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assessment of logging costs from forest inventories in the tropics

1. principles and methodology

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forestry industries division
forestry department**

**with the assistance of the
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FOREWORD

Forest resources are an important asset for economic and social development in many tropical regions. For more than 25 years the Forestry Department of the Food and Agriculture Organization of the United Nations has been assisting its member countries in making the best use of their forest resources and providing them with advice and support in their forest development activities. This has been the case, particularly in the field of forest inventory and logging, in the framework of forestry projects in the countries concerned and also through publication of relevant manuals and documents.

One link between these two disciplines has not been covered adequately, i.e. the assessment of accessibility, or more precisely, estimation of logging costs from forest inventory results and socio-economic data. In many preinvestment studies, and sometimes at national and international level, logging specialists have estimated exploitation costs making the best use of their experience and of the information at their disposal. However, general procedures and guidelines for the assessment of accessibility of tropical forest resources has not been provided and this subject was, until now, always treated on an ad-hoc basis.

In an attempt to fill this gap, the FAO Forest Logging and Transport Branch and Forest Management Branch, initiated a programme of work on this subject under the leadership of Professor U. Sundberg. A first pilot study was published in 1972 on the basis of forest inventory and logging data collected in a forest area in Madagascar. In 1973 a proposal was drafted for a "Major Study on Accessibility of Forest Resources" and in 1976 the Swedish International Development Authority provided funds for FAO to carry out the first phase of the study related to the assessment of logging costs in preinvestment studies.

This manual is the result of a team effort in which Mr. T. Klüwer, a senior FAO logging consultant took the largest share during a one year assignment in Rome where he worked in close collaboration with Mr. H. Chauvin, Chief, Forest Logging and Transport Branch, and Mr. J.P. Lanly, Forest Resources Surveys Officer. An expert panel on accessibility of tropical forest resources met on two occasions, the first time in Rome from 4 to 6 October 1976, to help in the formulation and design of the study and the second in Garpenberg (Sweden) from 4 to 7 July 1977, at the kind invitation of the Swedish Royal College of Forestry, to review the first draft of the manual as prepared by Mr. Klüwer.

The final draft was sent in January 1978 to the members of the panel and their comments incorporated in the text. At the same time Mr. Klüwer participated in a pre-feasibility mission to the National Forest of Tapajoz (Brazil) where he could test the methodology proposed and make some amendments.

This manual, being the first of its kind in the field of tropical forestry can certainly be improved and also complemented in order to cover the assessment of accessibility at national and subnational levels. However, in its present version, it is thought that it can be of much help to all interested parties: the forest owner in assessing stumpage, the user of the forest resource in estimating beforehand the cost of wood, and the forest inventory people in providing all types of forest and terrain information required.

Louis Huguet
Director
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TABLE OF CONTENTS

	<u>PART ONE</u>	<u>Page</u>
1. INTRODUCTION		1
1.1 Objectives and Scope		1
1.2 Limits		1
1.3 Outline		3
2. GENERAL PRINCIPLES FOR ASSESSMENT OF LOGGING COSTS		4
2.1 Introduction		4
2.2 The Exploitation Process		4
2.3 Exploitation Techniques		5
2.4 Cost Elements		6
2.5 Time Elements		8
2.5.1 General		8
2.5.2 Operational Time		8
2.5.3 Labour Time		9
2.5.4 Machine Time		9
2.5.5 Roundtrip Time		9
2.5.6 Recapitulation of Time Elements		10
2.6 Time Costing		12
2.6.1 Labour Costing		12
2.6.2 Machine Costing		13
2.7 Production Calculations		13
2.7.1 General		13
2.7.2 Stump Operation		14
2.7.3 Off-road Transport		14
2.7.4 Landing Operation		15
2.7.5 Loading		17
2.7.6 Main Transport		17
2.7.7 Unloading		17
2.8 Cost Assessment		17
2.8.1 General		17
2.8.2 Cost Formulae		18
2.8.3 Road Costs		21
2.8.4 Overhead Costs		21
2.9 Recapitulation		21

	<u>Page</u>
3. DATA REQUIREMENTS, COLLECTING & PROCESSING	23
3.1 Introduction	23
3.2 Overall Descriptive Data	24
3.3 Terrain Classification (Slope Assessment)	24
3.4 Areal Division (Assessment Units)	25
3.5 Stand, Tree and Log Data	26
3.5.1 Growing Stock (Inventory Data I)	26
3.5.2 Felling Stipulations and Exploitable Stock (Inventory Data II)	26
3.5.3 Utilization Assessment	27
3.6 Conditioning Factors	30
3.7 Road, Transport and Access Data	32
3.8 Economic and Socio-Economic Data	32
3.9 Recapitulation of Data Requirements	32
3.10 The Pre-Calculations and the Cost Assessment	32
APPENDIX 1 - GUIDELINES FOR PREINVESTMENT SURVEYS	33
APPENDIX 2 - BIBLIOGRAPHY	49

PART TWO

4. DATA BASE	1
5. PRECALCULATIONS	17
6. COST ASSESSMENT	61

CHAPTER 1

1. INTRODUCTION

1.1 Objectives and Scope

The objective of the manual is to outline a simplified methodology in assessing the logging costs of a forest exploitation, entirely based on the processed data of a conventional, low-intensity stock inventory and a number of other data, which, however, can be obtained without excessive extra field investigations being required.

Besides outlining the cost assessment procedure the manual is also intended to render guidance in collecting and processing of the required data. The guidelines are assumed to be sufficiently detailed to enable data collecting and processing as well as the subsequent cost calculating, without a high degree of specific expertise or technical experience in exploitation practice being required.

The result obtained through the assessment is an estimate of the average logging cost per m³ log volume delivered to a pre-selected delivery point in accordance with conditions set by given felling stipulations, determined production and utilization intensities and a number of physical factors prevailing in and specific for the area under assessment.

The cost assessment is restricted to cover the operations within the direct control of the management of the exploitation, i.e. to include only such operational performance which is carried out by means of own staff and own equipment.

Off-setting the calculated cost against the average net sales value per m³ permits an evaluation of the profitability of the exploitation and consequently of the economic accessibility of the area.

To assess the corresponding net sales value calls for separate calculations which are not covered by the guidelines of the manual. A reliable assessment may be quite complicated requiring specific local data observations, but it may be advisable in due course to expand the manual to include also this part of the overall assessment.

If optional felling stipulations or a different exploitation pattern or techniques can be considered, alternative cost figures may be calculated merely by repeating those sub-calculations which are affected by the varying basic data.

1.2 Limits

The manual is entirely focused on the conditions in developing countries and in particular the tropical countries. Even then operational options are much too varied and far too great in number to be covered by a single generally applicable cost assessment procedure, alternatively that a manual dealing with all possibilities would become entirely unmanageable.

Substantial restrictions in the scope of the manual have therefore necessarily been imposed.

In the first instance the terrain conditions and the forest type to be considered have been confined to dry-land, non-mountainous high forest, leaving out the extremes, i.e. proper swamp forest and proper mountainous forest, which both require the employment of highly specialized exploitation techniques.

CHAPTER 2

2. GENERAL PRINCIPLES FOR ASSESSMENT OF LOGGING COSTS

2.1 Introduction

The section is intended to give the general background of assessing the logging costs of a contemplated exploitation, when the detailed data of a proper feasibility study are not available.

The basic principles of the methodology are outlined and references made to the sections where the practical procedure in implementing the methodology is described.

2.2 The Exploitation Process

The exploitation process consists of a number of operations each representing a phase of the production. The basic elements of the process are as follows:

Stump Operation, i.e. the felling of the trees and the initial shaping of the logs ("bucking" or, when only the bole is separated from the crown, "topping").

Off-road Transport, i.e. the removal of the stems or of the logs from the felling site to a log assembly point, the "landing". Usually only a short distance is covered (few hundred metres).

Landing Operation, i.e. a varying number of sub-operations carried out after the off-road transport but prior to the main transport. Cross-cutting and trimming of the extracted rough logs to their final shape and size are usually the most important of the sub-operations, but otherwise as requirements may be: de-barking, scaling, marking, log protective measures and possibly other sub-operations.

Loading, i.e. loading at the landing of the trimmed logs onto a transport vehicle.

Main Transport, i.e. the transport from the landing to a point of delivery, the "delivery point", either where the logs will be consumed (e.g. a sawmill located in the vicinity of the exploitation area) or from where they may be despatched for further transport for instance to an export harbour. The transport from landing to delivery point may vary from a few km to 30 - 50 km and in some cases even more.

Unloading, i.e. simply unloading of the transported logs at the delivery point.

Long-distance Transport, i.e. the transport of those logs which may have to be despatched from the delivery point to another destination. The distance may often amount to several hundred km.

The above basic pattern will not apply for all exploitations. Obviously, the stump operation must precede all other operations, but in some exploitations transport is undertaken directly from stump to delivery point, or the logs may travel directly from the landing to the export harbour. Usually two (or more) delivery points are operated: one for logs to be processed locally (e.g. the log yard of a local sawmill) and one for export logs (e.g. a loading station on the state railway line). It may also be that logs are finally trimmed already at stump site, alternatively, they may not be trimmed until arrival at the delivery point. However, most of these deviations from the outlined basic pattern are merely a question of the break-up of the transport operation or an amalgamation of different transports. The modifications are closely related to different techniques being employed.

2.3 Exploitation Techniques

For the physical performance of the various operations numerous widely varying techniques are at disposal and an almost indefinite number of combinations of techniques can be made.

Many techniques can today be considered obsolete although still used here and there; others are so advanced that they are as yet only rarely employed. Some are confined to very restricted regions.

Felling may be carried out by hand-axe only or by a combination of hand-axe and manually operated cross-cut saws, or - as now practically universal - by powersaw (chainsaw). The felling cut may be placed near the ground or several metres above if the tree is badly buttressed, in which case a platform may need to be constructed for the feller to stand on. If a powersaw is used it is normal practice to cut through the flanges, standing on the ground.

The stem of the felled tree is cut free of the crown ("topping") and cross-cut ("bucking") either in order to remove defect or damaged parts of the stem, for instance the splintered butt-end and/or in order to divide a too large stem which could otherwise not be handled by the off-road transport equipment. Generally accepted practice is to restrict the cross-cutting at the stump site to a minimum ("tree-length extraction") owing to the usually inconvenient working conditions at the felling site; however, common features of tropical trees are large size and heavy weight and some cross-cutting is normally always required. Squaring of large logs is hardly practised any more and declimbing is rarely needed.

Off-road Transport. The logs to be removed from the stump may be hauled by animals, whether elephants, bullocks, donkeys, horses or any other local domestic animal or even by man-power. Animal extraction will invariably put narrow restrictions on the extractable log size and furthermore a tropical forest rarely offers very good conditions for any work animal. Mechanization of the off-road transport must, therefore, be considered the only rational solution unless very special conditions prevail.

Crawlers are now probably the most commonly used extraction equipment closely trailed by the wheeled skidder. The two are often used in combinations. Cable yarding may be seen, but is in general considered uneconomic under tropical conditions and only to be practised if other methods are not feasible - and the area will not be considered unexploitable. In swamp forests, cable yarding may be justified or logs may be floated out, possibly tied to dug-outs or be winched up on pontoons or barges and towed out. Lifting by helicopter or balloon is practised, but is still to be considered most unusual. Combinations of balloon and cableway with the balloon replacing the spare tree may also be seen.

The logs may be dragged directly over the ground ("ground skidding") or partly lifted (with or without an "arch" and "high-lead") or carried completely free of the ground (e.g. "forwarding" of small-sized logs and "sky-line" yarding). The hauling equipment may travel directly on the forest bed or on prepared trails; however, if so, these will invariably be of such a primitive and inexpensive construction that the term "off-road transport" remains justified. Employment of winch-lorries is not uncommon and may even be of increasing importance, where terrain conditions are favourable. In such cases, the off-road transport and the road hauling are amalgamated into one operation and one loading-unloading operation consequently saved.

The off-road equipment is not actually loaded but merely attaching itself to the log though usually only after some winching-in from the stump.

Unloading after the off-road transport is likewise a simple release ("dumping") of the log at the landing, possibly followed by some pushing and arranging, rarely proper stacking.

If crawlers and skidders are working together, it is common practice to let the crawler operate directly from the stump to an intermediate landing and let the skidder carry the logs from here to the roadside landing. Actual "bunching" is less common, as single logs are usually large enough to make up a full load.

Loading. Before the main transport the logs have to be loaded onto a vehicle or - in the case of river transport - into the river or on board a barge. Many types of cranes, booms and specialized loaders are available and various methods of pushing, rolling or dragging the logs onto the vehicle or into the river are also used. A simple, but often practised system, is to have the logs delivered by the off-road machine on an elevated soil ramp or on a set of prepared log skids from where a tractor then pushes them directly onto the truck. Self loading devices, mounted on and powered by the transport vehicle are quite commonly used.

The Main Transport also lends itself to a wide variation of techniques.

Very common and in most cases also a very rational method is truck hauling by a diesel truck with an attached pole-trailer, capable of carrying a load of 25 - 35 tons. However, numerous different weight classes and types of trucks do exist. Narrow-gauge railways may now be considered a left-over from previous times. River transport is a much practised technique in some tropical regions and logs are in that case either floated one by one or tied up in rafts, which again may either drift by themselves, properly steered by a crew, or be towed by a tug boat. The logs may also be loaded onto barges. Combinations of truck hauling and river transport are common. A very special transport method is floating of logs in narrow and shallow, excavated or blasted channels.

