably sink. In addition, swamps contain large amounts of organic matter which degrade continuously and lead to uneven soil surfaces.

Normally three conditions force the forest manager to cross a swamp:

(a) Major savings in distance and road construction costs:

It is possible in some instances to achieve much shorter road distances by crossing a swamp and cutting back on road construction costs. In this situation, one needs to weigh the *economic and social* cost of crossing the swamp as against the additional distance required to go around the swamp.

(b) Very high commercial stocking on the far side of the swamp

Where very high commercial volumes exist on the far side of a swamp, and the swamp crossing represents the shortest way to get such volume, it is clearly worth the while to cross the swamp because the volume to be sourced will justify the cost of crossing the swamp.

(c) The width of the swamp

The distance to be covered across the swamp is also a major consideration. Distances more than 100m could prove very challenging and safety considerations for loaded vehicles become a critical factor.

### 7.3 Methods of crossing swamps

There are three common methods usually employed to cross swamps. The status of the road, terms of long term use is a major consideration in selecting the option

#### (a) A bedding of logs and earth

The logger simply puts logs perpendicular to the road alignment and keeps adding logs until the desired level of the road is reached. Earth is then placed on the logs and compacted (see Figure 21).

This method requires a great deal of maintenance because the base of the structure is water logged and the earth keeps settling as logs sink and shift from time to time.

This option is suitable for a secondary road or a road that will not be used more than two years.



Figure 21: Illustration of road construction works across a swamp

#### (b) A multi-span bridge

In this case, a bridge consisting of several spans is constructed. This is normally a very reliable way crossing a swamp once care is taken to bind the logs properly with steel pins or wire-rope. Most local loggers use this method.

#### (c) Filling out the swamp

In this method, the organic matter and slush along the section of swamp along the road alignment is excavated and in its place sand or gravel is placed and compacted over a period of several months in the dry season. This method is very expensive and maintenance costs are high; and should only be used during for permanent roads.

## **Module 8: Recommended Road Safety Practices**

The golden rule for logging trucks is to ensure that the logging truck is seen from a distance, by day or by night. Heavy emphasis on visibility includes:

- a) Shocking colours-where the vehicle cab has a hot white, yellow or brick red colour so that it can be easily seen against the forest background
- b) Use of a rotating amber light on top of the cab (see Figure 22)



Figure 22: Typical logging truck with rotating amber lights  
*(Note the powerful horns and very visible colours - white top of cab, red bonnet and doors, silver bumper).*

- c) Travel with the headlights on all the time when in the forest; fog lamps for misty conditions
- d) Use of powerful horns

Other useful practices include

- a) All trucks should be equipped with radios
- b) Carrying large rear view mirrors as far as practicable
- c) Carrying fire extinguishers at all times
- d) All vehicles should carry safety Triangles (see Figure 23) to be used if they must stop ; the triangle should be placed at least 50 meters to the front and to the back of the truck
- e) All vehicles should carry logging rigs and appropriate tools for binding logs in place and to permit towing
- f) All vehicles should carry a first aid kit
- g) Drivers should be duly licensed to operate the specific category of machine being driven.
- h) Drivers should ensure that they eat adequately in line with the exertions required to drive a heavy-duty truck.

## REFERENCES

- a) Guyana Forestry Commission. 2002. *Code of Practice for Timber Harvesting. 2<sup>nd</sup> Ed.*
- b) Haussmann, Richard F. 1960. *Permanent Logging Roads for Better Woodlot Management.* Forest Service, USDA. 38p
- c) ILO. 1998. *Safety and Health in Forestry Work. An ILO Code of Practice.* International Labour Office. Geneva. Switzerland. 186p.
- d) Keller, Gordon & Sherar, James: 2003. *Low-volume Roads Engineering. Best Management Practices. Field Guide.* USDA. 158pp
- e) Klassen, A. Hasibullah, Ekaroza, M: 2006. *Planning, Location, Survey, Construction & Maintenance for Low-impact Forest Roads.* Tropical Forest Foundation, Indonesia. 69pp
- f) Kramer, Brian W. 2001. *Forest Road Contracting, Construction, and Maintenance for Small Forest Woodland Owners 35.* Forest Research Laboratory. Oregon State University. 80p.
- g) Walbridge Jnr., T.A. 1997: *The Location of Forest Roads.* Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 91p.
- h) Van der Hout, Peter. 1999. *Reduced Impact Logging in the Tropical Rain Forest of Guyana, Ecological, Economic and Silvicultural Consequences.* Tropenbos Series 6. Tropenbos-Guyana programme. Wageningen, The Netherlands. 335p.
- i) Vieira, Vivian, 1980: *Logging in Guyana and Considerations for Improvement.* Guyana Forestry Commission. Guyana.

## *Annex 1: Selected Notes (from Unasyva No. 70).*

### **Forest harvesting roads: meeting operational, social and environmental needs with efficiency and economy - C.H. Wells\***

\* Forestman & Associates Pty Ltd, P.O. Box 104, Samford 4520 Australia, Tel/Fax: ++(61 7) 3289 4245, E-mail: forwells@ozemail.com.au

#### **INTRODUCTION**

The planning and construction of forest harvesting roads is a major and expensive operation that is critical to the orderly flow of logs. In tropical environments, road development has to contend with difficult terrain and high and protracted rainfall. Traditionally, logging roads have tended to use high-impact construction methods featuring wide clearing widths, major earthworks and relatively crude construction standards. The justification for such practices has commonly been on the basis of economic and operational needs. Poorly located, constructed or maintained roads are inefficient and can cause major soil and water hazards with serious and long-term social implications to affected communities, which may be distant from the site of the actual road.

Codes of practice have aimed at setting basic standards to reduce these adverse impacts whilst still meeting operational and other needs. Such new standards are often opposed by the timber industry as being impractical and uneconomic. Experience in code development in tropical Australia and a review of harvesting practices in the South Pacific suggests that proper road construction, sound environmental management, beneficial social outcomes and operational economics need not necessarily conflict. With few exceptions, good practices can achieve production, social and environmental management needs economically.

While acknowledging the many examples of good roading practice, this paper concentrates on the problems that can occur and offers some basic, but key points that are considered fundamental to making forest harvesting roads effective, economic and environmentally responsible for all parties concerned.

#### **THE ROADING CHALLENGE**

The objective of forest roading is to provide a road network that achieves economic production whilst meeting environmental and social needs. Essential considerations are:

1) *Production needs:* The primary purpose is to provide a road network of a standard and density that guarantees operational access and the timely and economic delivery of the required volume of wood. Access requirement is relatively short term. Economics must consider both the direct costs of planning and constructing an optimum network as well as the indirect costs and production ramifications caused by impassable roads, slow haul speeds, accidents, vehicle damage and landowner disputes. Industry must address the total road economics.

2) *Social needs:* Logging roads may be required for other purposes well after logging has ceased. Forest services may require access for silvicultural operations. Governments and communities seek road infrastructure to serve the access and development needs of an area. The need is usually long term and may be at odds with harvesting requirements and logging road development.

- Landowners may obstruct or prevent roading for personal, cultural or financial reasons.
- Community demand for roads may be without essential planning and have unreasonable expectations as to the road standard, particularly bridges that can be afforded by the industry. The logging roads may not be appropriate to community needs and cause social problems and undesirable development.
- The community may have no capacity, skills or intent to provide essential and ongoing road maintenance.

Despite this, community approval is often essential to the continuous and uninterrupted use of roads for logging.

3) *Environmental needs:* Rooding can be a major and ongoing cause of adverse environmental impact. Impacts such as over clearing, visual scarring and accelerated land instability can have serious social and forest-sustainability ramifications. The primary problem tends to be soil loss and watercourse sedimentation. Roads and tracks are the sources of major sedimentation of watercourses with direct and ongoing impacts on community water supply and aquatic habitats. Environmental needs must be identified and then managed to avoid damage. Environmental concerns need to be addressed if logging is to remain acceptable.

The optimum forest road has to balance these needs and constraints in a way that is economic for the timber industry. This requires effective and economic planning, construction and maintenance of roads.

## ROAD ECONOMICS

**Key: If you do not know the real costs you cannot determine if you are economic**

The costs and economics of road development and use are of primary importance to the overall economics of a logging operation. Various figures are often quoted for different standards of roads but unless the nature of the road and the basis for the figures are known, these costs have little meaning.

During a review of logging standards in the South Pacific, logging managers appeared rather vague on the question of roading costs. This may have been corporate policy - not to reveal costs. However, it is suspected that many simply do not have the accounting procedures to determine the real costs of roading (or indeed any other element of harvesting) other than an overall operational cost per cubic meter. Further, observation of the often considerable range of equipment standing idle and the apparent inefficient organization and operation of equipment suggests that there are likely to be significant savings if the inefficiencies could be clearly identified and corrected.

If you do not know the actual costs (direct and indirect) of each component of road planning, construction and use, there is no way to determine:

- if you have an optimum economic outcome;
- where to concentrate supervision or resources to achieve further economies; or
- whether acquisition of equipment or adoption of different construction methods is viable.

Too often, suggestions for improvement (e.g. compaction) are rejected on the basis that it will cost more. The matter can only be evaluated by analyzing whether the investment achieves greater savings in direct or indirect costs in road construction or use.

Several points may be relevant:

1) The costs of roading must consider all elements. This will require that companies have appropriate accounting practices. Various texts can provide guidance on cost calculation to include all essential aspects and permit proper analysis and management of roading. Such procedures can be complicated. An alternative is to conduct studies on specific components to derive a reasonable cost estimate that can guide management.

2) Costs increase dramatically with road standards. Costs per kilometer quoted for major roads tend to be double those of minor roads. Conversely minimal-standard haul roads are relatively cheap. Clearly a properly designed road network, with each standard of road used in its appropriate place, will reduce and optimize total costs.

3) Rooding costs do not only relate to the direct costs of labour, equipment and material used in construction and maintenance but also to:

- cost and production impact of delays caused by road failures or impassability;
- cost and production impact of haulage over the current road standard; and
- cost and production impact of truck damage, repair and unavailability.

These indirect costs can be substantial and need to be factored into decisions on road standards, construction methods and maintenance intensity.

## PLANNING FOR EFFECTIVE, ECONOMIC AND ENVIRONMENTALLY RESPONSIBLE ROADS

### **Key: Time spent on effective planning can be an economic advantage**

The initiation and ongoing development of a logging operation has to contend with pressure for early and continuous production. This imperative may be at odds with the time needed to plan effectively. There is a common tendency to build with limited planning. Planning requires good survey and mapping information. Unfortunately, adequate maps may not be available. Aerial photography or inspection can be particularly useful but require training and interpretation. Global positioning system approaches can be useful for ground surveys, but require training and equipment. Time and resources spent surveying and planning should be weighed against the costs and problems caused by inadequate planning:

- Road alignments that are unworkable because the full length and practicality were not surveyed and roads had to be realigned or relocated.
- Tortuous alignments increase road lengths and incur an ongoing production penalty in haulage time and cost.
- Alignments that involve excessive side-cutting or watercourse crossings at great cost.
- Undesirable grades that limit use, compromise safety and results in vehicle damage and production penalties.
- Roads that do not tap the best resources and require long skid distances.
- Landowner disputes or road use disruption because of conflicts over social or cultural issues.