Unloading after the completed main transport may be a question of simply tipping the load off but in order to protect the equipment and the logs against damage, some mechanized equipment is usually employed. Most of the loading machines serve well also in the off-loading operation.

Up to this stage of the log production and transport process, normally all operations have been in the full control of the management of the exploitation and the physical performances are carried out by their own equipment.

If logs are to be further transported, i.e. if Long-distance Transport applies, a common system is to utilize existing public transport means, first and foremost state-railways. Obviously, additional loading and unloading operations are introduced hereby and equally obvious is that the operation is only to a certain extent controlled by management, which in many cases may render performance and cost estimates less reliable. This is one reason why - as already mentioned in the introduction - the outlined assessment does not include transport beyond the delivery point.

2.4 Cost Elements

The procedure in the cost assessment of a given exploitation is to assume a certain exploitation pattern ("production flow") and the technical means - or technical options - to carry out the various operations ("exploitation technique") and then to cost each operation and add the costs up. In addition to operation costs, cost of establishing and maintaining the necessary transport routes and the overhead costs must be considered. In order to assess road and overhead costs, it is necessary also to assume a certain yearly production ("production capacity") whereby also indications of duration in time of the exploitation are given ("exploitation period").

Following in the first instance the simplified production flow outlined in chapter 2.2 and restricting the assessment to operations until, but including, unloading at the delivery point, the costing comprises:

Stump Operation

Off-road Transport

Landing Operation

Loading

Main Transport

Unloading

to which must be added:

Cost of Transport Routes (construction and maintenance)

Cost of Overheads.

For all the operations, the performance (or production) requires a certain input of manpower plus a certain input of machine power. Both are conveniently quantified in time units.

The cost of the performance of each operation ("production costs" such as "cost of felling", "cost of off-road transport" etc.) can be expressed as the cost per volume unit and calculated through a costing of the two time inputs and relating the combined time costs to the volume produced in that time.

If a machine is not employed in the operation, only the cost of manpower applies, possibly supplemented by a cost of tools. In some cases also a cost of consumed materials may have to be included (e.g. log preservation materials).

The cost element related to transport routes will in a common present-day exploitation comprise a network of truck roads of 2 or 3 different standards, of which the construction cost is derived by means of a calculated cost per km related to the assessed road lengths of the various standards required for the entire exploitation. The total cost will then have to be distributed over the total volume yield, whereby a cost per m³ is derived. In practice the problem is more complex, as the total cost is actually accumulating over the years by yearly costs which are unlikely to be equally sized and, therefore, not directly proportional to the yearly volume yield.

Cost of bridges and culverts must be included in the road construction cost and may in certain cases be quite substantial.

Road maintenance costs will normally only apply to the main roads on which the trucks are travelling year after year. The yearly cost will increase gradually as the road is extended; however, the issue is further complicated by the fact that the road length under maintenance may change substantially from time to time for instance if a new branch road is opened up and a former one is abandoned.

Possible charges on the use of public roads and bridges as well as possible compulsory maintenance costs of such roads must also be included.

In general, road costs are one of the more complicated items to estimate in detail as elaborate field surveys and technical expertise are required in addition to which considerations as to interest charges on the capital outlays need to be made.

Overhead costs are also to be considered. They must comprise all those cost items which have not already been included under the individual operation costs, first and foremost the cost of management and supervision; furthermore operational costs of necessary administrative vehicles, boats, aeroplanes; office expenses; security expenses; insurance payments; taxes, fees and other official charges; workshop expenses (excluding direct labour and consumption of parts and materials, which must be charged to the machines operating costs); stores operating expenses; yearly survey and enumeration costs; all other general expenses.

In many cases a forest operation may be integrated with an industrial establishment (sawmill, veneer peeling plant, etc.) in which case certain administrative expenses, in particular overall management costs should only be charged proportionally to the forest operation.

Royalties and concession fees which are paid per volume and/or area unit must be included but shown separately, the more so when the cost assessment is meant to evaluate the non-established exploitation, as the cost assessment may then serve the specific purpose of negotiating the chargeable fees.

Establishment costs, comprising initial survey, inventory, mapping and planning expenses should likewise be included and shown separately to be charged as a yearly depreciation.

To estimate overhead costs in detail will require a very large number of sub-calculations and in an overall assessment of potential exploitation costs, arbitrary short-cuts may here be more required than for any other cost element.

2.5 Time Elements

2.5.1 General

It has already been indicated that the cost assessment is fundamentally based on an assessment of the two time inputs, the man-time and the machine-time.

Some comments on, and definitions of, time elements and time units many, therefore, be appropriate. Many different methods of analysing and quantifying the various time elements are in use, some of which go into great detail, for instance in order to ascertain exact machine operating costs. The following outline is somewhat simplifying the actually very complex issue keeping in mind the comparatively broad cost assessment which can feasibly be achieved. The terminology and definitions may sometimes differ from those applied elsewhere.

2.5.2 Operational Time

The "operational time" is used as a term for the total time of a full calendar year when a given operation can be carried out. In some cases performance is feasible throughout the year; however, in such cases, periods of reduced efficiency will usually be experienced. These may be so pronounced that operation is impossible or at least so uneconomic that work is deliberately suspended for some time. Climatic conditions are usually the influencing factor and the determining factor the machine's inability to perform to satisfaction. The "operational time" may comprise one or two, rarely three separate calendar periods.

The "operational time" will be assessed in calendar months and number of "working days", i.e. days when work is carried out. It will be understood that the number of feasible working days may be reduced in certain months, but can, on the other hand, also be increased if Sundays or holidays are worked which is quite common practice during the most favourable periods; the term "days worked" may then be more appropriate.

The "working day" contains a number of "working hours", however, more specific terms are required in the case of the hour units.

2.5.3 Labour Time

The number of hours when a labourer's time is at disposal may or may not be set by labour laws but, in any case, fixed daily and weekly working hours are usually established. For forest labourers the paid working hours will usually include time for transport to and from work ("camp-to-camp time") which may in certain cases reduce the time for actual work performance substantially. They may also include scheduled time for a meal-break, although this is less common. Both time elements can be fairly well estimated, and when deducted from the overall number of working hours, the "effective man-time" is derived, measured in "effective man-hours".

"Effective man-time" is then defined as the time when the labourer is present at the working site and fundamentally is actively engaged on performing the work to which he is assigned. Occasional - usually short - rests during the work should not be considered as reduced time, but rather as a work efficiency reduction, which, however, must be taken into account, especially under tropical conditions where the climate is often adverse to hard physical work. When no machine is involved in the operation the "effective man-time" determines the production.

The terms "crew time" and "crew hour" will in many cases be more in accordance with practical conditions. The terms are synonymous with "man time" and "man hour" and only indicate that more than one labourer is engaged on producing the same volume. The "crew hour" is, therefore, still only one hour, but may comprise several "man hours"; the "crew cost" will accordingly be the sum of these "man costs".

2.5.4 Machine Time

If a machine is employed, the "effective machine time", usually termed the "productive machine time" will determine the production. It is the time when the machine is actively working and it will for instance, in the case of a tractor engaged in off-road transport, include both loaded and unloaded travel as well as time for picking up or dumping the load. It excludes "down time" i.e. time for daily routine servicing, refuelling, etc., but includes waste time caused by delays such as: waiting for logs to be ready for extraction, waiting for heavy rain to stop, etc., which must be taken into account in the same way as lost crew-time due to work fatigue, i.e. as reduced efficiency.

Obviously, the machine cannot operate and production consequently not accumulate unless the operator is operating it. However, the operator has the additional duty of servicing the tractor: the "productive machine time" is less than the operator's "effective man-time" and "productive machine time" can, therefore, be quantified as a certain percentage of the "effective man-time", and will actually often have to be derived and "down-time" based on an estimate of this percentage. The total of "productive machine time" is termed "in-shift time".

In the case of a tractor or similar machine, the "productive machine time" will approximately equal the time the engine is engaged and accumulates operating costs. The engine is usually not switched off during short waste times, and even when not travelling the tractor is still working as it has "terminal functions", especially winching-in the load from the stump.

2.5.5 Roundtrip Time (trucks only)

The foregoing considerations do not apply to a truck which usually has no terminal functions, but often prolonged terminal time for instance if loading facilities are not sufficiently well geared to the truck capacity or departure and arrival of trucks at the landing are not adequately coordinated. If the transport distance is short, the terminal

time may proportionally be very substantial. On long distances the terminal time will, of course, be less pronounced per round-trip, but on the other hand working time may then be wasted due to the fact that time is not sufficient for the day's last full round-trip.

In the case of trucks, other time terms are usually considered more convenient, viz: "round-trip time" comprising time for loading, travelling loaded, unloading and returning empty, "standing time" which is the part of the "round-trip time" when the truck is present at the landing or the delivery point, either waiting to be loaded/unloaded or in the process of being loaded/unloaded and "travelling time" which will then comprise time for the loaded and the unloaded travel.

2.5.6 Recapitulation of Time Elements

The essential time elements have been recapitulated in table 1. The following comments to the table are pertinent.

- (i) For a daily paid operator, the "camp-to-camp time" is the time to which his wage pay applies. Even if paid on a weekly or monthly basis, the wage must be re-calculated to a daily, camp-to-camp basis, in order to derive the essential time cost unit, the crew cost per effective crew hour.
- (ii) The crew's down time comprises time for transport to and from the working site and regular, scheduled meal-breaks, etc., but not occasional irregular rest pauses, caused by work fatigue.
- (iii) For all machine employing operations, a certain percentage of the effective crew time is spent on servicing the machine (daily routine service, small repairs, greasing, refuelling, change of sawchains (powersaws etc.). For purely manual operations some time will normally be spent on sharpening or otherwise maintaining tools.
- (iv) Work delays which can usually only to a certain extent be anticipated are included in effective crew time and should be taken into account as reduced production efficiency rather than attempts being made to quantify the adverse effect in time units. They can be caused by any incident which prevents the crew from utilizing the full effective crew time on operational work, such as waiting for logs to be ready for extraction, waiting for fuel to arrive, waiting for heavy rain to stop, etc., and also the crew's possible, non-scheduled rest pauses during the day. The magnitude of work delays is dependent on how well the operations are organized and coordinated. The loading and the truck hauling operations are especially vulnerable, as the optimum balance between number of trucks employed and travelling time is often upset by changing distances and travel speeds.
- (v) The productive machine time is also the time unit for calculating machine operations cost.

The above comments are mainly in regard to the assessment of the cost of the two time inputs, crew time and machine time.

However, the time elements must also be considered in regard to production. The following comments are pertinent in that connection.

- (i) In the stump operation, the effective crew time will be spent on a number of time-consuming preparations before actual felling can be implemented: spotting the tree to be felled, moving the equipment to the tree, clearing the immediate surrounding for scrub, and - after felling and bucking have been completed - moving to the next tree. In addition to this, time will be required for sharpening or changing the sawchains, servicing the saw and refuelling. If the walking distance from tree to tree is long, i.e. if only a few trees are to be felled per

TABLE 1

TIME ELEMENTS

Crew	camp-to-camp time
Machine	in-shift time (gross working time)

STUMP OPERATION

Crew	crew's down time	servicing machine	effective crew time felling preparations, work-delays	felling/bucking
Machine	machine's down time	non-working in-shift time	productive mach. time	

OFF-ROAD TRANSPORT

Crew	$\frac{\text{crew's}}{\text{down time}}$	servicing machine	$\frac{\text{effective crew time}}{\text{loading/unloading, travelling loaded/empty work delays}}$
Machine	$\frac{\text{machine's}}{\text{down time}}$		$\frac{\text{productive machine time}}{\text{operating and work delays}}$

LANDING OPERATION

(Machine time (power saw) = effective crew time)

Crew	crew's down time	effective crew time de-barking, cross-cutting, scaling, etc. work delays
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LOADING OPERATION

Crew	crew's down time	servicing machine	effective crew time marking and scaling logs, loading, work delays
Machine	machine's down time		productive machine time operating and work delays

MAIN TRANSPORT OPERATION

Crew	crew's down time	servicing machine	effective crew time time for loading/unloading	travelling loaded/empty
			round trip time	
Machine	truck's down time	standing time idling and work delays	travelling time operating	

UNLOADING OPERATION

(as loading)

ha, more time is required for the displacement and still more if the terrain is difficult and walking is impeded. Another portion of the effective crew-time is required for the actual felling, more if the tree is large and still more if the tree is crooked and badly shaped. Much time may occasionally have to be spent on clearing hang-ups or to free the saw when stuck in the cut. Time for bucking will depend on the size of the bole, how convenient the bole is located on the ground for cross-cutting and - of course - how many cross-cuts are required. For felling and bucking time, the physical properties of the wood are also of influence, e.g. the contents of silica or latex, both of which will increase the required cutting time and also increase the number of necessary saw changes and thereby time for servicing.

General rules can obviously not be applied to the ratio between preparation time and actual productive time, but in extreme cases only 25 - 30% of the crew's effective time is spent on operating the saw, i.e. the productive machine time is short, compared to the effective working time of the crew.

- (ii) This is usually not the case in the off-road transport operation. When the operator has carried out the daily routine servicing of the machine, he will normally operate the tractor throughout the rest of his effective working time, i.e. productive machine time equals approximately the effective crew time less the machine's down-time.

The productive machine time comprises loading and unloading time as well as travelling time, i.e. the total round-trip time. The round-trip time depends on many different factors such as log size, the ease with which the logs are winched free of the stump, travel ease (rough versus smooth surface, hard versus soft surface, few versus many ground obstacles etc.) and - most important - the travelling distance.

- (iii) Also in the case of the loading operation the productive machine time is comparatively high. However, owing to the practical difficulties in coordinating loading capacity with truck turnover, work delays may in some cases be quite substantial. On the other hand, the loading machine often has other functions such as turning logs on the landing for cross-cutting or debarking, stacking logs, etc.
- (iv) The production determining time unit in the truck hauling operation is the round-trip time comprising standing time and travelling time. The truck's down-time is included in standing time.

2.6 Time Costing

2.6.1 Labour Costing

The basic wage for an individual labourer will usually be a fixed rate per day, rarely per hour or per month. Wage rates may be determined by labour laws (usually minimum rates only). Differences in the wage levels of different categories of labourers according to skill, responsibility and physical nature of the work are wide, but not always consistent.

Supervisory staff is usually paid on a monthly basis.

In addition to the basic wages, other direct payments often apply, such as food, housing and family allowances, leave pay, annual bonus, etc. Or services are rendered, the cost of which must be included in the total labourer costs: free housing, free transport, safety equipment, accident insurance, medical care, pension schemes.

It will in many cases be difficult to make an accurate estimate of the indirect payments, since much detailed information is required.

It is often found most convenient to assess the hourly cost as if a full year's employment applies. If actually the feasible annual operational time is much less than a year, it is thereby assumed that the labourer will be employed on other assignments during the off-season periods which is actually common practice.

The assessment of the essential time cost, the crew cost per effective crew hour requires separate estimates of:

- (i) the composition of each crew category;
- (ii) total cost per crew member for the operational period;
- (iii) total number of crew hours of the operational period.

The practical assessment of labour cost will appear from the guidelines specified in the pre-calculations, part 2, chapter 5.

2.6.2 Machine Costing

Machine costs can be calculated by means of standard formulae of which a large variation is in common use. The results obtained from different formulae are usually quite consistent.

For all machines except trucks the required cost unit is the cost per productive machine hour, comprising both owning cost and operating cost. The cost items are:

- depreciation
- interests
- insurance
- vehicle tax
- fuel
- lubricants
- maintenance and repairs.

For trucks, the time elements for costing are the standing time and the travelling time and, accordingly, the time cost comprises "standing cost" and "travelling cost", and the units are the costs per "standing hour" and per "travelling hour" respectively.

The practical assessment of the various machine costs will also appear from part 2, chapter 5.

2.7 Production Calculations

2.7.1 General

From the foregoing sections it will appear that the cost of the time units, crew cost per crew hour and machine cost per machine hour can be calculated separately and furthermore that the ratio between machine time and crew time can be estimated. This means that the total of the two time costs per one operational hour can be calculated.

When the volume produced in one operational hour is then calculated, the total time cost per m^3 - i.e. the production cost per m^3 - can be derived.

In the following, the general methods of calculating the various production volumes will be outlined.

2.7.2 Stump Operation

It has already been indicated how complex the time distribution to the various operational elements actually is. In order to make a detailed assessment of the felling production, e.g. the number of trees which are felled, bucked and in all respects made ready for removal an amount of specific data is required, which will be much in excess of practicable possibilities of an overall cost assessment. However, at the same time a very careful calculation may not actually be needed in the case of the stump operation since the cost is known by experience to be small compared to other cost items.

The method of estimating the production of the stump operation as adopted here is simplifying the issue considerably, however, the basis of the calculation is derived by means of a large number of practical observations and will in most cases yield sufficiently reliable approximations.

The quantification of the production is derived as follows:

- (i) a set of graphs (see part 2, chapter 5, PC 9.1.1) will give "basic operational time" per tree of a given diameter (DBH), which comprises time for all the functions the felling crew is required to carry out in order to make one standing tree ready for extraction, i.e. besides felling, topping and a limited amount of bucking also locating and walking to the tree, clearing the surroundings, servicing the saw, settling an assumed amount of hang-ups etc;
- (ii) the volume per tree of the given diameter is known from the inventory data and the time per m³ can, therefore, be derived and consequently also the produced volume per hour;
- (iii) adjustments to the calculated volume must be made in order to account for possible excessive cross-cutting requirements, buttressness, and the possibility of a larger number of trees being felled than utilized. The adjustment for terrain difficulties are incorporated in the graphs, inasmuch as a specific graph applies to each terrain class.

It will be noticed that the production in the stump operation is based on the effective crew time.

The practical assessment of the production volume will appear in part 2, chapter 5, PC 14.1.

2.7.3 Off-road Transport

The productivity of a tractor engaged in removing the felled and bucked logs from the stump to the landing can be quantified by (a) the time it takes to complete one full round-trip and (b) the volume transported in that time.

The required time comprises picking-up the load - usually after some winching-in from the stump - and dumping the load at the landing - possibly followed by some shuffling and pushing of the logs to arrange them in an orderly manner to facilitate cross-cutting - and travelling loaded from the stump to the landing and returning empty to the next stump to be operated.

The required travelling time is - as already mentioned - dependent on many factors: how long the travel distance is, whether the terrain is level or the tractor has to climb steep slopes, whether the surface is firm, offering good bearing and friction or soft, causing the tractor to "bog-down", whether the surface is smooth or riddled with depression or bumps, whether obstacles such as large boulders or windfalls are present to

the extent that the tractor is forced to deviate excessively from a straight travel direction. Furthermore, how heavy the load is and how easy the load is to handle (one or several logs per load, straight or badly crooked logs). The loading time depends on how easy the logs are winched in from the stump and how many logs are needed to make a full load. In addition to which of course all time elements are dependent on the type of machine and - not the least - the operator's skill in overcoming the numerous difficulties.

Whereas it is comparatively simple to assess an on-going tractor operation and to calculate valid average production figures, the problem of estimating a potential operation in detail is quite complicated and calls for knowledge of a large number of specific data, some of which will be understood from the above comments.

For an overall assessment it is, therefore, again necessary to simplify the issue and to a large extent to generalize on the basis of statistical information obtained from other operations. However, the specific conditions prevailing in the area under assessment must to a certain extent be taken into account, as conditions may change considerably from site to site, even within the same area. The off-road transport cost has normally a heavy impact on the overall costs.

The production of the tractor operation is derived as follows:

- (i) two sets of graphs are indicating the travelling time per completed round-trip for a crawler tractor and for a wheeled skidder respectively (see part 2, chapter 5, PC 9.21 and PC 9.31). Each graph applies to a specific terrain difficulty class and specific one-way hauling distances;
- (ii) indications are also given as to the required time for loading and unloading ("terminal time") per round-trip;
- (iii) the required basic round-trip time is thereby obtained;
- (iv) the travel time, however, needs to be adjusted for influencing factors other than the overall terrain difficulty and the hauling distance which are both incorporated in the graphs. Of the many conceivable factors, some of the most significant have been selected and quantified as will be explained later;
- (v) the load size is determined from a table of practical average loads, each applying to a specific terrain difficulty class;
- (vi) when the adjusted round-trip time and the load size have been determined as above, the production per hour can be calculated.

It will be understood that the time unit in this case is the tractor's "productive machine hour".

The practical assessment of the production volume will appear from part 2, chapter 5, PC 14.2.

2.7.4 Landing Operation

The term "production" only applies fully to the felling operation. In the off-road transport operation the question is merely of handling the felled volume and in the case of the landing operation, even reducing the volume.

The landing operation comprises - as previously mentioned - a number of sub-operations of which some of the essential and commonly occurring ones have been selected.

The selected sub-operations are: cross-cutting, debarking, scaling, marking and protective measures.

(i) Cross-cutting

To quantify the required time input, it is necessary initially to calculate how many cross-cuts are needed to re-shape the extracted rough log to its final size and appearance and then - by applying practically experienced standard values of work performances per hour - to calculate the volume which can be assumed to be cross-cut per effective man hour under the given circumstances.

The average number of logs produced per extracted log will be known from the stand, tree and log data, as explained in a later section. However, it cannot be concluded that the number of cross-cuts will correspond or in any way be directly related to the number of logs produced, as the division of an extracted log into two may very well require three cross-cuts or more and even a log which is not divided at all may still require a couple of cross-cuts, in order to clean-cut the ends or to produce a specific length.

For a practical assessment it is necessary to simplify and the guidelines will, therefore, provide various standard values for cross-cutting capacities per hour dependent on the average number of logs obtained per extracted log and the average diameter of the logs. The time unit is the effective crew-hour.

(ii) Debarking

Dependent on the individual species' proneness to insect attacks - but often only due to locally prevailing custom or specific demands from buyers - a certain percentage of the extracted logs will usually need to be debarked. The removal of the bark may be more or less difficult, dependent on the bark type. Debarking is usually carried out by means of simple hand tools.

The cost assessment must be based on assessed values of debarking requirements and practically experienced statistics of debarking per hour. The time unit is the effective man-hour.

The cost must include an allowance for tools.

(iii) Scaling and Marking

The operation is considered compulsory and the guidelines will comprise practically experienced statistical values of working capacities per hour. The time unit is the effective crew-hour.

The cost must include cost of materials.

(iv) Protective Measures

Although rational exploitation practice under tropical conditions provides removal of logs from the stump to the landing as well as from the landing to the delivery point with the least possible delay, protective measures in the form of spraying with insecticides and/or end-coating are practically compulsory. Storage in water - where feasible - may substitute protective measures.

The work performance must - as in the case of scaling and marking - be quantified by means of practically experienced statistical values of hourly capacities per crew.

The eventually calculated cost must include cost of insecticides and depreciation of spray guns etc.

The practical procedure in assessing the production - or rather, work performance - of the entire landing operation will likewise appear from part 2, chapter 5, PC 14.3.

2.7.5 Loading

The rated capacity of different loading machines can be obtained from available statistical information. The hourly production and thereby the loading cost per m^3 may, however, if calculated on this basis, be grossly misleading.

The point is that feasible loading capacity and truck turnover are hardly ever coordinated in such a way that frequent interruptions in the actual loading time are avoided. The costing should, therefore, rather be based on a "standing time" and an "active loading time". On the other hand, in that case the calculation may still be somewhat misleading as in practice the loader is usually required to carry out other necessary work functions such as turning and arranging the logs for cross-cutting and debarking and for sorting and stacking the trimmed logs; machine as well as crew may, therefore, actually be working also most of the "standing time", developing additional machine costs which would then not be taken into account.

It appears more appropriate to assume that the machine is working throughout the feasible machine time, although only for a certain part of the time on loading, the balance of the time being spent on auxiliary work. However, for reasons of simplifying the calculation the total charge can be made to loading.

2.7.6 Main Transport

The production determining time factor for a log truck is the round-trip time and based on the known volume per load, the time cost per m^3 can then be derived.

The load size can be estimated on the basis of available statistical information pertinent to the truck type employed. The practical problems in assessing the cost will merely be in assessing the round-trip time which is dependent on (a) the road distance, (b) the breakdown of the road distance in distances of different road classes to which different travelling speeds apply and (c) the ratio between standing time and travelling time.

2.7.7. Unloading

The practical operation is more simple and consequently also less costly than loading; however, standing time may less easily be utilized on auxiliary duties. The loading cost per m^3 was - as explained above - somewhat inflated, although the total cost can be considered as real. A reasonable approximation of the unloading cost is assumed to be obtained by considering the cost to be equal to 75% of the calculated loading cost and to omit separate time and production calculations for the unloading operation.

2.8 Cost Assessment

2.8.1 General

From foregoing sections, it appears possible to break down the entire exploitation process in a number of operations viz:

stump operation

off-road transport

landing operation

loading

main transport

unloading

to which comes the auxiliary operations:

road construction and maintenance

overheads (management, supervision, etc.)

As far as the actual operations were concerned, they could be quantified in the two time inputs, labour time and machine time, measured in hours.

Furthermore, it has been proved possible to cost the time units of the two time inputs and consequently also of the time inputs themselves. The sum of the two time costs comprises the total cost of the operation.

Finally, it has been seen that the production or the work performance of each operation can be quantified in a number of volume units produced or handled in that time.

In that case, the production cost per volume unit can be calculated by simply dividing the total time cost by the achieved volume.

2.8.2 Cost Formulae

(a) Leaving aside in the first instance the special considerations required to the time elements of the truck operation, the assessment as outlined above can be expressed in a simple cost formulae:

$$\text{cost per m}^3 = \frac{CT \times C_c + MT \times C_m}{V}$$

where:

CT = the effective crew time, measured in effective crew hours, which are required to produce the volume V, measured in m³

MT = the productive machine time, measured in productive machine hours, which are required to produce V m³

C_c = the crew cost per effective crew hour

C_m = the machine cost per productive machine hour

V = the volume in m³ produced in the operational time which contains the two time elements: CT and MT.

The formula can be reduced by dividing by productive machine time:

$$\text{cost per m}^3 = \frac{C_c \times \frac{CT}{MT} + C_m}{v_m}$$

where:

v_m = the volume produced per productive machine hour

The reduction only means that both time costs as well as the volume are expressed on the same basis, i.e. per productive machine hour.

However, the quotient $\frac{CT}{MT}$ is known, since machine time is a certain, practically experienced percentage of crew time:

$$MT = \beta \times CT \text{ or } \frac{CT}{MT} = \alpha \quad (\text{i.e. } \alpha = \frac{1}{\beta})$$

where: β = the machine time in percentage of crew time, expressed in decimals ($\beta < 1$)

α = the reciprocal of the machine time percentage ($\alpha > 1$)

The basic formula can thus be written:

$$\text{cost per m}^3 = \frac{C_o \times \alpha + C_m}{v_m} \quad (1)$$

where: C_o = the crew cost per crew hour, calculated by considering the crew composition, the sum of the total cost of each crew member and the total number of effective crew hours covered by the cost

α = is obtained by estimating the actually applicable machine time by means of practically experienced mean values, of the percentage of crew time and calculating the reciprocal value of this percentage

C_m = the machine cost per productive machine hour, which is obtained by means of available standard formulae

v_m = the production or work performance expressed in m^3 per productive machine hour which can also be calculated by means of standard formulae

In this form the formula is convenient when the volume is calculated on the basis of the productive machine time.