Planning, or the lack of it, sets the economic base of road construction, use and maintenance. Time spent in effective planning can result in substantial and enduring rewards.

### **Key: Planning should provide an effective and economic network**

The road system should involve an appropriate network of major, minor and haul roads of progressively decreasing width and standard to achieve the production needs with minimum total cost and environmental impact. Because costs and impacts tend to increase with both road standard and density, total efficiency will depend on optimal planning to meet the need with the minimum necessary infrastructure with overall economy.

**Road standards:** Codes of practice generally specify basic road design standards. The standard of the road at a particular point should reflect its purpose, life and design capacity in terms of volume and haulage speed. Observations in the South Pacific reveal that road standards, particularly for minor and haul roads, tend to be excessive in width and the extent of earthworks. Unnecessarily wide clearings for roads are more expensive, take longer to construct and have a greater environmental impact. It is suggested that while major haul roads should not be under built, greater use can be made of cheap and low-impact haul roads. Several elements are worthy of consideration:

- **Road classification:** This must have practical meaning and guide industry as to the required minimum road standards at a particular point. In the Asian-Pacific region, volume per week is used but this can be difficult to predetermine. The classification system must relate to need and it may be more meaningful to express this in terms of total volume, which is easily calculated prior to logging. If this approach is used then the point at which haul roads should become minor and then major roads can be simply



determined by both industry and the forest services. The question of classification needs closer analysis and specification.

- *Belief in haul road capability:* Where there has been a tradition of wide roads there can be great concern as to the practicality of the minimum standard of a haul road. Experience in Australia under conditions equivalent to most tropical situations demonstrated that haul roads with very narrow clearing widths and minimal formation can operate effectively and economically if appropriately managed and used.
- *Clearing width:* Clearing width should be kept to a minimum needed to construct the road construction, permit surface drying and provide sight lines. There is a common belief that road clearings must be very wide to permit sun drying. Road surfaces need exposure to sunlight. However, the width required to effectively achieve this can be quite narrow due to the high angle of the sun in the tropics. Some standards specify a permitted maximum width. Under this regime, logging companies tend to automatically clear the full permitted distance. The *Code of Practice for Forest Harvesting in Asia-Pacific* standard of one meter beyond the earthworks is more realistic (FAO, 1999).
- *Extent of earthworks:* It is common in the lesser elements of the road network to see excessive earthworks and lowering of the road into the terrain. Apparently this is caused by road builders cutting down to find a hard surface. This is time consuming and costly, complicates drainage and eliminates the possibility of re-growth of trees after logging. Given the limited use and life of such roads, it may be preferable to minimize excavation and utilize compaction to achieve a load-bearing surface.

**Roading density:** The issue of roading density relates to the spacing of minor and particularly haul roads. Whilst the subject of many texts, the planning of an optimum road density can be both complicated and difficult. The objective is a density/spacing that results in the lowest combined cost of roading and skidding. The basic considerations are terrain, volume per hectare and relative roading and skidding costs. If loggers do not know these costs, there is no way that an appropriate density can be planned. The cost of excessive or inadequate road density can be significant in terms of production costs and time.

Road standards and density should be the minimum necessary to meet needs economically.

#### **Key: Planning integration with logging needs**

Planning and road construction must meet the logging needs and be timely. Firstly, it is not uncommon to see roads and landings constructed, often with extensive earthworks, and then remaining unused, with the road becoming a massive skid trail. There may be weather-related reasons for this but clearly the time, costs and impacts of such works are considerable. The plan must meet the operational need.

Secondly, planning and road construction must be sufficiently advanced and ahead of logging to avoid haulage on unfinished roads. Poor planning, operational pressures and weather can result in haulage being attempted on unfinished sections of roads. This is not only difficult because of bogging and the need to tow trucks through the area; it can also have secondary adverse implications for skidding and loading with undesirable landings and skid trails being developed to overcome the problem of the unfinished road. Roading must be ahead of the needs, and planning should provide areas that can be worked in wet weather or where roading is delayed. Smashing through roads to meet the production target may yield the logs but can be hugely expensive because of low productivity, damage to roads and equipment, safety and the environment.

### **CONSTRUCTING EFFECTIVE, ECONOMIC AND ENVIRONMENTALLY RESPONSIBLE ROADS**

#### **Key: Construction to achieve the fundamentals of effective roading**

The engineering principles of road construction are well known. While forest roads cannot generally afford the detail, finesse and cost applied to public road engineering, they must at least achieve the fundamental requirements for a successful road pavement. Basically any soil can support any load provided it is compacted (to achieve strength) and it is kept dry (to prevent water entering the road and weakening it). A forest road must have a good foundation and a water-resistant or shedding surface. Unless a road achieves these two factors adequately, it will fail. An effective road will (i) be constructed from the base upward in layers that provide a good foundation and (ii) be provided with an effective surface. Too often, due to pressure to provide access, the forest road

builder ignores these fundamentals and attempts to solve the lack of load bearing capacity by excessive clearing, sun drying and gravelling. If the road is not delivering the production because of bogging or other failures, the chances are the fundamentals have been overlooked. In the long term this is poor economics that stops or delays production reduces travel speeds, damages trucks and ultimately costs more than good construction.

*Compaction* will improve almost any soil by increasing road strength and providing a smooth and strong running surface. Compaction of the subgrade and base course is essential if the road is to carry the design load without failure that will result in production inefficiencies, delays and costs. The subgrade should be compacted and fill material placed in layers and compacted by an appropriate number of machine passes. Effective formation and compaction will require the use of less gravel material with significant savings in the cost of extracting, carrying and spreading gravel. Compaction of the surface is equally, if not more, important than compaction of the subsurface. Surface compaction creates a strong pavement that can carry and distribute wheel loads over a greater area. Additionally, optimum compaction tends to seal the surface, limiting or preventing water entry. This has the advantage of:

- a smoother running surface permitting higher speeds and reducing vehicle damage; and
- less surface erosion (increasing road life and reducing maintenance costs), dust formation and sediment production.

Consolidation by leaving the road surface to settle over a period of time is a poor substitute for compaction. It is strongly suggested that effective compaction is worth the cost.

*Road drainage* must protect the road from surface and groundwater. Water entering the pavement or subgrade weakens the structure making it more susceptible to failure. Road drainage is fundamental to road life and effectiveness and two basic elements are involved:

1) Surface drainage should drain road surface water and divert this and other water from adjacent areas away from the road formation. First, surface drainage is provided by shaping and compacting the road profile to shed water in either a crowned, outsloped or insloped formation. The crossfall should be in the 4 to 6 percent range to shed water without making driving difficult or dangerous. The correct profile established in construction should be maintained by grading and recompaction. Second, a system of table, turnout and cross-drains should direct water away from the road area.

2) Subsurface drainage protects the road against water that has entered through the road surface and subsurface water that enters from surrounding areas or the water table. The objective is to prevent the road from becoming saturated in a zone between the surface and a level approximately one metre below the surface. This is achieved by surface drainage, compaction of the subgrade and pavement, and drainage or road elevation to keep the road above the level of the local water table.

Failure to provide effective drainage will result in:

- loss of the road through wash out or slumping resulting in road closure;
- failure of the road pavement, affecting production and production economics;
- erosion of the pavement with increasing surface roughness and need for resurfacing; and
- high soil loss leading to stream sedimentation and serious environmental impacts.

Lack of effective road drainage is a major problem. Primary issues are:

- lack of compaction;
- lack of effective surface profiling and the continuing maintenance of this profile;
- inadequate depth and capacity of table drains;
- inadequate turnout of table-drain water;
- inadequate number and size of cross-drainage and structures;
- improper grading practices with water not being drained from the road surface;

- inadequate maintenance of drainage systems;
- blading off the road surface because of poor construction; and
- lack of fill-protection or sediment-trapping systems.

The generally inadequate provision of cross-drainage is a major concern. Culverts and pipe cross-drains are expensive and time consuming to construct. Rollover water bars and inverts can be a simple and inexpensive alternative in some cases.

There is ample advice in the literature on the design and construction of effective and appropriate drainage and sediment trapping devices.

The combination of effective compaction and good drainage will result in an effective road. Conversely, inadequate compaction or drainage will, at minimum, cause inefficiencies and, in many cases, road failure. It is all too common to see road surfaces being bladed off to make them workable. This is not only expensive, but is a short-term measure that removes the road pavement and destroys the drainage system with disastrous environmental outcomes. It is also a certain sign that engineering fundamentals have not been achieved.

**Key: Culverts and crossings need care**

The construction of culverts and crossings is one area where codes require industry to undertake additional work for very important and sound environmental reasons. Watercourse crossings are locations where road construction can cause significant damage and sedimentation of streams. Important factors are:

- Sites for crossings should be excluded from initial alignment clearing and disturbance to avoid soil being bared and debris being pushed into the watercourse.
- Crossings should be planned and set out to preserve vegetation, except on the actual crossing alignment. Clearing should be confined within this area.
- Culverts and crossings are best constructed with an excavator because it is almost impossible for the work to be done by bulldozer without excessive disturbance. Excavators can easily complete all operations without entering the watercourse.

**Key: Gravel is expensive and gravelling should be managed**

Gravelling is an expensive operation and gravel may not be available, or may be of poor quality.

- The use of gravel should be based on need and relate to road standard and design life. Gravelling should be avoided on temporary roads.
- Effective compaction and formation may reduce the need for gravelling. Gravel may not fix the problems caused by poor compaction and formation.
- Forest roads cannot afford detailed analysis of gravel requirements and the sizing and mixture of gravel materials applied to public roads. However, some attention to these factors can yield benefits:

1) Size material: Firstly, the minimum gravel depth should be about 1.5 times the size of the largest particle. The use of unscreened materials can require greater volumes. Secondly, it is common to see unscreened material being hauled considerable distances only to be dumped and the larger materials graded off the road. Quite simple screens can be erected at the gravel extraction site to roughly size material. The appropriate size can then be dispatched to the appropriate course. Bottom courses can use large materials whereas surface layers should use finer materials to achieve a smooth running surface. Even simple screening can result in significant savings, avoid wastage and achieve an improved road surface.

2) Formations should be smoothed prior to gravelling to reduce wastage caused by having to fill irregular surfaces.

3) Compaction should be used to consolidate the gravel and increase its effective life.

**Key: Construction must be planned and actively supervised by competent people**

Road construction is a complicated and staged process that requires all phases to be achieved in an integrated fashion with minimum works if the road is to be built at the least cost possible. Unfortunately, road construction is commonly not supervised effectively, resulting in:

- slow, ineffective and uneconomic construction;
- excessive clearing, earthworks and wastage of valuable fill material; and
- unnecessary and excessive environmental damage.

Unless effective supervision is applied, an effective and economic road will not result. Effective supervision requires that the supervisor:

- knows the roading plan and the logging priority;
- understands road construction and the management of machinery;
- sets out the centre line and the boundary of clearing, earthworks and exclusion areas;
- manages the orderly and economic progression of each phase of construction;
- matches equipment and resources to tasks and operational needs;
- ensures that operators know what is required and are aware of problems;
- actively supervises and directs operations; and
- concentrates efforts in priority areas.

Responsible environmental management must be applied throughout the construction phase. Damage must be avoided as repair is usually difficult, costly, impractical or simply not done. Supervision must be aware of, and avoid, works that pose environmental threats.

**Key: Equipment must be appropriate**

Ideally road construction should have a range of equipment available so that each task can be achieved in the most efficient way. Equipment is expensive. For small operations or companies, the capital cost of acquiring bulldozers, graders, compactors and excavators may appear to be prohibitive. However, using bulldozers only for construction is inefficient. Larger companies have a greater capacity to utilize appropriate equipment with savings in earth movement, drainage, formation and gravelling.

- Bulldozers remain the major multi-purpose tools for clearing and earthworks. The type of bulldozer used should be matched to the clearing and earthmoving needs. While bulldozers can do many tasks, they may not necessarily perform these efficiently and it may be more economic to invest in purpose-built machines (e.g. graders for formation) than continue using bulldozers.
- Excavators are very versatile and effective construction equipment with significant advantages over bulldozers for excavation and placement of earth, battering of slopes and particularly for the construction of watercourse crossings and culverts. This efficiency tends to increase as conditions become more difficult (e.g. waterlogged). Their use is strongly recommended.
- Graders can spread material and form road surfaces to a high standard and most efficiently without the waste, inefficiency and poor standards resulting from the use of bulldozers.
- Compactors, whether towed or self-propelled, are important tools and their effective use can result in significantly improved standards and overall and long-term savings. Compactors should be matched to the soil type. Steel vibratory drum rollers are the most common. Other machinery including graders, loaders and trucks can assist in compaction, but this requires that the equipment varies the running track to compact the entire road surface. However, in general, this cannot match purpose-built compactors because ground pressures are much lower and the compaction is uneven. Compactors must be used properly, rolling the earth progressively from the edge to the centre of crowned roads with correct

engagement and disengagement of the vibratory mechanism to achieve a uniformly strong and smooth surface.

- Trucks and scrapers: Where soil movement distances are short (i.e. less than 50 metres), bulldozers will perform quite effectively. As distances become longer, bulldozer use becomes increasingly slower, uneconomic and wasteful in terms of lost materials. Trucks and scrapers become more economic with distance.

**Key: People must be trained and managed**

The effectiveness and economics of road construction are highly dependent on the skill and attitudes of the people involved.

- *Forest service staff* should inspect, identify problems and positively contribute to road construction. They cannot do this unless they have a practical understanding and experience of road construction and equipment management. It is not uncommon for forest officers to avoid inspection because they do not know the process or criticize without being able to provide answers. Training is generally needed and forest officers should have the knowledge to intervene in a situation before it becomes a problem. The industry has the right to expect that the forest officers are experienced and can provide helpful and productive suggestions. Forest officers must have the skills to be able to assess plans and evaluate road-construction operations.
- *Operators* must be trained, skilled and experienced in machine operation and construction and maintenance techniques. Essential elements are:

- 1) The operator must be trained in correct techniques. This may take time.
- 2) The operator must be given the time to practice and gain experience so that new skills can be applied with economic speed.
- 3) The operator must have incentives to encourage application of best practices. Incentives may be in the form of financial reward, security of employment or prestige.
- 4) Operators with good skills should be encouraged by seeking their advice and by allowing them to operate without unwarranted and demeaning supervision.

Training will only be effective where there is a corporate employment policy that seeks and values a core of skilled operators. Too often the operator is regarded as expendable and easily replaced. Such attitudes do not result in good operation and can prove to be expensive in the long term.

Investment in skills training can achieve:

- improved efficiency;
- safety;
- reduced machine damage and increased machine life;
- better and more effective roads with gains to haulage productivity; and
- reduced impact.

**USE AND MAINTENANCE: KEEPING ROADS EFFECTIVE**

Roads must be used and maintained in a way that preserves their lives and efficiency.

**Key: Roads should be used wisely**

There are times when roads should not be used. Under wet conditions, any attempt to haul timber may be counterproductive. Under these conditions the road is most sensitive to damage:

- Production will be slow, unsafe and counterproductive in terms of road and vehicle damage. Industry must provide for wet weather areas and log stockpiling to overcome these events.
- Use of the road will provide the highest threat of soil loss and stream sedimentation. Continued use with increased rutting will only worsen the situation.

The *Code of Practice for Forest Harvesting in Asia-Pacific* provides operational restrictions for felling, skidding and road construction but provides no guidelines for haulage. This oversight may need correction.

**Key: Maintenance must be applied and effective**

It is all too common to see a well-aligned and constructed road become ineffective, if not impassable, because maintenance has not been applied or is applied properly. Road systems must be maintained to ensure their efficiency and keep drainage and sediment control systems operative.

Proper maintenance requires a concerted inspection program with regular checks of drainage systems and early correction of faults.

Maintenance should be applied on both a preventative and demand basis. Proper road use requires a pro-active maintenance program based upon timely inspection of road conditions. Such checking should not only guide maintenance but should also be part of a learning process to analyze and correct failures. A supervisor should be responsible for regular inspections of road surfaces and drainage systems to identify wear, and plan for repair. Timely maintenance can save costly repairs and avoid inefficiency in the road system. The objective of effective maintenance is to maintain the efficiency and life of the road by:

- maintaining a good riding surface;
- maintaining effective surface and subsurface drainage; and
- correcting safety hazards to vehicular traffic.

A good operating surface will improve haulage speeds and reduce vehicle damage. It requires effective surface grading to smooth ruts and compact the surface to enhance the life of the grading. Drainage maintenance requires the surface profile to be restored as well as the table, turnout and cross-drains. Water must be able to freely drain from the road surface and then be managed in the side-drainage system.

While surface smoothing is usually done well, often little attention is given to the restoration of drainage systems. Common problems are:

- Grading material from the road to the sides instead of returning material to the road.
- Not using compaction with grading with the result that re-profiling has only short-term benefits and surface loss is increased.
- Surface grading creates a rill along the road edge and prevents surface water from entering the side drains.
- Not removing road edge vegetation, which stops free surface drainage and confines water to the road.
- Not reopening table, turnout and cross-drains.

Grading demands knowledge of the objectives, timing, skills and correct techniques in application. Good grading is more than just temporarily smoothing the surface.

**ASSESSMENT**

Road systems should be subject to practical forms of assessment of effectiveness and environmental management deficiencies:

- Cost assessment needs to cover total costs of skidding and haulage, in addition to the direct road construction and maintenance.
- Environmental effectiveness can be assessed via audits or monitoring programs. The Queensland Department of Natural Resources in Australia has developed auditing procedures and practices for their *Native Forest Timber Production Code of Practice*. Alternatively, or in addition, forest officers should utilize indicator-type monitoring systems soundly. Provided these are well designed and used cooperatively and positively, they can be useful tools for both government and industry. The aim is to identify and correct problems.

## FINAL COMMENTS

*The need to get smart:* Industry can react to the imposition of new standards in one of two ways. Firstly, it can fight, object and resist. This is rarely sensible or productive unless the standard is in error. The alternative is to accept and try to meet the standard. In Queensland, the introduction of a code was strongly opposed as being uneconomic. Two years later, the objections had disappeared. Industry quickly realized the value of the techniques and avoided problems or the need for corrective work - all parties gained.

*Seeing is believing:* Calls to change the *modus operandi* are often opposed because there is little or no experience in implementing new practices and there is disbelief in their effectiveness. There can be great value in visiting conforming operations and seeing how they work. Often lack of understanding or experience results in an enormous waste of effort as people "reinvent the wheel".

## RECOMMENDATIONS

Given the costs, economic consequences and potential environmental problems associated with poor roads, there may be value in:

- *Collating road construction and management information.* There are many appropriate texts, manuals and guidelines that can provide practical and relevant information on road construction. Preparation and publication of a list of useful information would be useful.
  - *Training programs* should be developed for roading supervisors, forest officers and operators to achieve similar benefits obtained from chainsaw and logging machine operator training. This should involve hands-on experience in equipment management and construction techniques. Development of road training is not a trivial matter given the need for access to land and equipment. Given the cost, such training may be best conducted on a regional basis.
-

**Annex II: Useful Notes on Equipment (taken from Unasylya-No. 69: Forest Roads in the Tropics II)****CHOICE OF EQUIPMENT**

Though not numerous, the essential machines and equipment for construction and maintenance work on forest roads are generally very powerful and expensive units and usually operated under very difficult conditions. In addition, they may have to be entrusted to half-fledged operators who are training while on the job. Maintenance of machines cannot always reach the standard laid down by the maker. For all these reasons the choice of equipment is nearly always a difficult problem for the chief overseer. There are two aspects to consider: deciding what to buy, and establishing a standard base depot.

***Deciding what to buy***

First, the two different aspects should be considered as one whole. In practice, special conditions obviously simplify the problem as they reduce the number of possible solutions.

It is useless to expect machines to perform work for which they were not made. Mechanical equipment just does not exist which can be adapted to all purposes. Mechanical construction tends to different solutions, but the models which are made are only a compromise between several exigencies which may be contradictory.

Thus equipment can be considered from the following points of view:

- (a) more or less compulsory periodic maintenance,
- (b) ease of dismantling in view of repairs,
- (c) operation by semi-skilled personnel,
- (d) strength of the wearing parts.

Forest exploitation depots are often isolated and have to rely on their own means of maintenance and mechanical repairs. This consideration leads to the choice, even at greater cost, of equipment which has a reserve of weight or of power, rather than of machines which would be made to work with no reserve of power.

When the equipment, say a tractor-grader, has many types or models, the exploiter must always consider the uniformity of his equipment; this consideration leads him to buy tractors of the same type and the same power. It is better to buy three tractors of 100 horsepower rather than one of 60, one of 100 and one of 140 horsepower. Repairs will be easier to carry out by a staff better acquainted with the equipment; spare parts will be more plentiful and eventually the machines can be cannibalized.

Mechanical breakdowns are inevitable, especially under working conditions which are often rough, as is the case with forest exploitation. Recourse to after-sales service is an almost daily occurrence. The assurance of efficient after-sales service for any given equipment is a very important consideration.

With regard to operating and maintenance staff it is often difficult to engage the services of competent men with knowledge and experience of all makes of equipment. When an exploiter employs a man really used to a certain make it is practically certain that this man will get the best results from the equipment he knows. This consideration can be of great importance in deciding whether to buy this or that machine.

***Constitution of a standard base depot***

***Tractor-grader.*** When the size of the depot warrants it, the basic indispensable item of equipment is the tractor-grader. This machine must be equipped as an angle dozer and have a rear-mounted forest winch. Owing to the working conditions in the forest, the tractor should have the necessary protective parts: a reinforced cabin to protect the operator and plates to protect the radiator and the gear casing.



In Sections 4 and 5 it was shown that felling and earthworks are carried out with this particular type of equipment. Generally the most suitable are tractors of medium power. This power must be chosen in relation to the forest to be exploited and to the size of the depot. It must not be forgotten that the tractor which is to build the road will work by itself and not as one of a number of other machines, as on public works. The same tractor could be used afterward for unloading, which requires less power but more maneuverability. The need for uniformity in the depot must be taken into consideration.

An annual program of road building, conforming to the specifications in Section 1, of from 8 to 10 kilometers of main road, can be insured by one angledozer tractor of 120/140 nominal horsepower operated by a trained man. This observation is based on 1,500 hours operating a year and 100 to 200 hours per kilometer of road already stumped and with the earthworks finished. These figures are only given as an indication: natural conditions are so variable that they preclude any more precise information.