If the volume is instead calculated on the basis of the effective crew time, the formula is more conveniently written:

$$\text{cost per m}^3 = \frac{C_o + C_m \times \beta}{v_o} \quad (2)$$

where: β = the machine time in percentage of crew time, expressed in decimals ($\beta < 1$)

v_o = the volume produced per effective crew hour

If no machine is employed the formula is simply reduced to:

$$\text{cost per m}^3 = \frac{C_o}{v_o} \quad (3)$$

(b) In the case of a truck, the production is based on the round-trip time, but in costing the machine time input the round-trip time is divided into standing time per round-trip and travelling time per round-trip. The effective crew time equals the round-trip time, inasmuch as the machine's down-time is included in the standing time.

The cost per m^3 can then be expressed by the following formula:

$$\text{cost per } m^3 = \frac{RT \times C_o + ST \times C_{ST} + TT \times C_{TT}}{\mathcal{L}}$$

where:

RT = round-trip time in hours

ST = standing time in hours

TT = travelling time in hours

C_o = crew cost per crew hour

C_{ST} = cost per standing hour, excluding crew cost

C_{TT} = cost per travelling hour, excluding crew cost

\mathcal{L} = the load carried in one round-trip, expressed in m^3

In keeping with the previous formulae a simplification can be obtained by dividing by round-trip time:

$$\text{cost per } m^3 = \frac{C_o + s \times C_{ST} + t \times C_{TT}}{\mathcal{L}}$$

(4)

where:

"s" and "t" are the standing time and the travelling time, both expressed in percentage of the round-trip time (in decimals) \mathcal{L} = the load carried per hour of the round-trip time.

The various components of the formula can be known as follows:

RT, ST and TT must be calculated on the basis of known hauling distances on various (known) road standards and the practically experienced travelling speeds corresponding to varying road standards.

C_o : the crew cost per effective crew hour is calculated - as before - on the basis of the crew composition, the crew cost and the number of effective crew hours.

C_{ST} and C_{TT} : the cost per standing hour and per travelling hour respectively can be calculated by means of the standard formula for the machine cost of the truck.

\mathcal{L} : the full load size per round-trip is known as a practically experienced mean value, and \mathcal{L} is the somewhat abstract value "load per round-trip hour", obtained by dividing the load by hours per round-trip.

(c) In recapitulating the above and recalling the comments previously made on the time units for production calculations, the following table applies:

<u>Operation</u>	<u>Production derived on the basis of:</u>	<u>Costing Formulae</u>
Stump operation	effective crew time	(2)
Off road transport	productive machine time	(1)
Landing	effective crew time	(2) (cross-cutting)
		(3) (other sub.oper.)
Loading	productive machine time	(1)
Main transport	round-trip time	(4)
Unloading	n.a.	the cost is calculated as 75% of the loading cost

2.8.3 Road Costs

Road costs, comprising costs of construction and maintenance of roads, bridges and culverts are - as already mentioned - quite complicated to assess in detail and equally difficult to distribute over the produced volume to a cost per m³. Complications arise from the fact that road costs are accumulating over the entire exploitation period by yearly unequally sized instalments. Variations in the yearly construction cost stem from varying length requirements per year - depending on the stocking of the yearly felling coupes - and varying costs per length unit - depending on topography and soil conditions.

The overall road cost assessment for a potential exploitation when a proper road planning survey has not been carried out must necessarily be based on comparatively few exact data and broad generalizations.

Road costs cannot just be assessed by means of a simple formula, but require a number of sub-calculations to determine:

- (i) the overall length of the totally required road net;
- (ii) the distribution of the total road length to various road standards;
- (iii) the cost of construction per km of roads of various standards;
- (iv) the volume to be served by the established road net, possibly section-wise;
- (v) the road length under maintenance each year and the yearly cost of maintenance per km.

2.8.4 Overhead Costs

The assessment of overhead costs also requires a number of sub-calculations which - if a high degree of exactness were required - would constitute a substantial task and require access to a large number of specific data. It may often be found necessary just to estimate a certain percentage of the total costs and assume this to cover the total overhead costs.

2.9 Recapitulation

The complexity of the exploitation process due to possible different sequences of the operations and the many technical options and combinations of options which can be considered indicate in the first instance the need for assuming a specific exploitation pattern to serve as the skeleton of the cost assessment. Only some of the technical options have been considered in this manual. The pattern which needs to be selected in each case, will have to be as far as possible in accordance with a practically feasible implementation.

The cost is then assessed by estimating for each operation the required input of man-power and machine power, costing the time inputs and calculating the production derived in that time.

Practically experienced average values of required time inputs as well as production figures are available but the problem is to select such values which are most likely to be valid under the given circumstances. The selection must be based on the best assessed and most obviously influencing factors such as the felled volume per ha, the volume per extracted log, the mean diameter of the felled trees etc., ("stand, tree and log data") and the overall terrain conditions as determined on the basis of slope measurements.

Both sets of factors may change considerably from one part of the area to another and the need for selecting different sets of values for different parts of the area is thereby indicated, i.e. it appears necessary to sub-divide the area into smaller area units within which the factors are of approximately the same impact and indicate one set of time input values and production figures, specific for that particular area unit.

However, the standard time inputs and corresponding production figures selected on this basis are still too broad to permit a satisfactory cost estimation for a specific area. It is necessary to consider also some Conditioning Factors which are of influence although usually not with the same impact or at least not quite so obvious in their effect as the two first mentioned. Still, the impact may occasionally be serious enough. Factors of this nature are: thick underbrush, uneven surface, soil of limited bearing capacity, presence of large boulders, etc., which all obstruct the execution of the operations in the terrain. Species or wood features such as high content of silica or latex, severe buttressness, thick bark etc., are adverse in their influence on felling and cutting ease.

The large number in itself indicates the need for considering only some of them but besides their number, they are also often difficult to assess in the field - at least in a practical way - and, furthermore, the quantification of their impact - once they are properly assessed - often creates problems.

The necessity of knowing further some data is evident: Economic Data, such as the basic wage rates of different labourer categories, the cost of different categories of machinery and materials, import duties, etc., the various Road Data partly for estimating road costs partly for estimating hauling costs, Climatic Data in order to estimate the length of feasible operational time and performance efficiency.

In the following chapter, attempts will be made to specify which information is considered essential and how the necessary data can be obtained, processed and presented. The chapter serves as general background for the actual assessment procedure which is set out in detail in part 2 of the manual.

CHAPTER 3

3. DATA REQUIREMENTS, COLLECTING & PROCESSING

3.1 Introduction

In this section the required data for the overall cost assessment will be specified and brief descriptions of collecting and processing the data will be given.

The method of assessing the overall cost as proposed in this manual provides that a certain amount of data is available at the time of initiating the assessment, readily processed to be used for a number of sub-calculations or as direct input in production and cost formulae. Strictly speaking, the collecting and processing of these basic data are not concerned with the cost assessment as such, however, a brief description facilitates the understanding of the assessment procedure and permits modifications and amendments in situations when the outlined guidelines do not fit entirely.

The types of basic data, which are necessary when initiating the cost assessment are:

Overall Descriptive Data:

Geographical data

Topographic data

Soil data

Climatic data

Forest data

Slope Data (terrain classification)

Specific Exploitation Data

Stand, tree and log data

Conditioning factor values

Road transport and access data

Economic and Socio-economic Data

General economic data (currency, rate of interests etc.)

Equipment and materials (acquisition costs, handling charges, import regulations and duties, insurance rates etc.)

Taxation (concession fees, stumpage rates, etc.)

Labour (wage rates, fringe benefits, legislative)

The economic and socio-economic data will apply to the overall area under assessment whereas the specific exploitation data need to be related to smaller geographical units, the Assessment Units, as a range of widely differing data values is often found within the same area.

3.2 Overall Descriptive Data

These data serve in the first instance to locate the area under assessment geographically and to give a broad general description of the overall conditions under which the exploitation will be carried out. Besides permitting an initial classification, the data will also render guidance on determining feasible techniques or options of techniques and estimating yearly operational periods.

The inventory report will normally give quite a comprehensive description from which the specific data can be extracted as required. The necessary data are listed in the Data Base in part 2, chapter 4, DB 3. The section may serve the inventory team as a check list of the data which should at least be provided.

The data will be obtained from general atlases, topographic maps, aerial photographs, general geographical, topographic and botanical documentations on the region and/or the area, climatic statistics etc., all duly supplemented by field observations made in the course of the inventory.

3.3 Terrain Classification (Slope Assessment)

A terrain classification based on slope variations may be obtained from map observations, through photo interpretation or by means of field measurements. The two first mentioned methods yield a "macrodescription" of the terrain whereas a classification based on field recordings reveals substantially more details, inasmuch as it gives a "microdescription" of the terrain and much better indicates the conditions, which the equipment is actually likely to meet with in the area.

A "microdescriptive" terrain classification based on principles recently developed by CTFT has initially been selected and the corresponding requirements for data collecting and processing are recommended for incorporation in future inventories.

For more details of the principles and the practical application of the system, reference is made to the attached appendix 1. 1/

The practical implications can briefly be summarized as follows:

- (i) a terrain classification system is introduced, which comprises 5 different classes or degrees of difficulties in respect of the terrain conditions under which the practical operations will be carried out. 2/

1/ For full explanation of the system, reference is made to the bibliography.

2/ As the "borderline" between class 4 and 5 (the two, representing the highest degree of difficulties) is not sufficiently well substantiated, only 4 classes are operated, the two most adverse classes being lumped together as class 4.

- (ii) the area is divided into a number of geographically identifiable area units, each belonging to one of the above terrain difficulty classes.

3.4 Areal Division (Assessment Units)

The division of the area in area units of different terrain difficulties would constitute a sufficient break-down of the area, provided that other conditions need not be considered.

However, the density of the exploitable stock is another major factor of influence on the operational performance and thereby on the economy. If the stock density varies considerably over a given area, it will become necessary to impose a further division of the area based on stock data.

In practice this may be achieved through photo interpretation or by computation of the inventory data according to special designs, but in either case the result will be that the area is divided into smaller areal units each characterized by a specific combination of stock density and terrain difficulty.

Each of these area units constitutes an area for which a separate set of logging costs will be assessed. Each being characterized by a specific terrain condition and a specific stock density, it is possible to estimate a standard performance of the various physical operations applying only to that particular area unit, since two major criteria for selecting correct standard performance values have been adhered to.

These area units, termed the "Assessment Units", constitute the final breakdown of the entire assessment area.

In establishing the assessment units, endeavours have to be made to limit their number in order not to complicate calculations unduly. Preferably the number should not exceed 10. Endeavours also have to be made to delineate assessment units in the approximate same order of size. If, therefore, one or a few units are much larger than the others a division of such units, entirely based on the areal extent should be made. On the other hand, excessively small units which might have been derived from the initial division, should again be eliminated by including them in adjacent units.

Occasionally, a specific species distribution may constitute the criterion for the subdivision of the area, rather than the stock density. This, however, does not change the general principles of the areal breakdown.

Species distribution and stock density may of course be so uniform that a division based on stock data is not at all required. The same may also apply to the terrain conditions. In such cases the delimitation of the assessment units should be based on the criterion which applies or - if none applies at all - the division may be completely omitted, in which case, however, a division still needs to be made in order to calculate meaningful main transport costs.

The processed data will be made available in the form of a map with the assessment units delimited, numbered and coded in order to facilitate identification as to geographical location, terrain difficulty class and stock density/species class. A table will be provided specifying the size of each assessment unit in ha and other relevant area data.

The principles and practical assessment procedure is described in detail in the guidelines for inventory work contained in appendix 1.

3.5 Stand, Tree and Log Data

3.5.1 Growing Stock (Inventory Data I)

The conventional inventory data are available in a number of tables contained in the inventory report. They are those related to the growing stock and are computed from the basic measurements taken in the course of the inventory in the field and sometimes on aerial photographs. The field observations in respect of the growing trees always include the measurement of the diameter (girth) at breast height or - when the tree is buttressed - at a point within 50 cm above the buttress. Measurements are invariably made "over bark", but a deduction may be made to reduce the measurements to apply to the "under bark" diameter. Recordings of the diameters are often made in diameter classes and the data are segregated in species, or possibly species groups. Height measurements may or may not be taken, but if so, usually only the height up to the crown point is measured. When no height measurements are made - as the case often is - the relation between height and diameter (or volume per tree) may be obtained through special analysis of a sample of felled trees.

The processed data as presented in the inventory report usually only comprise:

Volumes per ha

Numbers of trees per ha

both referring to the total growing stock, segregated in species (species groups) and diameter classes. The volume is the volume of the clear bole under or over bark. Young trees below a certain diameter are generally recorded by numbers only, if at all included.

The growing stock figures are the very basic of all volume calculations related to the cost assessment of the exploitation and they represent the total of the possible yield of the area. Prior to serve as components in production and cost calculations, they need substantial processing. The growing stock figures are not included in the data base but pertinent details of the collecting, processing and presentation will be found in the guidelines for inventory work in appendix 1.

The growing stock data need to be computed per assessment unit in order to yield the required stand, tree and log data.