**Other equipment.** A towed **rubber tired roller** of less than 10 tons with ballast is perfectly suitable for the compaction of embankments and the carriageway. Only a very large depot would need a sheeps' foot roller.

A **self-propelling grader** of average or low power would give the best service. In a small depot, a towed grader is more economical.

A **rubber-tired agricultural tractor of 40 to 60 horsepower** is necessary for towing the rubber-tired roller, the towed grader and the mobile workshop. This tractor should, if possible, have a 4-wheel drive and be fitted with a scoop bucket for loading the maintenance material (gravel or unsorted laterite) for the road.

One or two **dump trucks** of a standard make (2 to 3 cubic meters) are indispensable for the transport of improvement material.

A **towed scraper** could prove very useful when a large depot is situated in an area of uneven ground where road works necessitate extensive earthworks.

Costly machines like powerful self-propelling graders, self-propelling scrapers, low loaders, are only suitable for a depot which is equipped with several tractors and where it is certain there is much work to be done.

Work connected with earthworks and road improvement can justify the purchase of a **low-powered crawler tractor of, say, 50 horsepower** easy to move on a 5-ton truck. Its transportation for a short job makes it unnecessary to move a large tractor on a special type of low loader.

The acquiring of useful if not indispensable equipment for stocking a depot envisages great expense. That is why a close relation exists between the size of the depot and the production from the area to be exploited, which makes the presence of this equipment justifiable and economic.

## MAINTENANCE OF EQUIPMENT

The success of every exploitation depot depends on the good condition and output of all the machinery. Each time a machine stops because of a breakdown, it paralyzes all or part of the depot where this machine is operating. To reduce these breakdowns to the minimum the operators and the mechanics and fitters should keep in mind the following principles, which are the fruits of experience gained in numerous depots.

1. The *maintenance* of equipment always pays at all levels. It is equally rewarding to the operator as to the foreman and again to the depot chief. To abuse equipment is to bring the depot to a hastened end.

2. Maintenance must be *preventive*. Regular maintenance reduces the length of time the machinery is out of use while repairing breakdowns. One hour daily devoted to maintenance can often avoid a repair which would take a whole day.

3. All maintenance and repair work should be entrusted to the *grade of staff* best able to do it, so that the immobilization of the machinery is reduced to a minimum.

4. The *instruction manual* on operating and maintenance, which is provided by the maker for every machine, is a precious document, which is compiled to be read and whose instructions must be followed. It is a guide to good treatment for obtaining the best results.

5. No maintenance or repairs are possible unless the workshop is stocked with *essential spare parts*.

#### ***Allocation of maintenance and repair work***

"From each according to his ability." This saying could govern the allocation of responsibility to various workers for maintenance and repair work. Thus daily maintenance should be done by the operator, running maintenance performed in the depot itself, minor repairs entrusted to the central workshop of the enterprise, while general repairs should be given to specialized workshops (outside).

*Daily maintenance.* It is incumbent on the operator himself to do the daily maintenance work, as follows:

- (a) fill the fuel tank, preferably every evening to avoid condensation in a half empty tank,
- (b) fill the radiator with water,
- (c) clean the fan blades,
- (d) top up the engine and gear box,
- (e) grease daily, preferably when the engine is warm,
- (f) test tire pressures,
- (g) test tension of tracks.

*Regular maintenance.* This corresponds to a service at a garage and is often entrusted to a peripatetic breakdown mechanic. Every day he visits the machinery which cannot return to the garage; if possible he is present when it starts up in the morning; he checks the fuel and oil consumption, supervises the daily maintenance, the tightness of bolts; he examines the state of the wearing parts: track rollers, bogey wheels, tractor tires; he checks the breakdown equipment.

Basically he has available hand tools and some consumable spare parts: filters, bolts. Whenever possible it is better to put a light trailer equipped as a greasing unit at his disposal, and eventually, an electric welding outfit.

*The central workshop.* This part of the enterprise carries out the minor repairs and the stationary workshop is therefore situated in the most convenient place, either in the principal depot, or in the geometrical center of several depots, or in an urban center so that the movement of machinery can take place under the best conditions. The workshop:

- (a) makes incidental repairs,
- (b) reconditions the various attachments or accessories,
- (c) carries out periodic overhauls,
- (d) is equipped with the necessary machine tools,
- (e) is the main spare-part shop.

According to the size of the undertaking, the central workshop will have sections or different sites for the following works:

- (a) place for washing, which is essential before any repair work,
- (b) repair bays, installed so as to have bays for machines or vehicles with independent entrances and exits,
- (c) special bays, eventually aiming to separate machines and vehicles,
- (d) provide a large bench in each bay for partial reassembly,
- (e) bay for stacking attachments and accessories,

- (f) bay for machine tools, with the tool store separated from the plant,
- (g) fixed or semi-fixed compressor with several points for cleaning or inflation,
- (h) electric generating plant, quite separate for safety,
- (i) forge, quite separate in case of fire,
- (j) store for spare parts with a special place or bay for each type of machine or vehicle,
- (k) special store for tires.

The **fuel depot** is placed at a lower level, or, failing that, separated from the workshop by a ditch and a bank to give protection. Men trained in repair work are set apart for the central workshop. Some repairs, for example the repair of tires, are carried out either by the mobile repair unit in the forest or the central repair workshop. This depends on the size of the depot, the capabilities of the personnel, the distance between the different sub-depots and communication facilities.

It is often possible to make use of the services of specialized workshops outside the forest- enterprise. This has the advantage of sparing the repair shop from having to do long and intricate repairs which can take up a large part of its time to the detriment of carrying out less important repairs, which is its proper function.

### ***Spare parts***

The regular stocking of spare parts is a major problem, which it is difficult to solve for two reasons. One is that the specialized makers are often in another country. The other is that machines working on forest exploitation or on road making undergo very rough usage which makes for a high consumption of spare parts. The customer can be guided in his choice of equipment by the quality of the after-sales service given by the maker: it is a proof of good performance. To maintain a spare-parts store stocked to satisfy all demands is a challenge requiring many qualities on the part of those in charge. Here are some concrete suggestions to help when ordering stocks:

1. Order in good time, taking into consideration delays in dispatch, so that the spare parts ordered may be available when are required and thus the machine need only be stopped for the time taken to effect the repair.
2. Describe the parts ordered; name them in accordance with the instruction manual and give the identification number.
3. Mention the type, model, number of engine to be repaired. For a part of an important mechanism, give also the type, model and number of the mechanism (motor, self-starter, etc.).
4. Mention complete details of the document on which order is based (title, date, edition, page).
5. Give precise instructions for dispatch: address of receiver, method of transport, packing, delivery date.
6. Draw up each order in such a way as to facilitate the task of the dispatch clerk, who may not be a mechanic and who has to deal with a large number of parts.

**Annex III: Additional Notes on Road maintenance (Taken from Unasyuva No. 69.)****Road Maintenance**

It has already been stated in Section 2 that forest roads suffer more damage the more frequent the traffic. There is a general tendency to use increasingly heavily laden logging trucks and to use these in the wet season as well as in the dry season. Thus maintenance works are becoming correspondingly more and more necessary and demanding. It is on good road maintenance that the regularity of forest transport depends.

The various types of deterioration will now be recapitulated and then the means by which they can be repaired will be discussed. In the preceding section maintenance work on drainage ditches has already been examined; this section will be confined to the work done on the carriageway itself.

**DETERIORATION OF ROADS ON NATURAL SOIL**

In practice the well-known results are:

1. the formation of corrugations,
2. the formation of ruts and ridges, more often found on single-track roads,
3. the loosening of gravel due to the tangential forces of the wheels of the vehicles,
4. the formation of transverse or longitudinal gullying,
5. the carrying away of fine clayey material by surface water from the carriageway toward the shoulders and the side ditches.

In Section 2 it was established that the cambered cross section given to the carriageway is intended to resist these deteriorations or, better still, to reduce them. The object of all maintenance is to maintain efficient drainage (see Section 8), and to maintain or renew the camber of the carriageway.

***Corrugations***

These are a phenomenon well known to all these who have traveled in tropical countries on earth roads. When they are made of lateritic earth or when the surface has been improved by a layer of gravel or un-graded laterite, forest roads are liable to corrugate in spite of the small amount of daily traffic and the moderate pace of the vehicles.

The term 'corrugation' is given to parallel ridges more or less at right angles to the road axis. The space between the crests is generally about 60 to 70 centimeters while the difference in height between crest and bottom of the next hollow is often about 4 to 5 centimeters. In order to pass over the corrugations and reduce the violent shaking to which vehicle and driver are subject when traveling over corrugations, it is better to attain a minimum speed so that the vehicle keeps to the crest of the corrugations. In this way, those parts of the vehicles which are suspended - wheels, springs and axles - never have time to follow the profile of the undulations and to go down from the crest to the next hollow. The difference in height increases with the number of passages and at the same time tamping by the wheels compacts the ridges of the undulations so that they gradually harden.

***Ruts and gullies***

On single-track roads, the wheels of vehicles nearly always use the same track. This repeated passage tends to compact the track used more intensely than the rest of the road and the wheels of the vehicles tend to pull the gravel out from the road surface and scatter it to the sides. These two combined create ruts in the tracks used by the wheels and make ridges on the edges of the ruts, which, in turn, impede the lateral run-off of rainwater toward the ditches and, by canalizing the rainwater, create gullies which damage the carriageway along the axis of the road.

On a perfectly regular cambered road, rain water runs off evenly in the form of a sheet of water. A stone, a tuft of grass, a slight hollow are in effect obstacles which lead to water collecting into a network of tiny rivulets; these rivulets cut small gullies and each time it rains these gullies are deepened by erosion.

During the rainy season every storm causes an intense washing of the roadway and the shoulders, and carries away to a greater or less degree the fine clay particles of the surface layers. These fine elements are the binder and make for the cohesion of the compacted layers of the road.

In the dry season the cohesion grows less and these fine particles are transformed into dust and the wheels push them off the road. Maintenance must be directed toward preventing their dispersal and bringing them back on to the carriageway by limiting the loss of material and by making a certain amount of re-compaction possible by the traffic itself.

## **MAINTENANCE EQUIPMENT**

Experience shows that the only possible solution nowadays is to suppress the corrugations before they become too troublesome. To do this maintenance should consist of lightly reshaping the surface to restore the camber. Whatever machine is used for this operation, it is essential to see that the material restored to the roadway is equal to that which was scattered toward the shoulders either by the traffic or by erosion. During reshaping material must be brought back on to the surface; the new profile must not be obtained by carving off a layer from the road and throwing up the material taken off in a ridge along the edge of the formation. The ideal solution is to eliminate the undulations as soon as they appear and before they have reached an uneven stage which is troublesome to traffic, and before they can harden.

There are two types of equipment used: either a motor grader which planes off the pronounced and hardened corrugations (a powerful and very expensive machine), or a locally made drag, which rubs down the growing ridges before they harden (a light cheap machine).

Recourse to the motor grader demands an experienced and very skilful operator, whose recruitment is often one more difficult problem to solve.