3.5.2 Felling Stipulations and Exploitable Stock (Inventory Data II)

The growing stock includes all diameter sizes and all species. Only part of this stock is normally exploited in the period for which the cost assessment is meant to apply. Before proper figures for calculating potential productions can be derived from the growing stock figures it is, therefore, necessary to realize in detail how much of the gross stock will actually be utilized, i.e. to specify the Felling Stipulations.

The felling stipulations will identify and specify those species and those sizes which are actually intended to be exploited. Felling stipulations will only apply to one given situation and they may change considerably from time to time, the main trend being that an increasing number of species will be exploited gradually as resources of the better known species become depleted and the need for a fuller utilization of the forests more marked. Marketing considerations are usually of most significance, both in regard to species selection and choice of minimum diameters, but other considerations may also apply such as special protective regulations or government instigated minimum felling limits. The implication may also be that felling of certain non-marketable species is made compulsory, for instance as a silvicultural measure.

The felling stipulations need to be specified in full detail prior to further processing of the growing stock figures. Being a main prerequisite for the cost assessment, they are included in the data base.

It will be understood that for a given cost assessment it is possible to assume alternative felling stipulations if the assessment is to evaluate the cost aspects of different exploitation intensities.

By applying the felling stipulations to the growing stock figures as these are presented in the inventory report, the Exploitable Stock is derived.

The exploitable stock is presented exactly as the gross stock, i.e. per each assessment unit per species (or species group) and per diameter class. The data are the volumes per ha and the corresponding numbers of trees per ha.

3.5.3 Utilization Assessment

3.5.3.1 Introduction

The calculation of exploitable stock data is the first step toward obtaining the stand, tree and log data which are needed for the cost assessment, such as the number of felled trees and the corresponding volume, the volume actually extracted, the average volume per log extracted, the net yield per log extracted etc.

The computation of these specific data is made possible by means of a number of ratios which are provided through a systematic analysis of a number of felled trees, the "Utilization Assessment". For practical reasons the utilization assessment will often have to be carried out outside the assessment area for instance in an ongoing exploitation operating under approximately the same conditions and in similar environments as envisaged for the one under assessment. The utilization assessment is a necessary complement of the inventory work and the readily processed data should be available when initiating the cost assessment. Details of collecting and processing the data are therefore not concerned directly with the cost assessment; however, they are included in the guidelines for inventory work given in appendix 1 to which reference is made for more complete information.

The stand, tree and log data which are eventually to be used for the various calculations of the cost assessment are overall average values, not values applying to each of the inventoried species. For that reason and also in order at all to be able to derive applicable ratios, it is necessary to condense the exploitable stock figures, i.e. to summarize both volume and number of trees per ha to totals of all species and sizes which it is intended to harvest. In doing so it is also possible to calculate a mean diameter (weighting by number of trees in each diameter class) and of course the average volume per tree. A mean height ("bole length") corresponding to the mean diameter may be obtained from established height-diameter (or volume) equations.

The result of this computation will be that for each assessment unit, the following figures of total exploitable stock are obtained:

average volume per ha, all species and all sizes

average number of trees per ha, all species and all sizes

mean volume per tree

mean breast-height diameter (DBH)

mean height

Although these figures are not to be used directly in the cost assessment calculations, they are the basis of all further calculations and are therefore included in the data base.

As the distribution of the total volume to species will however be required for certain specific calculations (e.g. mean weight and buttressness) the species distribution by volume per ha, applying to each assessment unit is likewise included in the data base.

Prior to dealing further with the utilization assessment and the details of the stand, tree and log data derived therefrom, it may be appropriate to review some special aspects of the volume assessment, viz. the changes in volume from operation to operation.

3.5.3.2 Volume Changes

The Exploitable Stock as selected and calculated on the basis of the felling stipulations may after all not be felled in total.

Such Felling Omittances are quite common and may be caused by the felling crew's anticipation of interior defects in individual trees, and may, in that case be more pronounced for certain species, or they may just be due to crew negligence (insufficient supervision). Other reasons may also apply, but in principle felling omissions ought to be small, however, they are in practice quite often experienced to be too marked to be entirely disregarded.

Deduction of the felling omissions from the exploitable stock yields the Felled Stock i.e. the number of trees and their corresponding volume actually felled.

Even if a tree is felled it may still not be utilized at all, alternatively only utilized in part.

Total rejects may be caused by severe interior defects disclosed only after the felling has been completed or a tree may be seriously damaged in the very process of being felled. It may also be that prevailing felling regulations make the felling of a certain species (or size) compulsory although known to be non-marketable.

Partial volume reductions apply to practically all utilized trees. If only topping of the felled trees is practiced, the volume loss will only be small, but if severe partial defects are discovered after felling (e.g. butt-end hollowness) or if felling damages occur, the loss in volume may be substantial.

Reduction of the felled trees should be avoided at the stumpsite to the extent possible, owing to the inconvenient working conditions, which are usually prevailing there. However, some trees may contain an excessive percentage of defective or felling-damaged volume, rendering extraction of the full length obviously irrational and some loss in volume will therefore practically always be experienced.

Total rejects and partial volume reductions caused by bucking of the felled trees make up the total Stump Loss.

When deducting the stump loss from the felled stock, the Felling Yield is obtained, i.e. the number of trees and their corresponding volume which are eventually made at disposal as the production result of the stump operation.

Further qualifications of the felling yield are the number of logs which are produced and the average volume per log. These data indicate a certain degree of cross-cutting intensity in the stump operation and also give indications of some practical aspects of the off-road transport (many or few logs per ha, small or large logs in the load). They are, therefore, required for assessing the work requirements of these two operations.

The felling yield is also the volume intended for extraction in the off-road transport, and as the felling yield usually equals the extracted volume, it may rather be termed the Extracted Volume.

It is of course conceivable that a prepared log will after all be left behind by the tractor crew, if for instance found to be located in an unmanageable position or if it proves too heavy for the tractor to handle. However, in the case of a rationally organized and reasonably well supervised operation, the total felling yield will actually be extracted.

Losses in the course of the off-road transport from stump to landing will normally be quite insignificant and can be ignored, meaning that the felling yield is actually extracted and delivered at the landing in total.

At the landing the extracted logs are reduced to their final shape and size. Especially when "tree-length extraction" is practised, the volume reduction, the Trimming Loss may be substantial but the number of logs may, on the other hand, be increased by large extracted logs being divided into two or more logs as requirements may be. The volume is normally assessed under bark, even if debarking is not practised.

The extracted volume less the trimming loss equals the volume which will be available for loading and despatch in the main transport operation. As losses in the course of the main transport are normally insignificant and can be ignored, the volume prepared in the landing operation for loading and despatch equals the final yield of the exploitation process which is eventually delivered at the delivery point. It can therefore rightly be termed the Net Yield.

The latter assumption is reasonable in the case of a truck hauling operation where possibly lost logs en route will usually be salvaged later, but it does not apply if river transport is practised. In such cases the losses en route may be very substantial. However, as previously mentioned, the cost assessment only considers truck hauling.

As the cost assessment also does not include storage and reloading at the delivery point or further transport from the delivery point, possible losses or volume reductions after unloading at the delivery point are not considered. They may comprise actual losses en route and/or during the loading on board an ocean-going vessel and also possibly final trimming losses prior to shipment.

The above may be recapitulated as follows:

<u>The data are:</u>	<u>Term:</u>
assessed:	<u>Growing Stock</u>
determined and applied:	felling stipulations
derived:	<u>Exploitable Stock</u>
adjustment:	felling omissions
derived:	<u>Felled Stock</u>
adjustment:	stump loss
derived:	Felling Yield = <u>Extracted Stock</u> - Landed Volume
adjustment:	trimming loss
derived:	<u>Net Yield</u>

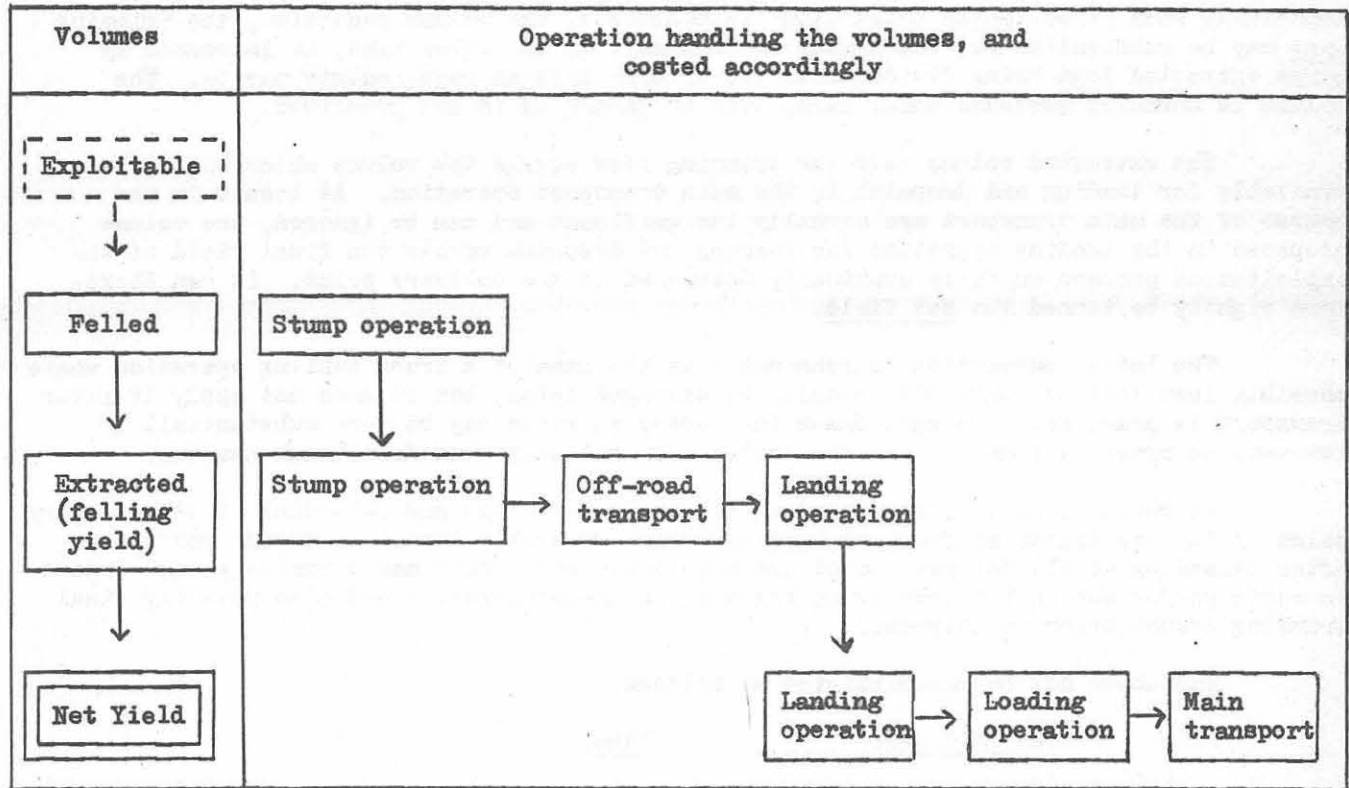
3.5.3.3 Application of the Data from the Utilization Assessment

As previously mentioned, the stand tree data provided by the inventory were the exploitable stock data, obtained by applying the felling stipulations to the gross figures of the growing stock. The data are specific for each assessment unit but they are to be confined to average values of volume per ha, number of trees per ha, DBH and height, before they can be used in the assessment calculations.

The data which are required as key parameters in the various production formulae of the cost assessment are those just dealt with in the foregoing section.

Whereas the growing stock figures are permanent until exploitation is implemented, changed felling stipulations will yield a new set of stand, tree and log data, based on all calculations which must then be carried through, in order to obtain a cost assessment applying to the new stipulations. This, for instance, has to be done if the economic aspects of optional exploitation intensities are to be evaluated. A new field assessment of the utilization data may not necessarily be required.

The various volume categories as derived through the utilization assessment are related to the operational costs as recapitulated below:



It will be understood that the cost per m³ of each operation applies in the first instance to the volume handled in that particular operation (e.g. off-road transport cost is calculated per m³ extracted volume). The operational costs calculated in this way are of interest when evaluating exploitation options or when comparing with other exploitations. However, the final cost to be derived through the cost assessment is a total average exploitation cost per m³ of the net yield. It is therefore necessary to adjust each calculated cost to apply to the final net yield before adding up the individual costs; for instance, the basis of the off-road transport cost is the extracted volume but the extracted volume is reduced at the landing through the trimming loss and the extraction cost per m³ net yield must therefore be obtained by multiplying the cost per m³ extracted volume by the coefficient:

$$\frac{\text{extracted volume}}{\text{net yield}} \quad (> 1.0)$$

This "cost/volume adjustment coefficient" is directly obtained from the utilization assessment.

3.6 Conditioning Factors

It has already been mentioned that the practical operations whether in the terrain, at the landing or on the roads will meet with conditions which may only, to a certain extent, be accounted for by the two main factors: terrain as quantified through the terrain classification and stand, tree and log data as quantified through the utilization assessment.

Such additional Conditioning Factors are mainly confined to one of three categories: those related to the trees or the wood; those related to the terrain and soil and those stemming from the climatic conditions.

Numerous factors can be imagined, which in one way or another may influence the ease with which, for instance, the stump operation can be carried out; the distance between trees to be felled (time/consuming walking), thick underbrush, rugged terrain surface, many obstacles such as windfalls and large boulders (impeding walking), crooked or badly leaning trees (increased chances of saw jamming and other felling hazards) dense canopy (increased chances of "hang-ups", especially if also lianas are present), large diameters of the trees, excessively large buttresses (increased time for cutting compared to derived volume), high content of silica (increased number of saw changes), many branches which need to be trimmed off, thick bark which may have to be removed etc.

Likewise, numerous similar - or sometimes the same - factors can influence the ease with which the off-road transport operation is carried out: thick underbrush, (e.g. bamboo), impeding the movement of a tractor; large and heavy obstacles (e.g. large boulders or windfalls) which will force the tractor to deviate from a straight travel direction in order to bypass; slippery surface soil, causing the skidder wheels to spin; poor bearing capacity of the soil, which causes the tractor to bog down etc.

Many of the factors only appear sporadically and the impact on the overall performance efficiency of an operation may be quite insignificant if the relative appearance of the factor is sufficiently small. Others, however, occur much more commonly and may in some cases have a marked and obvious influence. Unfortunately, practically all of these factors are also difficult to assess - at least if excessive extra field work is to be avoided - and furthermore difficulties are experienced in quantifying the impact of a possibly well assessed factor, due to lack of systematic investigations in the case of tropical exploitations.

After a thorough analysis, six conditioning factors appear to be sufficiently important to warrant a quantification of their impact viz:

- Buttressness of the trees
- Bark, or rather, Debarking Requirement
- Underbrush
- Surface Evenness
- Surface Obstacles
- Soil Firmness

The number is small compared to the number of conceivable factors and neither the method of assessing the factors in the field nor of the quantification of their impact on operations can claim to be well substantiated; however, it is assumed that the adopted method will render the possibility of taking at least the extreme appearance of one or more factors sufficiently well into account so as to increase the reliability of the eventual cost assessment somewhat.

The method of assessing the factors in the field and the initial processing of the data will appear from the guidelines for the inventory work in appendix 1 to which reference is made for more details.

The result of the inventory assessment is included in the Data Base and the practical utilization of the factor values is dealt with in the Pre-Calculations, both contained in part 2 of the manual.

Concerning climatic influence on the operational performance, an adverse effect often appears quite obvious. Climatic data are usually easy to obtain and are also useful in other contexts (e.g. determination of operational periods). They will therefore be supplied by the inventory and included in the Data Base, but the use of data for the purpose of adjusting the general work performances is more problematic. However, in the Pre-Calculations, an attempt has been made to take the assumed influence of varying climatic conditions into account by indicating adjustment coefficients to be applied to production formulae. A comprehensive study on the effect of climatic factors can be found in the bibliography.

3.7 Road, Transport and Access Data

The need for specific data to evaluate the economic implications of establishing access to the area and for estimating required road constructions, transport distances etc., is obvious.

The data are collected in the course of the inventory field survey, partly by direct observations in the field, partly by recording relevant information obtained from public service departments, local entrepreneurs and possibly existing exploitation enterprises.

3.8 Economic and Socio-Economic Data

Equally obvious is the need for a large number of economic and socio-economic data: rate of interest, taxations, cost of equipment and materials, basic wage rates, cost of applicable fringe benefits etc.

The data are obtained from public service departments, labour laws, wage regulations and - whenever possible - from possibly existing exploitation enterprises.

3.9 Recapitulation of Data Requirements

The data which have been dealt with in the foregoing are all basic data required for the two elements of the cost assessment, i.e. the time costing and the production calculation.

They are pre-requisites for the assessment and are recorded in the Data Base.

The Data Base constitutes the systematically recorded information at hand when initiating the actual cost assessment. The practical procedure in carrying out the cost assessment would therefore be initially to ensure that the Data Base is complete and all data properly coded for easy identification and references.

Once the Data Base is properly established the cost assessment can be initiated.

The Data Base is presented as chapter 4 of part 2.

3.10 The Pre-Calculations and the Cost Assessment

The Pre-Calculations, chapter 5 of part 2, contains the pertinent guidelines in carrying out the numerous calculations which eventually will result in the comparatively small number of data from which the cost assessment proper is derived.

The Cost Assessment is presented as chapter 6, part 2 of the manual.

These three chapters contain appropriate guidelines in collecting, grouping and processing the required data and endeavour to outline a standardized and not too complicated calculation procedure in reaching the final result, the single average cost figure for the entire assessment area.

If optimal solutions are required, e.g. if different transport possibilities or different exploitation intensities may be considered, the question is merely of repeating those calculations affected by alternative basic data.

The three chapters are coded separately with a code index preceding each chapter. The codes are identified by symbols preceding the code numbers viz:

Data Base	DB - code number
Pre-Calculations	PC - code number
Cost Assessment	CA - code number

Appendix 1

GUIDELINES FOR PREINVESTMENT SURVEYS

The methodology described in this manual for the assessment of logging costs in tropical forests relies on the provision of certain physical data which are to be collected and processed within the framework of a preinvestment survey. These data are presented in chapter 4 in sections DB1 to DB4 ("area map", "area summary", "overall descriptive data", "specific exploitation data"). Although the meaning of these data can be easily understood, some guidelines are needed on the best way to collect, quantify, process and present them for their subsequent use in the logging cost calculations. This is the more necessary as the methodology proposed in this manual for the assessment of logging costs calls for some inventory requirements which are not necessarily fulfilled in most preinvestment forest surveys carried out at present in the tropics.

Basically these guidelines refer to four important subjects:

- (i) terrain classification: in the methodology proposed the studied area is divided into assessment units, with each having the same topographic configuration or terrain difficulty class; information will be provided on this classification and guidelines given on the corresponding stratification in the forest inventory work;
- (ii) conditioning factors: indication of the most important ones and guidelines on their recording and processing for use in the logging cost calculations;
- (iii) utilization factors: the volume to be exploited is not the volume felled, which in turn is not the volume extracted, itself smaller than the volume delivered; guidelines will be given on how to estimate the ratios between these different volumes, which are needed in the logging cost calculations;
- (iv) provision of inventory results: it is important to provide sufficiently detailed inventory results and present them according to certain standards in order to ease the calculation of logging costs and to avoid reprocessing the basic inventory data; guidelines will also be given on these aspects.

1. Terrain classification and related issues

1.1 Introduction

The terrain features which have a bearing on logging are either related to slopes, or to ground surface. The latter are taken into account as conditioning factors (see section 2 of this appendix while slope needs to be considered separately. There are two ways of introducing slope in the logging cost calculations. One is to have the mean slope (over a given area) introduced directly as a parameter in the cost formulae for the various logging operations. An example of this is given in the evaluation of logging costs made in several FAO forestry development projects ^{1/}. Another possibility is to stratify the studied area in fairly homogeneous subdivisions, each corresponding to a given terrain difficulty according to an existing terrain classification. This approach is the one followed in this manual.

^{1/} see e.g. "Evaluation of Accessibility of Forest Resources - A Pilot Study on Logging Costs from Inventory Data" (FO:Miso/72/15). FAO - 1972.

Most tropical forest surveys involve a stratification of the inventoried area which is based almost invariably on stand condition criteria (composition and total stocking), although it may also take into consideration the general topography. This stratification is aimed mostly at improving the precision of the stand and stock estimates obtained from field sampling. It is carried out either before or after the selection of the field sample from remote sensing imagery (generally conventional aerial photographs) and is used for subdividing the studied area in various "strata" (or at least it is providing the sample estimates of their respective areas). These strata correspond generally to different forest/vegetation types, or "condition classes" (according to dominant height or crown cover density). The criteria used for this type of stratification ("forest stratification") are usually well correlated with the most important parameters to be estimated, e.g. total growing stock above a minimum diameter, or exploitable stock (i.e. above the minimum exploitable diameter) of a given species, or of groups of commercial species. There may be in addition a "geographic" stratification of the inventoried area when information is requested not only for the whole area but also for geographic subdivisions, such as "blocks", "compartments" etc. In this latter case the smallest "report unit" or "reference unit", i.e. the smallest unit for which inventory results are given separately, correspond generally to the area covered by each individual "forest" stratum within each "geographic" subdivision. If there is "forest stratification" without "geographic stratification" or "geographic stratification" without "forest stratification" then the smallest report unit will be respectively forest strata for the whole inventoried area or the geographic subdivisions themselves.

The methodology developed in this manual for the assessment of logging costs introduces a third type of stratification based on topography. The superposition of these three types of stratification leads in most cases to an excessive number of "assessment units" for the calculation of logging costs, which will correspond to small patches scattered over the whole area under study. Some simplification has to be sought. In addition to providing some explanation on the terrain difficulty stratification recommended in this manual, the following sections will give indications on the best ways to combine the various stratifications in order to arrive at a meaningful division of the studied area into assessment units. By "meaningful" it is understood that the final division should result in a small (say less than 10) number of relatively large, homogeneous assessment units, each composed of one block for which inventory results should be provided separately.

1.2 Stratification according to terrain difficulty

1.2.1 Presentation of the terrain classification recommended in the manual

In the framework of the UNDP/FAO Forest Development Project in Gabon (1968-1973), slopes (say over 10 to 20 m distance) were measured at each point every 50 m on the long axis (inventory line) of each 250 x 40 m (0.5 ha) rectangular recording units, four measurements being taken at each point (forward and backward along the inventory line, and left and right, at right-angles). The steepest slopes in the four elementary planes determined by these four directions around each point were calculated by the relation $P = \sqrt{P_1^2 + P_2^2}$ (P_1 and P_2 being the slopes recorded in the two perpendicular directions of each plane). All P values were then classified by 10% intervals.

Rather than determining for each area an overall mean slope which would condense all the slope information in a single mean value, it was deemed more useful to represent graphically the distribution of the slopes P in the area concerned by a curve of the cumulated percentages of the 10% slope classes. These curves are drawn on a semi-logarithmic graph, with the logarithms of slopes on the x-axis and the cumulated area percentages on the y-axis. The following table gives the cumulated percentages found for the area.

Slope percentage classes	Number of P values		Cumulated percentages %
	absolute	%	
0-10	57	42	42
10-20	37	27	69
20-30	24	18	87
30-40	8	6	93
40-50	6	4	97
50-60	3	2	99
60-70	1	1	100
Total	136	100	

The curve of cumulated percentages obtained in this way for a given area is then compared to a predetermined set of similar curves separating various terrain difficulty classes called "easy", "medium", "broken", "difficult" and "very difficult". These limits have been established empirically from the study of various forest areas in Gabon and Ivory Coast.

They are shown in figure 1. In most cases the curve for a given area with fairly homogeneous topographic conditions will fall largely between two such limit curves and the corresponding area will be qualified accordingly.

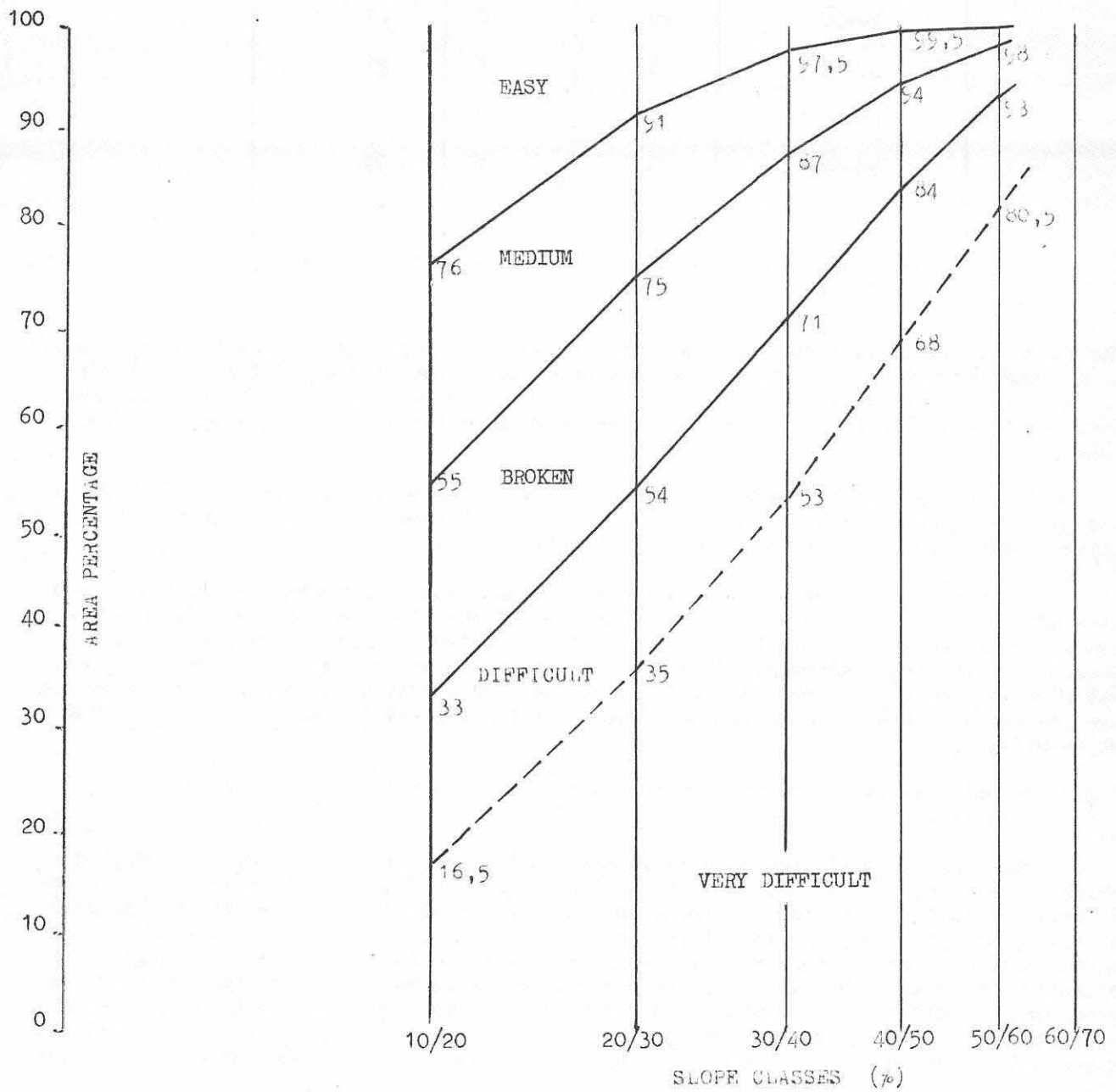
The number of slope measurements done in the field is necessarily limited by the size of the field sample used for the estimation of the stand parameters. It would be useful to assess the terrain difficulty class of a given area from measurements on aerial photographs and maps, which could be done as numerous as desired. However, the above set of curves should be used carefully since the actual slopes as measured on the ground are generally steeper than their measurements on the topographic maps or on the aerial photographs.