Light equipment like a drag may be used after the first shaping at the time of construction or after a general shaping with, if possible, the addition of gravel or un-graded material followed by compaction carried out a little before the end of the rainy season. If light equipment is used for maintenance its use must be very regular.

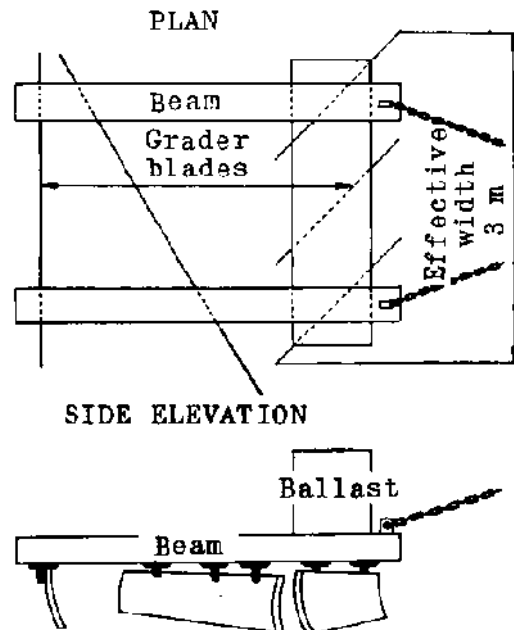
### ***Drags***

Technicians engaged in the struggle against corrugations have invented several types of tools and materials which are easy to make locally.

In Sudan and in west Africa a piece of equipment called Tolard No. 5 (Figure 45) has been increasingly used. Blades from a grader are fixed obliquely to a chassis of heavy beams. The chassis at the same time carries a box for ballast, which is used according to the results desired for each section of the road. The angle of the blades tends to roll back the material toward the center of the road.

In Ghana, drags developed by the Public Works Department have been used over the whole country since 1951. These drags are made of sections of salvaged railroad line 30 to 35 centimeters high, cut to a length of 3 meters. These iron rails, weighing between 270 and 310 kilograms are drawn along flat, so that the flanges plane off the irregularities on the carriageway. Concrete blocks can be placed between the rails to give these drags increased weight up to a total of about 540 kilograms (Figure 46).

FIGURE 45. - Plan and side elevation of the Tolard No. 5 drag.



#### *Use of drags*

The use of drags has been intensely studied, especial: in Ghana, where the following rules have been recommended:

- 1 On the first pass when the corrugations must be leveled more concrete blocks are used as ballast. During subsequent passes to prevent the development of new corrugations the drag is used without ballast. It is always possible to concentrate the blocks of concrete on the outer part of the drag to maintain or even improve the camber of the carriageway.
2. In order to remove corrugations which have appeared, the traction chains or cables are adjusted in such a way that the outside edge of the drag is ahead of the inside edge by a distance equal to about one and a half corrugations, i.e., about 1 meter. The drag thus slewed round deals with the ridges, and the loose material is moved toward the center of the road. In the case of subsequent passes intended for light maintenance, the angle should be decreased until the drag is perpendicular to the road.
3. In the rainy season, work should be undertaken only several hours after each storm has passed, so that the surface has time to dry again, and to avoid making a lot of mud.

It is understood that these drags wear out somewhat quickly, according to the nature of the roads that they "plane." Their useful life, whatever the type, is about four months on laterite roads; this corresponds to a treated length of about 3 to 5 kilometers It seems that they wear out more quickly in areas of coarse sand.

These various drags should be pulled by agricultural tractors of 30 to 40 horsepower or, if absolutely necessary, by dump trucks. The speed depends on the effective work accomplished. It varies from 6 kilometers per hour for a first leveling to 10 k.p.h. for regular light maintenance passes. When a lighter effect is required, it is better to reduce weight rather than increase speed.

The frequency of passes depends on the season, the type of soil and the amount of traffic, as it is known that corrugations appear more quickly as traffic becomes greater. On the other hand, when there is less traffic, it is better to act before the corrugations harden, as they do after an interval of two to three weeks.

On most forest roads, which are subject only to light traffic, a pass every week or fortnight is enough to maintain the desired standard. In all circumstances, the frequency of the work must be in relation to the local conditions of soil and traffic according to the season.

One of the inherent advantages of these various types of drags is their gentle treatment of earth roads. The planing causes a small loss of surface material which adds to the losses caused by traffic and erosion. It is essential to control to the maximum extent this wear on the carriageway and to bring back the loosened material, sand and gravel, to the road center instead of forming ridges along the sides near the ditches. It has already been seen that the repair of the shape of the road can be made easier by redistributing the road material; in this way ridges due to traffic are obliterated at the same time as the corrugations. In the rainy season the small lateral channels are filled in. On the shoulders, the growth of vegetation is controlled. All these result in maintaining or re-establishing the camber of the road and in assisting the run off in thin sheets which makes only slight channels in the carriageway and shoulders.

### ***Maintenance- graders***

A self-propelled grader or even a small towed grader is an excellent machine for regular maintenance work on earth roads or for the spreading of improvement layers of unsorted laterite. When maintenance work is in progress, it often happens that the grader's passes leave some material on the edge and speed up the wear on the road surface. It is a good thing, however, to bring back from the shoulders to the carriageway the fine particles washed away by erosion. Operators are rare who admit, in maintenance work, that the blade of their machine should only attack the crests of the corrugations or the lateral shoulders or ridges caused by the circulation of traffic. It is essential, however, that the blade does not cut anywhere into the compact and stable layers of the carriageway. It is well worth taking trouble over the recruiting and training of grader operators and the supervision of the work entrusted to them. Furthermore, maintenance work should only be carried out when it is really necessary and according to the planned frequency. Maintenance graders should therefore only leave the garage for a good reason and not just to grade for the sake of grading. A foreman is often obliged to use his equipment on work other than maintenance and construction.

In considering the use that can be made of low-powered self-propelling graders, it must not be forgotten that there are very much lighter towed graders on the market which can give comparable service. Besides, the workshops of forest exploiters can make simple drags quite cheaply by drawing inspiration from the ideas given above.

The use that can be made not only of maintenance graders, self-propelled or towed, but also of equipment like simple drags has already been discussed. The use of these drags, which is very economical, unquestionably avoids the untimely damage, often very serious, which an insufficiently experienced operator can cause to a carriageway which he is endeavoring to repair.

### ***Holes or potholes***

In some places hollows appear in the shape of wide-mouthed bowls which collect rain water. When the rest of the carriageway has dried and can be used by vehicles, the quantity of water collected in these hollows is too much to evaporate between two heavy showers. The wheels of passing vehicles cause the surface soil and water to mix in each hole; this encourages the water to penetrate deeply and all the area round the hole becomes plastic; the surface softens and deep ruts develop after the passage of a few vehicles.

Maintenance work should be undertaken as soon as possible after the appearance of the potholes to prevent the destruction of the carriageway. The first operation consists in drying out the pothole by a small furrow directed toward the nearest side ditch and dug down to the level of the bottom of the hole. Then, once the hole is quite dry, it is filled with material of comparable composition and hardness to the surface layers of the roadway around it, in order to reestablish as uniform a surface as possible.

It is useless to try to fill up a hole without drying it out first, as the water which stays in weakens the surface layers of the road and quickly destroys its strength.

When holes are filled with the help of stones or hard pieces of laterite, this hard material is in contact with the weakened surface layers which offer no resistance so that the harder pieces sink into the deeper layers of the road.

### **MAINTENANCE GANGS**

Maintenance work should always be carried out by specialized gangs permanently engaged in this occupation. Continuous maintenance by a small gang is always more economical than spasmodic work carried out by a larger gang at appreciable intervals. Damage to the road surface advances so rapidly that spasmodic maintenance comes too late and necessitates partial reconstruction rather than simple maintenance work.

It is a mistake to neglect the training of a gang of men specialized in maintenance work. This technical training is a simple matter as it is based mostly on the development of powers of observation and common sense.

Each specialized gang can be entrusted with a section of the road. Each gang is given regular work which is easy to carry out with hand tools: wheel barrow, shovel, pickax, rammer and ax. More important work is entrusted to a team which is responsible for the whole road system and uses mechanical and motorized equipment.

The different maintenance activities just examined are corrective measures applied to the damage which the road surfaces undergo. To obtain the best service from compacted earth roads, it must be stressed that nothing replaces strict discipline in haulage. Exploitation of forest produce can continue in the rainy season, for there is scarcely a month when there are not enough dry days to permit sufficient transport to cope with a fairly regular production despite the effect of the climate.



#### **Annex IV: Very useful notes on Timber Transport by truck, Tractor Trailer**

##### **Hauling by truck, and by tractor-trailer**

Log hauling by wheeled vehicles on roads naturally needs quite different mechanical equipment from that used for skidding. However, the recent great improvements in tropical logging methods has now combined the skidding and hauling operations into one continuous and direct transportation of logs from the tree stump to the mill. This revolution in logging methods began by the introduction of crawler and wheeled tractors. So far, this new method has not made as much progress in the tropics as in North America and in Europe, but eventually it will be generally accepted and the planning and construction of new hauling roads will have to be adapted to the future needs of high speed transportation of very big loads (Figure 43).

The alignment and construction of tropical hauling roads for modern transport have to comply with two important factors which determine the relative construction costs: the small marketable timber density in many of the proposed areas, and the short duration of seasons favorable to hauling operations. Dependent upon the volume of traffic to be carried, there will be a great difference between the main and feeder roads, and their methods of construction. Traffic and maintenance costs on earth or "dirt" roads will also depend upon the type of soil and the climate.

The average density of merchantable timber species in tropical countries varies between the limits of the highest density of one tree of 5 or 6 tons per hectare, such as okoumé in Gabon, to the lowest-known density of one tree of 6 to 10 tons per 16 hectares, such as mahogany on the Ivory Coast. Fortunately, the average density does not imply an even dispersion rate over the whole forest area, and logging is usually facilitated by finding small groups of marketable trees in certain parts of the forests.

Such widely scattered and difficult logging conditions have recently been improved by the increasing number of merchantable species now exploited in most tropical forests. In relation to such a larger volume of timber extracted, the costs per transported log are obviously lower and make possible the construction of better and more roads.

The duration of seasons favorable to hauling operations is another decisive factor when forest roads are to be constructed in the tropics. Some countries have definite rainy and dry seasons but, in others, dry spells may be interrupted by shorter or longer rains, reducing the time favorable for hauling to a few weeks per year. For example, in 1954, in the mountainous parts of central Paraguay, only 15 days could be used for hauling during the whole year. With a small log output it may be possible, by careful planning, to concentrate all the timber transport during the dry season or the dry spells. Wide lanes on both sides of the roads should be cleared of vegetation to permit quick drying out. Hard road surfaces permit heavier loads and a higher average speed, and also less wear of roads and vehicles. Driving is easier and general efficiency higher.

If the dry season is not long enough for hauling the entire volume of timber estimated, the planner has to consider the construction of all-weather roads, well built with a hard surface and low grades. The present trend of traffic needs in most tropical countries indicates the early construction of highways and super high ways, admitting loads of 40 to 50 tons, traveling at a speed of 80 to 90 kilometers per hour. In some countries of west Africa such highways already exist, in others they are under construction.