1.2.2 Stratification of the studied area according to the terrain difficulty classification

There are at least two main advantages in the terrain classification described above. The first one, already mentioned, derives from a fuller utilization of the slope information collected during the field inventory (or possibly from the topographic maps or the aerial photographs). The classification is in a certain way more "powerful" than a classification which would be based only on a mean slope. The second advantage is directly connected with this first one and can be expressed this way: two areas of the same class should be quite similar and therefore it should be possible to apply to one area the values of logging parameters already found for the other, as far, of course, as topography is the sole or the overwhelming determining factor for the parameters concerned.

In the case when no other criteria for stratification are to be considered, e.g. if the area under study is fairly homogeneous in terms of composition and total stocking, and with no geographic stratification, the area should be divided into a limited number of units of homogeneous terrain conditions. These subdivisions, which should be geographically identifiable, composed of one block and of comparable sizes, will be the assessment units referred to in the manual.

Figure 1. Curves of cumulated percentages separating terrain difficulty classes



Their number should not in any case exceed 10. Two or more assessment units may correspond to the same difficulty class; this may happen if one difficulty class is much more represented than others and/or if this difficulty class characterizes two or more geographically distinct parts of the studied area.

Inventory results will obviously have to be provided for each assessment unit. This means that the division according to terrain difficulty class should be made before the final processing of the inventory data, and each sampling unit assigned to its assessment unit ^{1/}.

1.3 Combination of terrain difficulty stratification with other types of stratification

As it has been mentioned above, other criteria than topography are considered in most surveys. This is the case when differences in composition or in total stocking are significant within the studied area; then the gain in precision on the estimates of the stand parameters is worth introducing a stratification. This applies in particular when different forest vegetation types are found in the studied area, e.g. swamp forest as opposed to forest on dry soils, or pure stands of a gregarious species surrounded by mixed forest, etc. Also a geographic stratification may be required if the area has to be divided for its management and utilization, e.g. division in watersheds, by a large river, by limits between concession areas or areas of different ownership or tenure, administrative boundaries, etc.

Before inventorying the area, or at least before processing the inventory data, a final division of the area must be decided on, integrating the three different types of stratification, with the aim of obtaining a limited number (say smaller than 10) of homogeneous (in terms of topography) assessment units, composed of one block, of comparable size, for which inventory results will be provided separately. The following should assist in shaping up this divisions:

- (i) division into homogeneous topographical units should be made from the interpretation of existing topographic maps and/or remote sensing imagery (aerial photographs, radar or satellite images). Field checking is in any case indispensable if this division is decided prior to the field inventory; indeed microtopographic features are often not visible, and the forest canopy tends to "smoothen" terrain features. Stereoscopic observation of conventional aerial photographs or of the overlap between adjacent radar strips is recommended. It is also worth mentioning that radar images are most useful for an overall assessment of terrain conditions, which are further enhanced by shadow effects.
- (ii) The stratification based on stand conditions can be considered, if needed, as an independent division of the studied area, so that two or more of the corresponding strata can be found in a given assessment unit. If we consider for instance the common case of narrow strips of swamp forest along the creeks which are easily identifiable on large or medium scale aerial photographs a stratification between these swamp forests and the forests on dry soils will

^{1/} Statistically, this division according to terrain difficulty class will be either a stratification "a-priori" if the selection of field sampling units is made independently for each assessment unit, or a stratification "a-posteriori" if this division is made after the sampling design has already been decided on. The sampling error formulae will, of course, have to correspond to the actual type of stratification.

be useful for reducing the sampling error of the estimates. However, this network of strips of swamp forest cannot form a consistent assessment unit. Therefore, in this case, the division into assessment units should be made independently from the stratification swamp forest/forest on dry soils, and most or all the assessment units will include both types of forest. It would be different if some swamp forests were wide enough to be considered as individual assessment units (e.g. very wide swampy flats along main rivers). Another stand stratification to be considered independently is the one in "condition classes" i.e. in dominant height and crown density classes, which may result in an intricate patchwork of stands and cannot be integrated adequately in the division in assessment units. In all such cases estimated mean volumes or numbers of stems at the assessment unit level are stratified estimates (i.e. weighted by the relative area of each stratum within the considered assessment unit). Intermediate results at the stratum level within each assessment unit can also be tabulated since they are calculated in the data processing procedure. In terms of data processing, it will be said that the assessment unit is the "inventory unit", while the whole studied area will be a "group of inventory units".

- (iii) If the stand stratification results in fairly large blocks of forest area, then it should be incorporated in the final division in assessment units. The boundaries corresponding to the three types of stratification should be adjusted and "generalized" in order to end up with a limited number of assessment units of comparable size.

2. Collection and processing of conditioning factors

2.1 Introduction

In order to further specify the conditions under which some of the operations will be carried out and accordingly to incorporate appropriate adjustments in the production (or performance) calculations, observations need to be made on the presence of a number of conditioning factors. Of the numerous conceivable factors, six have been selected for quantification, viz:

Tree/Log Factors	{	Buttressness
	{	Debarking Requirements
Environment Factors	{	Underbrush
	{	Surface Evenness
	{	Surface Obstacles
	{	Soil Firmness

2.2 Buttressness

- (i) Certain species are characterized by the presence of well developed flanges extending from the base and sometimes reaching several metres above ground level. In the case of a heavily flanged species the felling time of an individual tree will be substantially increased, and when the felled stock contains a high percentage of such species, an adjustment of the calculated average operational time per tree of the stump operation is to be taken into consideration.

- (ii) For each assessment unit, fill in a table as follows:

Assessment Unit

	(1)	(2)	(3)	(4)
Species-Spp. Group	Volume/Ha, exploitable		Code for Degree of Buttressness	Percentage of Volumes coded "b"
	in m ³	in % of total per ha		
Reference Code:	DB 4.2.1			
Name - Spp. Code:	(m ³)	(%)	("a" or "b")	(%)
TOTAL		100		

Remarks:

- ref. (1) the species distribution by volume per ha will appear from the table in the data base, DB 4.2
 - ref. (2) calculate on the basis of the volumes in (1) and the total of (1)
 - ref. (3) based on indications from the botanical and technical literature, code each species (spp. group) in respect of buttressness, using the following indications:
 - "a" The species is non-buttressed or only moderately buttressed, i.e. the diameter measured at breast height on the matured tree and including the flanges if extending above breast height does not exceed twice the diameter of the solid trunk measured at breast height.
 - "b" The species is buttressed, i.e. the diameter, including the flanges and measured as above exceeds twice the diameter of the solid trunk.
 - ref. (4) extract from (2) the percentage values of all species, coded "b" and add up.
- (iii) Calculate the factor values by means of the following indications and transfer for each assessment unit to the table in DB 4.8.

	<u>Factor Value</u>
Total of "b" < 25%	1
" 25 - 50%	2
" > 50%	3

2.3 Debarking Requirements

- (i) Certain species are usually debarked as a protective measure against insect damage. In the case of commonly utilized species, information on actual (customary) debarking requirements can in most cases be obtained from the technical literature or by means of local indications. Otherwise, consider that the bark is to be removed if the bark thickness of the matured tree exceeds 5 cm.
- (ii) For each assessment unit, fill in a table as follows:

Assessment Unit

Species-Spp. Group	(1) Volume/ha, exploitable	(2)	(3)	(4)
	in m ³	in % of total per ha	Code for Debarking Requirement	Percentage of Volumes coded "b"
Reference Code:	DB 4.2.1			
Name - Spp. Code:	(m ³)	(%)	("a" or "b")	(%)
TOTAL		100		

Remarks:

ref. (1) the species distribution by volume per ha will appear from the table in DB 4.2

ref. (2) calculate on the basis of the volumes in (1) and the total of (1)

ref. (3) code each species (spp. group) in respect of debarking requirements, using the following criteria:

"a" debarking is not required

"b" debarking is required

ref. (4) extract from (2) the percentage values of all species, coded "b" and add up.

(iii) Calculate the Factor Value by dividing the total of (4) by 100 and transfer to the table in DB 4.8.

2.4 Field Observations

The conditions under which the off-road equipment operates are already characterized by the difficulty classification of the terrain as obtained through the application of the terrain classification system described in detail in Section 1 of this appendix. The influence of the terrain on (a) the travel time and (b) the time for load charging the off-road equipment is incorporated in the indications of the basic time for the two time elements (see PC 9.2.1 and PC 9.3.1).

However, in addition to the topographic conditions of the terrain, also such features as the presence of underbrush, the evenness of the surface, the number of surface obstacles found and the condition of the soil in respect of bearing capacity, thrust capacity etc., may differ considerably; accordingly, the influence of these factors on operational performance must be taken into consideration as a further qualification of the terrain difficulty class.

Observations in the field should therefore be made as further specified below. In order to keep the field work at a practicable level, the additional observations should be confined to a limited number of the sample plots of the inventory, say 10%.

The procedure will be that the team walks the entire length of the borderlines of the selected plots. Endeavours should be made to follow the straight lines to the extent possible even if underbrush vegetation has to be cleared by machete and/or obstacles have to be climbed. In the course of walking the borderline, observations should be made and an evaluation recorded for each plot as described in the following.

2.5 Underbrush

- (i) Endeavour to evaluate the overall dominating condition of the plot in respect of underbrush vegetation including juvenile trees and possible creepers, lianas etc. Code the plot in accordance with the following indications:
 - (a) the underbrush is in a state between open and scattered or - if more dense - is only composed of weak and thin vegetation rendering little or no difficulty in walking along the straight line. Clusters of tough vegetation may occur (e.g. bamboo), but infrequently only, and easily bypassed without excessive detouring;
 - (b) the underbrush is more closed and tough and walking along the straight line requires clearing by machete. The vegetation and/or the frequent presence of juvenile trees above 15 cm diameter clearly appear to be obstructive to the travel ease of off-road equipment and/or clusters of tough vegetation are frequent and will cause considerable detouring in bypassing ("cruising");
 - (c) the underbrush is very dense and tough, rendering walking very exhaustive and obviously obstructing the free movement of off-road equipment seriously.

2.6 Surface Evenness

In the course of walking along the borderline, record the number of crossings of gullies, narrow creeks, etc., when these are deeper than 1 m and less than 3 m wide. Endeavour to evaluate the overall condition of the plot in respect of surface evenness and code in accordance with the following indications:

- (a) the surface is even to moderately uneven. Possible dents (bumps) are mostly wider than 3 m and less than 1 m deep (high). The number of crossings of gullies averages less than 5 per 100 m of borderline;

- (b) the surface is uneven to rugged with the frequent appearance of deeper and/or narrower dents; the number of crossings averages less than 5 per 100 m of borderline;
- (c) the dominant feature of the surface is the frequent crossings of gullies, which exceed 5 per 100 m of borderline;

2.7 Surface Obstacles

Only observe obstacles which are obviously obstructing the free movement of off-road equipment, e.g. heavy boulders and/or stumps exceeding 50 cm in height, larger fallen trees, protruding roots, etc. Disregard obstacles which can obviously be pushed aside without difficulty by a passing tractor, i.e. obstacles to be observed are such which either need to be bypassed by detouring or require the engagement of the dozer blade in removing. Record the number of obstacles located on the borderline and code the plot in respect of surface obstacles as follows:

- (a) the number of obstacles is 5 or less per 100 m of borderline;
- (b) the number of obstacles per 100 m of borderline exceeds 5 but is less than 20;
- (c) the number of obstacles per 100 m of borderline is 20 or more.

2.8 Soil Firmness

The aim is to evaluate the plot in respect of the soil's capacity of supporting the off-road equipment. At the approximate centre of the plot, dig a 50 cm deep hole. Observe the humus layer and the removed sub-soil and code the plot in respect of soil firmness, following the indications below:

- (a) the humus layer is 10 cm thick or less. The sub-soil consists of gravel or laterite and will obviously compact well under tractor-tracks;
- (b) the humus layer may reach a thickness of 35 cm but the sub-soil is as above, or less firm (e.g. clayish) but stabilized by high content of stones;
- (c) the humus layer may reach a thickness of 35 cm and the sub-soil is loose or soft (sand, clay). Alternatively, the humus layer exceeds 35 cm in thickness.

2.9 Insert the codes of each plot in a table as shown below and complete the table

Assessment Unit

[illegible]

* calculate the Factor Values for each factor by means of the following indications:

	<u>Factor Value</u>
$b + o < 20\%$	1
$b + o \ 20-50\%, \ o \leq b$	2
$b + o \ 20-50\%, \ o > b$	3
$b + o > 50\%, \ o \leq b$	4
$b + o > 50\%, \ o > b$	5

Transfer the Factor Values for each assessment unit to the table in DB 4.8.

3. Assessment of utilization factors

3.1 Introduction

The volume estimates given in forest inventory reports are very seldom comparable because they do not relate to the same concepts of volume. Volumes considered can include the whole tree, with branches or the bole only, or the "free" or "merchantable" bole. It may be with or without bark. But, even more important, allowance may be made for defective parts (whether external defects or internal decay) in relation to a given end-use. These volumes are called "net volumes" as compared to "gross volumes" which include both non-defective and defective parts. Generally all volumes are derived from the corresponding numbers of stems by the application of volume functions (or taper functions) established from a sample of carefully measured standing or felled trees of similar specifications.

The main reason for assessing "net" volumes instead of "gross" volumes is to try to better adjust to possible utilization of the standing trees. Inventory reports will, for instance, provide means or totals of "net sawtimber volumes" or "net veneer volumes". However, subsequent measurements made in logging units in the framework of utilization studies (or "recovery studies", or "harvesting intensity studies") show generally that net inventory volumes can be quite different from those actually extracted. In addition to the subjective biases in the estimation of "defect", it happens that standing trees or parts of felled trees are left for various reasons which could not be determined by the inventory team: internal decay could not be detected or assessed properly, market conditions may have changed since the time of the inventory (e.g. quality standards may have been lowered or raised) felling or bucking may have been deemed difficult or impossible (e.g. tree dangerous to fell, likely to fall in unmanageable position, log damaged during felling, log irretrievable) or accessibility or management regulations may have resulted in increasing the overall utilisation of the forest with reduced selection of trees and logs.

This is why it is strongly recommended that all tropical inventories provide estimates of gross volumes, which can constitute an objective base for subsequent assessment of the recovery in logging units, in similar conditions of utilization, accessibility, market, logging and management. In fact it is a prerequisite for the methodology proposed in this manual for the assessment of logging costs. The most useful concept of gross volume will in many cases be the gross volume over bark of the bole from the stump or the top of the buttresses to the crown point (i.e. the origin of the lowest crown forming branches, living or dead). From the gross volume of the selected species above their minimum exploitable diameter (felling stipulations), which is called in the manual exploitable stock (see section 3.5.1 of the main text), the volumes handled in the successive stages of logging will be determined through a utilization study carried out in logging units. Even if the net volumes determined by the inventory could equal with an acceptable accuracy the actual volume exploited (called "net yield" in section 3.5.1 of the main text) - which cannot be the case in many instances as indicated above - it would still be necessary to obtain estimates of the volumes handled in the logging operations (called "felled stock" and "extracted volume" in section 3.5.1 of the main text) to estimate precisely the logging costs. It can be argued that the differences between the felled stock and the extracted volume, and between this latter and the net yield could be in some cases neglected. Even in these cases experience shows that felled stock can be significantly lower than the exploitable stock and the corresponding ratio will have to be estimated.

A utilization study therefore appears as an indispensable complement of a pre-investment survey in a tropical area, not only for an acceptable assessment of the percentage of the inventory gross volume (exploitable stock) which is likely to be utilized, but also for getting an estimate of the volumes likely to be handled in the logging process.

3.2 Design and implementation of a utilization study ^{1/}

To this end the utilization study in a given preinvestment survey will provide an estimation of the utilization factors i.e. ratios of the volumes felled, extracted and delivered (respectively called "felled stock", "extracted volume" and "net yield") to the "exploitable volume", i.e. the gross volume given by the inventory of the selected species and dimensions. First of all the species to be exploited should be classified by groups of similar use in order to reduce to a reasonable size the amount of work for the utilization study. If one or a few species are of utmost importance, they may of course be considered individually. Utilization factors will be determined for each such group.

The study will consist of following a sample of standing trees in the harvesting process within one or several logging units. Some of the trees of each given group and of the right diameter classes will be left standing for various reasons and the comparison of their volume with that of the felled trees will provide an estimation of the "felling ratio" (DB 4.4.2) for the corresponding group. Measurement of the volume of the sections (or total trees) left at the stump will allow in turn for the estimation of the "extraction ratio" (DB 4.4.4) for the species group considered, i.e. the ratio of the "extracted volume" to the "felled volume". Finally measurements at the landing of the "trimming loss" and of the final logs as prepared for main transport will provide an estimate of the "yield ratio" (DB 4.4.5) that is the ratio between the volumes of the delivered logs ("net yield") to the "extracted volume".

Several guidelines are useful for conducting a utilization study:

- (i) A good sampling of the trees is of critical importance, although it is difficult to achieve. Causes of bias are many and every effort should be made to reduce their impact. The guiding principle is that it should be as representative as possible of the utilization alternatives considered in the preinvestment study, as regards marketing (e.g. export, or local processing, or a known combination of both), harvesting regulations and techniques and general terrain conditions and accessibility to utilization or export centres. If one or several logging units exist already in the studied area or in the immediate vicinity, then they should be used for the utilization study. If not, logging units with most similar utilization conditions will be selected outside the studied area. As far as possible more than one logging unit should be considered in order that the utilization factors do not reflect the recovery obtained by one logger only.

For each group of species, the "felling ratio" should be estimated by comparison of the tally records and the log books, if these two documents are reliable enough. If not, a survey should be made over a sufficiently large area in the various logging units either recently exploited or being exploited in order to assess the proportion of "exploitable volume" left standing, if any.

The sample of trees felled and followed in the process of logging should be distributed among the logging units selected in order to get a minimum of trees (say 50) for each group of species. In most cases it will be assumed that for a given species, group size and age distribution of the sample trees will be the same as for the trees in the inventoried area.

^{1/} See also "Manual of forest inventory with special reference to mixed tropical forests", page 125 - 128. FAO - 1973

- ii) For the sake of homogeneity and accuracy, the measurements of all sections of the trees felled will be measured by frustums of similar length (say 1-2 m approximately) to which the same type of geometric formula is applied (Smalian or Huber formulae). The section left at the butt and that left at the crown point after topping will be considered as a single frustum, while the whole log to be extracted (or its parts) will have to be divided virtually in several frustums of approximately equal length. Measurements will be made over bark and no allowance should be made for internal or external defect since the initial reference volume is a gross volume over bark. A special tally sheet should be carefully designed for all these measurements to ease the subsequent processing which can be manual or, if needed, with the help of desk computers. If trees are not numbered by the logger and logs marked in relation with the number of the trees, a numbering device should be worked out by the person responsible for the utilization study in order that the logs can be referred to the corresponding trees. Generally speaking, there is no special difficulty in the implementation of such a study, however, it has to be carried out with much care and order. Even in the case of an important logging unit with a large daily output, experience shows that it is difficult for a two-man crew to have a complete record for more than 20 trees per day.
- iii) The various utilization ratios can be simply obtained for each species group by totalling the volumes of all the corresponding sample trees at each stage of the harvesting process and dividing them. For instance, the "extraction ratio" for a given group of species will be obtained by totalling the volumes of all the logs extracted from the felled trees sampled and dividing this total by the sum of the gross volumes of these trees (i.e. volume of butt, top and felled bole). Application of the volume equations used in the inventory to the felled trees during the utilization study would be erroneous since these gross volumes would be assessed differently than the volumes they have to be compared to (volume of extracted or delivered logs). This is why geometric formulae have to be applied to the assessment of the volumes of the trees felled and of the logs and the sections left in the forest or at the landing. For the assessment of felling ratio, i.e. the ratio between the total volume of trees actually felled and the total volume of exploitable trees ("exploitable stock"), the volume equations used in the inventory should be used for trees left standing and trees actually felled. As a consequence the gross volumes of trees felled will be assessed in two ways - application of volume equations and measurement of sections with application of geometric formulae - and this will provide an opportunity to check the fitness of the volume functions used in the inventory, correct them if necessary, and possibly also add these additional sample trees to the sample used for the elaboration of the volume equations.
- (iv) The values obtained for the utilization ratios are sampling estimates since they are derived from only a small fraction of the forest area concerned if logging is going on in the studied area, or, as is often the case, from one or several areas in logging units outside the studied area. Their precision depends on the size of the sample, viz. the number of trees observed and measured for each species group. Stratification of the "exploitable stock" in quality classes is a way to improve the precision on the utilization ratios. If quality assessment on a tree or log basis is made in the course of the field inventory, then the "exploitable stock" for each species group can be subdivided (or "stratified") in volumes corresponding to each quality class. The same type of quality assessment can be made on the trees observed and measured during the utilization study, each tree or each frustum being qualified. In each species group, utilization ratios can be estimated for each quality class and an overall stratified estimate calculated by weighing the estimates by quality by the percentage of this quality class in the "exploitable stock".

If: V_1, V_2, \dots, V_k are the total volumes ("exploitable stock") of quality classes 1, 2 ... k for a given species group in one assessment unit (or the total inventoried area), estimated from the field inventory,

- V is the corresponding total estimated volume (all qualities together):

$$V = \sum_{i=1}^k V_i$$

- $q_1, q_2 \dots q_k$ are the values of a given utilization ratio (e.g. "extraction ratio") for the same species group for the quality classes 1, 2 ... k, estimated by the utilization study,

then the stratified estimate of the utilization ratio, q , all classes together, will be:

$$q = \frac{V_1}{V} q_1 + \frac{V_2}{V} q_2 + \dots + \frac{V_k}{V} q_k = \sum_{i=1}^k \frac{V_i}{V} q_i$$

The quality of the trees is well correlated with the utilization ratios. Therefore a prior stratification of the standing exploitable stock in the field inventory through quality assessment will significantly improve the precision of the estimates of the utilization ratios. This is one of the main advantages of quality assessment carried out during the field inventory. But it must be realized that quality assessment by itself (i.e. without a utilization study) cannot provide realistic estimates of the "net yield" for the many reasons already indicated in the introduction.

4. Processing and presentation of inventory results

The methodology proposed in this manual for the assessment of logging costs is based on the provision by a given preinvestment survey of certain amounts and types of results. Apart from two main exceptions already dealt with in preceding sections - i.e. introductions of a terrain stratification, leading to a final subdivision in assessment units, and determination of utilization factors through a utilization study - the required information is provided by any sound preinvestment forest survey.

Experience shows that in many cases there is not a full utilization of the information recorded. The results presented in the inventory report are then but a fraction of the results which could have been provided. The reasons generally given are twofold. They refer first to the "readability" of the report, which should not contain an excessive amount of result tables and be clear and short enough to be fully utilized by the decision-makers concerned. The second type of reason is more technical: the more detailed are the results the less precise and reliable they are since they are based on fewer measurements (e.g. the results for one single species are generally less precise than the corresponding ones for a group of species including this one, or the results corresponding to volumes or numbers of trees in a given diameter class are estimated with a larger sampling error than those related to a wider diameter range). Therefore the person responsible for the inventory thinks it not convenient to publish certain detailed results.

With regard to the first reason, it can be said that inventory reports should always be complemented by a summary to be presented to the decision makers where only the most important results are highlighted. Then it should be possible to process and tabulate many useful detailed results. Concerning the reduced precision on detailed results a word of caution should be given in a good place mentioning their relative reliability especially when the corresponding sampling error is not printed.

The loss of information stemming from a partial processing of the basic inventory data should be avoided. Generalization of computer processing makes the production of a greater number of detailed tables much easier than in the case of manual processing. It must be kept in mind indeed that the users of the inventory information - and particularly those who have to assess the cost of wood - will obviously prefer not to go back to the basic data and reprocess them to obtain the results they need (even if they are prepared to do so, they may not be in a position to do it if the original data and programmes are not retrievable or difficult to use for many reasons).

Inventory data should therefore be processed and the results presented as completely as possible. Below, guidelines are given concerning some aspects of the processing and presentation of inventory results related to the calculation of logging costs.

The detailed presentation of inventory results should be such as to allow for changes in the utilization pattern over time. This is the more necessary as an inventory is often carried out several years before the studied area is exploited; this increases the risk of the inventory becoming useless if the results are not comprehensive and detailed enough.

- (i) Thus it is important for instance that mean numbers of stems and volumes are calculated and printed by fairly small diameter intervals, say, 10 cm diameter classes. Minimum exploitable diameter may be indeed reduced or increased by 10 cm in the management regulations between the time of inventory and the time of harvesting. If figures are given by 10 cm diameter classes it will then be easy to determine manually the incidence of this change on the "exploitable stock".
- (ii) The same applies when the change in felling stipulations relates to the species harvested. Many forest inventory reports provide results by groups of species but not by individual species. This proves to be in most cases a shortcoming. Whatever is the value of the groupings made, changes in the market situation, in accessibility, in harvesting and management regulations will tend to modify the list of exploitable species and the groupings made. If results by individual species are not available, then it will not be possible to calculate the new "exploitable stock" if there are changes in the list of exploitable species (the situation is even more critical when the list of inventoried species has been deliberately limited, since, in that case, a solution cannot be found by going back to the basic data). If the length of the stand and stock tables is deemed too important for reproduction in the inventory reports, at least a few copies of the full tables should be available at a known location for subsequent use.
- (iii) Many conditioning parameters are better and more objectively assessed at points or over small circular areas around points rather than on the total area of each field sampling plot. Mean estimates of these parameters generally recorded by classes (see section 2 of this appendix) should be processed as proportions of the area of each assessment unit in each class of the parameter, i.e. ratio of number of points with each class of the parameter to the total number of points in the assessment unit concerned.

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In addition to the above documents, the reader may refer to Performance Handbooks published by logging equipment manufacturers.