A suitable tractor for picking up a load in the forest and carrying it directly to the sawmill is the self-propelled, self-loading Tournahauler built by the Letourneau-Westinghouse Company. The present model can transport only 20 tons at a maximum speed of 40 kilometers per hour, but other tractors and semi-trailers which take loads of 30 tons are already operating in several tropical countries, with speeds limited only by local road conditions.

#### **CONSTRUCTION OF MAIN HAULING ROADS**

Tropical countries do not often have good public roads which can be used as main hauling roads in the forest areas, and the opening up of new logging operations is often limited or even prevented by the lack of suitable public highways. Local regulations for wet weather may stop all traffic as soon as the rain starts, and it may not be

resumed until the road has dried out to a degree decided by the road authority. Where no logging transport is permitted on public roads, the only alternative is obviously to build a main road for the whole length from the forest to the terminal station if the log volume and the log prices can support the construction costs, or to abandon the whole logging project. As only low-class roads are usual in the forests of underdeveloped countries, this often determines the size of the projected logging operation.

The choice of grades for main hauling roads depends on the danger of erosion by rainfall, on the loading capacity of the trucks and trailers in use, and to some extent on the desired transport speed.

A truck with a given traction power on level ground, at a given speed, will lose 25 percent of this power on a 10 percent slope, and 50 percent on a 20 percent grade.

If timber transportation in the tropics, traveling at 80 kilometers per hour and with maximum loads of 40 tons, is to depend upon public highways, it would be advisable to build special roads for haulage with the same gradients and capacity which would have a solid roadbed and a concrete or oil-bound hard and smooth surface. However, owing to high construction costs, concrete or macadam hauling-roads have, so far, been built for only a few important logging sites and, if the timber volume per hectare cannot be substantially increased, there is no justification for these roads. Even in tropical countries where fast public highways already exist, timber transport must continue to bring out small loads on minor roads, which will necessitate reloading at the junction with the public highway. Haulage roads will therefore continue to be designed for the lower limits of both loads and speeds, with adverse grades up to 8 or 10 percent. On such roads, apart from the softening and deterioration of the roadbed by raindrops from overhanging branches, erosion of the road surface by the flow of rainwater has to be controlled. The steeper the slope, the greater the danger by the slipping of vehicles on earth and gravel roads, and the higher the repair and maintenance costs. A short heavy downpour may do much more harm than continuous soft rain, and the frequency and violence of rainstorms determine the choice of slopes for hauling roads. Records of the maintenance and repair costs of local roads damaged by rain are useful guides.

Truck speeds on straight stretches of low-class public roads will seldom exceed 40 kilometers per hour, and only the main highways constructed in recent years on the west coast of Africa admit truck speeds up to 80 kilometers per hour. Such a speed is an important factor when planning new hauling roads, which may have to be adapted in the future to these high speed limits. The time factor is very important since the introduction of tractor or truck hauling, as transport times are closely checked and their possible reduction is of economic importance.

Sometimes smaller loads which can travel at higher speeds on longer distances are more economic but, on short slow roads haulage costs can be decreased by transporting heavier loads. In some countries the load limits of public roads, built for animal traction, have been increased during recent years by improvements to the road surfaces but the bridges have not been strengthened sufficiently for heavy trucks.

The first task in road improvement is the consolidation of the existing roads to support 5-ton vehicles, to reinforce softer road sections and to widen the curves. To ensure the circulation of 5-ton trucks at an average speed of about 25 kilometers per hour is a considerable achievement and may satisfy for some years the demand for better transportation facilities.

The next step is usually the reinforcement of the existing bridges. Short bridges for only 3-ton loads, built in many countries in the past, may have to be reinforced and widened for the passage of 5-ton trucks, or tractors with trailers. On bridges with very short spans, only half the total load on a long vehicle may actually be on the bridge at one time, especially if a trailer is used.

For wide rivers, the cheapest way of crossing is often by ferries, of adequate carrying capacity, which may be replaced by bridges as soon as the traffic intensity requires it.

Construction and maintenance costs of forest roads have to be kept as low as possible owing to the relatively small volume of timber to be transported, and concrete or macadam roads are usually too costly. Most logging roads consist only of the natural ground surface cleared of all vegetation and of the humus layer. Smaller trees are uprooted by hand, or by a bulldozer which also pushes the roots and other vegetation to the sides of the road.

Larger trees, with large buttress roots, are avoided where possible during the alignment. If not, the roots are cut about 20 centimeters below the future road level to prevent damage to the dozer and grader plates, and to the tractor shoes and truck tires. Large tree roots are seldom extracted completely because of the difficult refilling work which has to be repeated several times before the ground finally settles into the hollows left by the roots.

Dry clay soil or wet sand can each give very good ground support, but dry sand or wet clay soil are almost impassable by wheeled transport. These extremes are seldom found in tropical forests: owing to the lack of sand and gravel or of clay soil, it is often difficult to get a good ground mixture to provide the desired support. The natural soil roadbed should be given one year, or at least one rainy and one dry season, for natural consolidation before any traffic is permitted. Unfortunately this advice is not always observed by small logging enterprises, and much damage is often done to the roads.

To avoid such a long waiting period for a roadbed to consolidate, compacting with rubber-tired rollers may be successful, provided that the moisture content of the ground is suitable for cementing the mineral parts of the soil. Rolling dry ground has very little effect.

A far better method to increase soil compaction is with the Hyster Grid Roller or Letourneau's earth-packing Sheepfoot Roller or Power Packer. These have big drums fitted with short Hat-headed replaceable steel pegs of 15 to 25 centimeters in cross-section for crushing and packing the ground with the weight of the water or with sand-filled rollers, of 15 to 40 tons, distributed by the "stamping feet" over very small ground surfaces. A few passages with the Sheepfoot Roller, working in units of two to four drums, either pulled by tractors or self-propelled, packs the soil ready for traffic after a few hours of drying out. Such mechanical equipment is costly, however, and is rarely used on forest roads, as soil compacting is usually done by the crawler-tractors during the clearing and grading of the roadbed, and by the general logging traffic.

Road surfacing hardens the road surface and increases its impermeability. It also provides a better run-off of the rainwater. As tropical logging operations cannot support the high cost of concrete or macadam roads, except in a few exceptional cases, the usual surfacing of forestry roads consists only of giving them a crowned cross-section to maintain them in good rolling condition, and to avoid holes through which the rain can penetrate into the roadbed and so weaken its resistance. In order to improve the resistance of the surface of dirt roads, in sections with an unfavorable mineral composition, suitable soil should be added during the grading to obtain a good binding of the sand and clay particles. Suitable gravel or stone deposits may be found locally for the consolidation of the roadbed in soft places and on slopes. Laterites are frequent in many tropical forests and, when hardened by exposure, provide one of the best binding materials for sandy soils

Heavy loads of 15 to 20 tons, even when hauled at low speeds of 10 to 20 kilometers per hour, require a much stronger and more expensive road construction, especially where bridges have to be built.

Ditches on both sides of the road in flat country should be at least one meter wide and 50 centimeters deep. Standing water in the ditches, caused by insufficient slope or by vegetable or mineral obstruction, should not be tolerated, as it may soften the roadbed by infiltration and delay drying out after rain. The slopes of the ditches will generally be the same as those of the road, but for grades of 5 percent or more, frequent inspection is needed to avoid erosion.

For the construction of large culverts, durable hardwoods should be used, as for logging roads it is not advisable to make them of concrete. It will often be found that the original number and size of the culverts is too small and supplementary culverts are often needed to avoid road inundations and flooding.

More important for the drying of the roadbed is the felling and clearing of all overhanging trees to permit the exposure of the road to the sun and to increase the circulation of the wind for carrying off the moisture. The width of the clearances should be adapted to the amount of rain and to the geographical position and direction of the roads. For a road running east to west at 8 degrees north, the southern roadside clearance should be much wider than for the northern one, to get the longest possible sun effect during the day. For roads running north to south the clearances on both sides may have the same width, up to 10 to 12 meters each, determined by the height of the adjacent forest and the prevailing wind velocity.

## FEEDER ROADS

Owing to the limited volume of timber and the short period of exploitation, the planning of feeder roads rarely offers any difficulty, and their construction costs are reduced to a minimum. Along these temporary tracks, cleared through the forest quickly and easily by one or two passages of a crawler tractor, trucks are able to penetrate the forest nearer to the felled trees. The shoes of the tractor also destroy the sharp edges of tree stumps which could damage the tires. Gradients should be, as far as possible, those adopted for the main hauling road. However, for short distances only, the grades of feeder roads may be anything up to 15 percent for adverse slopes, and up to 20 percent downhill.

To drain off the rainwater from feeder roads, a slight crossfall of the road surface toward the valley is usually sufficient, without causing any special erosion damage. In flat country it may be advisable to raise the crowned road surface above the rain water level and, if necessary, to dig ditches along both sides of the road for quicker draining and drying. Soft spots should be filled with gravel or stone where available, or temporarily with brushwood. For heavier traffic, use poles or slab wood from sawmills, laid across the roadbed and kept down at both ends by longer and heavier timber. If the cross-poles are not properly pegged down at the roadside transportation can be very dangerous and speeds reduced.

The necessity of clearing lanes along both sides of feeder roads for quicker drying out is a matter to be decided locally. If the periods of dry weather are long enough for the hauling out of all timber cut, any side clearing would be a loss of time and money. However, large boughs overhanging these roads, as stated above for longer roads, should always be cut or the trees felled, to avoid deterioration of the road by rain dropping from the branches.

## LOG TRANSPORT BY TRUCKS

Trucks with a capacity of 3 tons have been used by small logging firms in west Africa during the last few years for short hauling from forest to river or to railroad landings. In this capacity they have proved to be quite suitable and efficient for low-class roads and slow loading with only simple mechanical equipment. They are either two-axle or six-wheel trucks, usually without a four-wheel drive or even a winch to get them out of bad places. They have not been designed for timber hauling and the bodies and engines do not last more than three or four years owing to the heavy strain to which they are exposed.

Despite all the difficulties which have had to be overcome by this method of transportation, some important conclusions can be reached for future logging operations. Log transport by truck is much cheaper than by railway. The flexibility and adaptability of trucks open up access to forests which cannot be logged by railroads, and often represent the only available economic haulage system. New trucks of European or American manufacture are now available of various sizes and capacities. Some types have devices and equipment specially designed for timber transport. Many of the two- and three-axle trucks have only a rear-wheel drive, and not always a front winch for self-salvage on the road. Some types are fitted with two hand-operated winches for log loading, and some with motor-driven winches for self-loading. It is not possible to give details of the many truck, tractor and trailer types that are available.

On the other hand, there are some disadvantages with truck transport. The tires of double wheels on the rear axles may develop two faults. During their use on low-grade forest roads, the tires are exposed to severe damage by stones squeezed in between them; and when rolling on hard-crowned roads, the inner wheels wear out quicker than the outer ones, and have to be changed frequently to get the same service life of the tires. These inconveniences are the chief reason for the present manufacture of single, wide-based tires of greater diameter, with which most heavy duty trucks and tractors of recent construction are now being equipped. Rolling with slow speed on rough or soft ground, with an air pressure of only 0.8 kilogram per square centimeter, the wide nylon tires mold themselves around the obstacles without being damaged.

They increase the ground adherence and the traction capacity of the truck, and compact the roadbed. Inflation and deflation of the tires, formerly done by hand, is replaced by a mechanical system, operated by the driver without stopping the truck.

Other disadvantages of these trucks are, first, their short platforms, limited normally to 4 meters, and not permitting the transport of logs longer than 6 meters; and, secondly, when logs are to be transported on public roads, the low maximum weight per axle or per wheel. On first-class public highways, this is fixed at 8,000 kilograms for a four wheel rear-axle, or 2,000 kilograms per wheel; and 3,600 kilograms for the two-wheel steering axle. The total weight of a loaded truck is generally distributed so that only one third to one quarter of it is supported on the front axle, and two thirds to three-quarters on the rear axles. For a 12-ton truck, and a one- to two-thirds load distribution, this means 4 tons on the front axle or 2 tons per wheel, and 8 tons on the rear. In the first case of the truck of 12 tons cross weight, with two axles and six wheels, all the wheels carry an equal load of 2 tons. In the second case, 12 tons for three axles and 10 wheels, the front wheels each loaded with 2 tons, and the rear wheels with only 1 ton. The load distribution of one to two thirds of the 16 tons cross weight is not possible, as the front wheels would then have to carry 5.3 tons or 2.65 tons per wheel, an overload which is not permitted on public roads. For reasons of safety (see *also* Figure 44), the truck loads cannot be moved farther to the rear, nor increased in weight or length, and so another load distribution on a greater number of axles is necessary. This is made possible by the addition of a trailer. The platform of the truck, which had become useless, is replaced by a bunk, mounted over the center of the rear axle, or of the two tandem axles, thus transforming the truck into a tractor.

#### LOG TRANSPORT BY TRACTOR AND TRAILER

The timber load on a tractor-trailer unit is so distributed that the front wheels of the tractor have to support only the weight of the motor and of the driver's cabin. The total weight of the load is carried by the two rear axles of the tractor, and by one, two, or even three, tandem axles of the trailer, thus permitting loading of all axles to capacity, which is up to two tons per wheel.

Such heavy loads however are admitted only on first-class highways, for travel speeds of up to 80 kilometers per hour, and never on lower-class forest roads. The total cross weight of the heaviest tractor-trailer types used on the west coast of Africa does not exceed 30 tons, carrying a payload of about 22 tons, distributed in the way shown in Figure 45. The ground pressure of the front wheels is the same as for the example cited above for main highways, but the lower travel speeds on the better main roads make them supportable. The eight wheels of the tandem axles of the tractor with the trailer could, theoretically, also support two tons each, thus increasing the load capacity from 26 to 36 tons; or to 16 tons on two tandem axles, which the road can support only at a minimum spacing of the axles. The smaller the spacing between the tandem axles, the greater the stress on the road for a given load and speed.

In industrial countries, tractors and trailers are built today to any required size and loading capacity. They are adapted and equipped for long timber transport with fixed wooden "reaches," or with telescopic steel tube reaches. The giant Euclid (Figure 46) and Berliet tractor-trailers cannot be used at present in tropical forests as there are no hauling roads capable of supporting them; but no limits can be set to the rapid evolution of 30-ton timber loads, rolling already on main hauling-roads in west Africa. The driving power for tractors and for trucks is usually provided by diesel motors but older vehicles are still using petrol. The engine power is normally transmitted to the rear axles, but many tractors and trucks are fitted with a front-wheel drive. The latest improvement in the transmission of the driving power is the diesel-electric four-wheel independent electric drive of the Letourneau-Westinghouse Tournahauler (Figure 47) or Tournaskidder.

The length of service of tires show great differences, depending on the manufacturer and the location of the plant. Goodrich tires, produced in the United States, are better and more resistant than those made in Goodrich plants located in certain rubber-producing tropical countries. The service depends on the road-class and gradients, and on the loads they carry; also, to a great extent, on the driver's ability. For rough roads, with steep grades, which need heavy traction power to pull the loads uphill and even more power for the braking on the downhill run, the maximum safe mileage for front tires can be as low as 4,000 to 5,000 kilometers. On better roads and with better grade conditions the average length of service may reach 15,000 to 20,000 kilometers. On good hard roads tires of reliable manufacture, mounted first on the front wheels and, after a certain mileage, on the rear wheels, may last as long as 80,000 to 100,000 kilometers. It is a good policy to use for the front wheels tires in top condition, to replace them after 40 to 50 percent wear and then to put them on the rear wheels. Having reached their "safe mileage" life, tires from high-speed transport can still give many miles of service on slower hauling roads, where they are not exposed to the hard wear of brutal braking.

Overloading vehicles, frequently done to profit from additional payloads, greatly reduces the service life of tires. Overloaded tires become hot very quickly and the risk of blowout is much greater. Heavy impacts on bad roads, which do not allow for the complete absorption of the shock entailed, are the most frequent reasons for bad damage to tires and also to other constructional parts of a vehicle.

Tubeless tires are becoming more generally used in the tropics. They are lighter, they do not accumulate heat as rapidly as tires with tubes, and they have good protection against normal blowouts. Reliable information regarding their wear and service life in the tropics is not yet available.

Heavy vehicle Lypsoid tires with an elliptical cross-section, of 44 × 28 inches; or 112 × 71 centimeters and with a low inflation of only 0.7 kilogram per square centimeter are mounted on a vehicle manufactured by the Anglo-American Export Company. The ground contact area, being larger than that of standard tires, keeps the ground pressure down to 0.32 kilogram per square centimeter, which is lower than that of crawler tractors, thus permitting easy traverse over soft sand or deep, swampy ground. The vehicle is equipped with two gas or diesel motors, of 120 to 180 total horsepower, and either of them can be detached at will, by push-button coupling or uncoupling. They are placed transversely in front of the wheels. This cross-country vehicle has not yet been used in the tropics, but its constructional features may be interesting for tropical logging in mangrove and swamp forests.

#### *Tire maintenance*

Tractor and tire manufacturers publish rules on tire maintenance, the observance of which helps to increase the service life of tires for all kinds of trucks, tractors and trailers. Tires should be selected to suit specific loads and the working conditions. Tire manufacturers have designed tires to meet heavy working conditions, but it is not always possible to get the right tire for a given job, and a compromise is often unavoidable.

Tire pressure should be checked regularly. Under-inflation causes excessive flexing and increased tire deflection which, in turn, leads to heating and uneven tire wear. When tires are used at comparatively low speeds over soft ground conditions, it may be desirable to reduce tire pressure from that recommended for transport on hard or paved road surfaces. This will promote better traction and less rolling resistance and will reduce the risks of tire cutting by sharp impacts. Overloading and over-inflation above the manufacturers' indications should be avoided, for they may result in high cord stress, with possible blowouts from sudden jolting and also increase the danger of cuts by sharp stones or flints. Tire pressure should be checked when the tires are cool. If checked when warm or hot, allowance should be made for the pressure built up by the higher temperature.

The surface over which the vehicles operate is a very important factor for the service life of tires. Good haulage roads not only prolong the life of tires, but also permit higher haulage speeds. Careful selection and training of drivers is also necessary. Good drivers will avoid obstructions which may harm the tires, and they will also avoid the spinning of the drive wheels.

The condition of the tire treads should also be checked regularly, especially in wet tropical climates. All damaged tires should be marked and removed for repair as soon as possible. Cuts should be probed for stones, nails or other foreign material. The steel rims should be checked for damage, particularly along the flange, as this may cause cuts in the tire bed. Tires in storage will deteriorate from exposure to direct sunlight, moisture, grease or oil, and should be kept in a dark place which is cool and dry. Tires should not be stored near electric motors, which are a source of ozone, nor near petroleum products or fumes. If necessary, they can be stored outdoors but then they should be covered with waterproof material. It is essential that moisture be kept from the inside of the tires, and the best way to ensure this is to mount them on wheels and to inflate them to 50 percent of the operating pressure.

For tractor-trailer units of a total weight of 8 to 10 tons, the powerful brakes of the tractors alone may be sufficient for small gradients and for speeds up to 40 kilometers per hour. But it is to be remembered that brake-linings and tires can be damaged by the heat produced from sustained long braking. For bigger vehicles and higher speeds, the trailer should be fitted with the same braking system as the tractor, which is usually with vacuum or hydraulic brakes, controlled by the truck driver. On forest roads with steep grades it is advisable to use trailers with brakes to avoid wear and fatigue of the motor used for braking.

### *Semitrailers*

Logs of more than 20 feet in length usually have to be loaded on to semitrailers. The heavier butt ends are supported by the bunks of the tractor and the lighter ends by the trailer. Depending on their density and size, the weight of large single logs may reach 8 or even 10 tons, and tractors and trailers have to be adapted for the safe hauling of heavy loads up to 20 tons and 50 feet in length (Figure 48).

Many of the tractors formerly mounted on double wheels, have now been replaced by those with large single wheels. Carrying no load on the return trip to the forest, the trailer bumps along the road, wearing out tires and coupling gear. This is often avoided by loading the empty trailer which weighs about 1,500 or 2,500 kilograms onto the tractor, and carrying it on the return trip (Figure 49).

To facilitate the loading and unloading of the semitrailer, a simple scaffolding is rigged at the terminal station. Its construction by local untrained labor is simple, and suitable timber is usually available on the site. Any available mechanical winch can be used. The telescopic tongue of the trailer, adaptable to a wide range of log lengths, is attached to the protective steel frame of the driver's cabin. A cable sling, permanently attached to the center of the trailer, permits easy lifting and lowering. The frame behind the driver should be strongly built or reinforced to protect the cabin against any forward shifting of the load on downhill sections or on sudden braking.

The minimum hauling distance at which carrying a semitrailer on the return trip begins to be profitable, is about 30 kilometers on west African roads. The time taken in loading and unloading the trailer is of secondary importance, compared with the danger that the empty semitrailer can be badly damaged, even on short runs; and a higher travel speed is of course permitted with the carried trailer.

Tropical timber is usually produced in long lengths (Figure 50), and is often hauled by tractors with semitrailers. Another great advantage of the trailer is that it can be loaded without the tractor. But trailers are not permitted on public roads in several tropical countries, and they will probably not be used until the tropical forests are eventually logged for pulp wood.

### **CALCULATION OF TRACTOR OPERATION COSTS**

When and where a tractor can profitably be used for logging purposes in the tropics, and when it should be replaced, can only be decided by a careful cost calculation based on meticulous records kept over a long period. Operation costs of any logging vehicles include four main items: fixed investment: estimated depreciation and repairs; fuel and maintenance; and, finally, wages, including welfare costs and unemployment compensation.





When calculating investment costs, it must be recognized that transport and delivery costs, import duties and taxes may reach over 100 percent of the original purchase price. Also that the tractor delivered to the tropical logging site may cost twice or three times as much as at the factory. Depreciation and repair costs require many years of recording and comparison before a proper estimate can be made.

### *Depreciation*

In temperate zones, tractor manufacturers assume an average tractor life of 10,000 working hours or a service life of five years, based upon 2,000 working hours per year. If a logging tractor operating in tropical forests, with rainy seasons of four to six months, can average 180 to 200 working days of five to six hours per year, totaling 1,000 to 1,200 working hours, this is a good average achievement. The normal depreciation period in most tropical countries being estimated at five years means that a tractor may be written off after about 5,000 working hours.

Both the above figures - the five years' depreciation limit and the 5,000 working hours - are basic figures for cost calculation, but the real service life cannot be actually established until the tractor is finally scrapped, and this may vary very widely. Unpublished operation costs, obtained with crawler-tractor yarding on the west coast of Africa, give evidence of more than 9,000 working hours over a period of nearly eight years. Such good results are profitable for the tractor owner, but cannot be regarded as applicable to all conditions. With growing experience in the tropics, the average real service life of tractors has substantially increased above the original depreciation period, thanks to more careful driving and better maintenance. But, although tractors now have a longer life, the great increase in their cost price has prevented any reduction in actual logging costs.

As the number of working hours varies greatly, annual depreciation rates must be based on the actual working hour costs in the different years. The resale value of a tractor at any given time, or of separate parts such as the engine or usable spare parts at the end of its service life, will obviously be applicable only in those countries where a fair demand exists for secondhand tractors. A formula for depreciation, worked out for taxation purposes by the French Government with the intention of stimulating capital investment, may be of interest for tropical logging operations. As depreciation is heaviest during the first year, the following diminishing rates were established (Table 3).

TABLE 3. - DELIVERY VALUE OF TRACTOR, OR ANY SIMILAR MECHANICAL EQUIPMENT, VALUED AT \$ 20,000 AND A DEPRECIATION PERIOD OF FIVE YEARS;

Year	Method of calculation	Depreciation balance	
		<i>U.S. dollars</i>	
1st	40 percent of \$ 20,000	8,000	12,000
2nd	(\$ 20,000-8,000) less 40 percent	4,800	7,200
3rd	(\$ 20,000-8,000-4,800) less 40 percent	2,88	4,320
4th	(\$ 20,000-8,000-4,800-2,880) less 40 percent	1,72	2,592
6th	Estimated only	2,692	2,160
	TOTAL	20,000	

### *Repair costs*

Repair costs are always very heavy in the tropics, not only because of the expensive spare parts, but also because of the lack of skilled mechanics and workshops within reach of forest operations. Repair costs and the much greater wear of all mechanical equipment in tropical countries has to be foreseen. Electrical equipment, for instance, suffers from moisture and from rough roads; sandy soils wear out the crawler tracks after 2,000 to 2,500 working hours (two or three sets are often used during the tractors' service life and one pair of crawler-tracks costs about one third of the tractor's purchase price). For wheeled tractors, the Forestry Equipment note No. C.14.56, of the Food and Agriculture Organization, assumes an average tire-life of 5,000 hours; i.e., 5,500

hours for tractors of 40 to 50 horsepower; and 4,500 hours for those of 25 to 30 horsepower. Time alone, however, without taking the mileage and road conditions into account, does not give a correct estimate of tire depreciation or of its service life. At an average speed of 8 kilometers per hour a tractor would travel 40,000 kilometers in 5,000 hours, or only 20,000 kilometers at half the speed. If the service life of a tire were to be reckoned in terms of time alone, which is, of course, not the case, its life per kilometer would be doubled when traveling at half speed.

Fuel and lubrication oils usually have to be imported, and their cost delivered to the logging sites is much higher than in industrial countries. The higher consumption rate for both fuel and lubrication in tropical countries is partly due to evaporation, and partly owing to the higher working temperature of the tractor engines.

Maintenance costs include cleaning, refueling, oiling, greasing and small repairs made by the driver. They are best dealt with as part of the wages of the driver and his helper, for the time employed. Under tropical working conditions, a rate of 20 to 25 percent should be assumed.

#### *Wages and associated expenditure*

Wages for the driver, and his assistant choker man, are generally lower than in industrial countries. Costs have to include all expenses for medical treatment, sick pay, health insurance, pensions, paid holidays, welfare collections, etc. Transportation costs to and from the logging area have to be added to the wage costs as well as part of the salary of the supervisor.

#### *Overheads*

To get a true picture of tractor operation costs, overhead expenses should only be charged against them in proportion to the total timber harvesting costs; including survey and cruising costs, camp construction and maintenance, felling, bucking, bunching, skidding, loading and transport. In small logging operations it is usually of little value to keep separate costs for bunching, skidding, loading and transport, and it is sufficient for all cost calculations to have a reliable total figure for all four items. Bigger enterprises, operating with two or more tractors, need separate daily working records for each operation.

Examination of operation costs incurred in tractor logging on the west coast of Africa, and their comparison with those of Kalimantan and Sarawak, confirm that the increasing experience of the Africans with crawler-tractor logging is gradually reducing costs. When tractor yarding started on the west coast of Africa some 30 years ago, it was only profitable to log timber species of high merchantable value, such as mahogany or okoumé, the sales prices of which could support the high logging costs. Other timber species, of smaller value, could not then be logged profitably with tractors. Tractor efficiency has now been greatly improved by roadmaking, better loading and forest clearing, and both managers and labor have had time to get familiar with mechanized logging. The resulting reduction of operating costs is now permitting the economic extraction of new timber species of lower merchantable value.

For the calculation of operation costs of the additional equipment used with tractors, such as skidding pans, sleds, bummers, sulkies and arches, winches and winch cables; they should be considered as forming a single production unit, to which all the above cost factors can be applied.

Observations and checking of the transport costs of about 1,600 logs on the Ivory Coast, made a few years ago, yield some interesting conclusions. Records have been made of vehicles with loading capacities of 8 to 26 tons, over transport distances from 20 to 260 kilometers, with truck and tractor-trailers, gasoline or diesel driven, also with loads carried by trucks only, or by tractors with semitrailers. Observations of hauling periods extending beyond the dry favorable season into the bad road conditions of the rainy season, demonstrate the necessity of reducing both the speed and the loads by 20 to 25 percent during the wet periods, thus producing a corresponding increase in fuel consumption per volume of timber. In other African equatorial regions, cost savings of up to 50 percent were claimed for diesel-driven vehicles.

The influence of better road conditions on transport costs are summarized below:

1. *Increased hauling loads.* High class roads permit heavier loads at normal speeds and this obviously reduces transport costs. If the wages of the driver of a 20-ton tractor with semitrailer are the same as for a 10-ton unit, the wage costs per ton are obviously 50 percent lower in the first case. High-class roads are normally built with easy slopes, permitting bigger loads to be transported without slowing down. A 100 horsepower tractor, with semitrailer, will pull a 10-ton load without difficulty uphill on a good road with an 8 percent slope. If a road cannot be improved, or if a steep slope cannot be avoided, loads may have to be reduced by 20 to 25 percent, representing a corresponding increase in costs. A transport manager will always try to keep transport costs down by well-calculated maximum loads for each type of vehicle and for the existing road conditions. During both dry and wet seasons, he will try to keep the loads for each trip as close as possible to the established maximum. From past experience he may let the morning transport start with smaller loads and increase them during the day if the roads are drying out.

A useful cost-saving measure consists in stopping log-hauling on low-class earth roads as soon as it starts to rain, and to resume it after the roads have sufficiently dried out. In addition to the necessity to carry smaller loads with the same vehicles on soft, muddy wet roads, heavy expenses may have to be faced for the repairs to the roads damaged by the traffic. Experienced loggers in the tropics know that it is much more economical to concentrate or limit all timber hauling to dry weather periods.

2. *Higher travel speed and shorter times.* Transport speed has a similar influence on transport costs as the volume or weight of the loads, and shows the same trend. The faster a heavy load can be delivered, the smaller are the costs. It makes a great difference in cost if a bad road causes a tractor with a semitrailer to make four hauls a day only, instead of five at the same wages and almost the same fuel consumption.

3. *Smaller repair and maintenance costs.* Drivers, interested on a bonus basis in the volume of timber to be transported, will try to get the best profit from a given hauling job, and tend to drive the engines they do not own themselves at the highest possible speed, without regard to road conditions or to the capacity of their vehicle. It must also be remembered that the daily cleaning and maintenance work is longer and costs more for vehicles on wet, dirty roads.

4. *Smaller depreciation costs.* A vehicle used on bad, rough roads is worn out faster than on good, smooth roads and, if it is written off in three or four years instead of five, depreciation rates will be 40 or 20 percent higher. Considering the delivery costs of a tractor-trailer unit to the tropics, costs which may be three to four times the purchase price at the factory, as already shown in the section on tractor costs, the actual depreciation costs per ton/kilometer kilometer will obviously be greater.

#### *Relation between loads and hauling costs*

The load weight on a vehicle is not the only factor influencing transportation costs, as the volume of the timber may be of equal importance particularly for bulky loads. A tractor with a semitrailer and with a loading capacity of 10 tons should be able to carry, theoretically, 10 cubic meters of logs with a wood density of 1,000 kilograms per cubic meter or 20 cubic meters of logs of 500 kilograms per cubic meter; but the actual loads also depend on the volume of each individual log and its weight, which must be kept within the capacity of the available loading equipment. Traffic regulations generally limit the loading-width of tractors and trailers to 2.40 meters, and sometimes to only 2.25 meters. Fortunately the limited width can be compensated by the load lengths, which are fixed generously at 12 or 15 meters, and often permit log loading up to the vehicles carrying capacity. However, the overhang of logs, loaded on trucks alone, should not exceed 50 percent of the length of the platform, or of the spacing between the bunks of the tractor and the trailer. For tractor-trailer hauling, the weight of the log overhang is generally balanced by the weight of the heavier leading butt ends of the logs. It is not difficult to compose loads of 12 to 15 tons with log lengths of 5 to 6 meters and with a density of 800 kilograms per cubic meter; but vehicles with a loading capacity of 18 to 20 tons or above require a minimum log length of 7 meters. Long logs should always be placed on the bottom layer and shorter logs on top of them to keep the main weight of the load between the bunks. The height of log loads is limited to the free passage height of overhead crossings, in most countries at 3 meters. For reasons of stability and safety log loads are very seldom loaded to such a height in the tropics.

One important factor which determines the composition of loads is the capacity of the available loading equipment. A loading crane capable of lifting 7 tons for a distance of 5 meters is an expensive machine, which is justified only for the handling of large volumes of timber. The lifting capacity reduces the loading length of a 120-centimeter log, of 600 kilograms per cubic meter density, to 10 meters, and to 6.3 meters for a 1,000 kilograms per cubic meter density. When in a green condition, many tropical timber species approach the 1,000 kilograms per cubic meter density, but rarely a diameter of 120 centimeters. If the mechanical loading equipment is not capable of lifting such heavy logs, they are loaded from a platform by cross-haul.

When loading a tractor-trailer unit of 10 tons capacity with a 7-ton log, this being the heaviest the mechanical loader can handle, the load has to be completed by adding a log of about 3 tons, to make up the full carrying capacity. A suitable log has to be picked out from the log pile, and this needs a correct log tally list. The total hauling volume needed for at least one day should always be stored ready at the landing place. It might be considered possible to make up the remaining 3 tons with another log 120 centimeters in diameter but, at the same density of 600 kilograms per cubic meter, this log would be only 4.3 meters long, which would be too short for the spacing of the bunks. A longer log should therefore be found with a smaller diameter; and a log 80 centimeters in diameter and 7.5 meters in length would give exactly the needed weight. However, such well-fitting logs are seldom available, and even with the best hauling organization, vehicles are rarely loaded to full capacity, thus increasing the actual hauling costs.

Annex V: Recommended Safety signs for forest roads

