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Forestry Commission Booklet 43

Forest Road Planning

A A Rowan

Cover picture: Aerial view of part of Torridge Forest in Devon showing an effective network of roads serving hilly terrain. *Photo by* I. A. Anderson.

FORESTRY COMMISSION

Booklet 43

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by

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Forestry Commission

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All the figures are based on sketches by the author and by Forestry Commission engineering staff.

1. INTRODUCTION

The construction and maintenance of forest roads represent a substantial investment by timber growers and this needs careful planning to get full value for money spent.

Forest roads are built to provide access to the forest for general management purposes and for the transport of timber to the market. The building of forest roads involves heavy capital expenditure and, in addition, there is a continuing charge for road maintenance. Against this, actual movement costs along roads are less, distance for distance, than movement costs across country. Forest road planning is thus essentially concerned with determining the combination of on-road and off-road transport systems that is likely to give minimum cost overall. The object is to seek the best solution and this invariably means exploring alternatives.

Forest owners, particularly those with smaller woodland properties, may not have ready access to civil engineering expertise. Forestry Commission civil engineers have extensive experience in the construction and maintenance of low-cost forest roads, and may be able to give advice. Requests should be made to the local Conservator of Forests.

The network of roads constructed to meet the needs of harvesting will, almost invariably, meet all other forest needs. Where roads are constructed in advance of harvesting requirements, they should be laid out primarily to meet the requirements of timber haulage. Exceptions to this rule are roads which are required for social reasons, e.g. access to houses, or where there is some legal obligation on the forest management to construct or maintain certain roads; roads in the latter category should form part of the forest road system wherever possible.

Roads for access prior to planting, or for other purposes in advance of harvesting, should be evaluated in economic terms, and an example of this is given on page 13. Pre-planting roads must be justified on the basis of savings on establishment operations.

The degree of investment in roads depends on the harvesting system or systems chosen, the standard of road required, and the costs of road construction and maintenance in each particular situation. It is also influenced by the volume of timber produced by the forest. The relative importance of these factors varies from one forest to another, and each is discussed below.

Other factors which a forest manager may have to take into account are:

Financial considerations, including availability of capital, taxation position and current interest rates.

Sporting, amenity and recreation, and the requirements for (or restrictions on) access which they demand.

2. CHOICE OF HARVESTING SYSTEM

This choice is fairly complex, and full treatment of the subject is outwith the scope of this publication. Choice is affected by:

The Timber Crop
- Type of cut proposed (thinning, clear felling)
- Volume per hectare produced
- Size of cutting unit
- Species
- Stability of the crop
- Size and quality of the trees

Terrain
- Ground bearing capacity, roughness and slope

Resources for Harvesting
- Capacity, qualifications and efficiency of workers
- Type, productivity and availability of machinery

Markets
Demand for timber
Dimensions, quality and amount of timber required
Environment
Effect of harvesting system on scenery, recreation, soil erosion, water pollution

The influence of these factors varies, and the introduction of new and more elaborate harvesting machinery widens the range of possible choice. The system chosen will usually be the one which satisfies the various constraints of crop, terrain, resources, markets and environment at minimum cost per cubic metre produced. This minimum cost includes road construction and maintenance costs, delivery costs and logging costs to roadside.

Consideration of alternative harvesting systems leads to the choice of one system. Should the choice lie between two or more systems, all of approximately equal merit, the final choice must be made on non-technical grounds. For example, which system is easiest to manage and control? Which system involves the least departure from present practice? Which system requires the least capital investment, both long-term and short-term? The last criterion may result in the choice of harvesting system which involves longer extraction distances and a lower investment in roads than would possibly be the case with other harvesting systems.

The method and cost of extraction is of prime importance in determining the intensity of roading. In this country extraction is by some type of tractor or by cable-crane, the choice between them depending largely on terrain. Road planning now and in the future should obviously be based on the most advanced methods currently available, and frame-steered skidders and forwarders can generally operate over all but the very poorest bearing surfaces if a carpet of branches can be provided: they can travel over rough ground (e.g. with obstacles or drains up to 0·5 metre height or depth at less than 5·0 metre spacing and some severer obstacles in addition); and on slopes up to 33% uphill or 40% or more downhill, provided the ground is not too rough in addition. It is difficult to give precise limits for machine performance because this varies with the machine type, the particular site and recent weather conditions, and the skill of the driver. Cable-cranes can operate on all sites in this country including those which are too severe for tractor work.

3. CHOICE OF ROAD STANDARD

This is directly affected by the harvesting system chosen, and in particular by the method of road haulage. If it is proposed to convey timber from every point on the forest road system direct to customer by means of large lorries (say 30–32 tonnes gross vehicle weight), a higher standard of road is required than if timber is to be moved by tractor and trailer to a collecting point for road lorries adjacent to a public road. The costs of constructing high-standard roads initially may not be much greater than for constructing roads to lower specification. On the other hand, the costs of up-grading existing roads to a higher specification may be considerable.

Selection of standard of forest road should take account of the standard of public roads with which they connect. When the latter are of low specification, the likelihood of their being upgraded should always be considered. The choice of road standard will lie between:

i. High Specification Roads

These give large-capacity road vehicles access in all weather.

ii. Intermediate Specification Roads

A certain number of existing forest roads are of this type, which may restrict the size and type of road haulage lorry that can use them. Choice of standard is largely dependent on the extent to which these restrictions affect road haulage costs on the public road system and normally one of three courses of action needs to be chosen; viz:

Improvement to High Specification
Accept restrictions imposed by existing standard on road haulage vehicles, and retain road in its present form.
Keep the present road standard and operate intermediate-haulage tractors or lorries to a load transfer point on a high-specification road.

iii. Low Specification Roads

These may be temporary roads and tracks, used by special lorries or tractors; the latter may transfer their loads to normal road haulage lorries at an appropriate point on a high-specification road.

The optimum standard of forest road should be carefully assessed, both for proposed new construction and for improvements to existing roads. The optimum standard will not necessarily be the same for each part of the forest. The requirements of each part of the network must be considered separately, and there should be no attempt to reach uniformity for its own sake. When choosing standards, the estimated costs of roads should include all costs relating to transport, including bridges, passing and turning places, etc. Brief definitions of road specifications are given in Section 11, Forest Road Specifications, page 19.

4. CHOICE OF ROAD SPACING

The decisions on road standard and extraction method lead to the selection of an optimal road spacing. This spacing is the one which minimizes the total of off-road transport costs (i.e. extraction cost) and road costs (i.e. construction and maintenance costs). Minimum total costs occur when movement cost—that part of extraction cost which varies according to the extraction distance—per cubic metre equals the road costs per cubic metre extracted. In practice, the total costs are near the minimum over a range of road spacings (see Figure 1), and the spacing to be selected should be the widest within this range. The reasons for this are two-fold. Firstly if road spacings wider than the theoretical optimum are chosen there may be substantial savings on investment at the cost of small increases to total cost. Secondly, road investment, once made, is irrecoverable. Off-road transport, on the other hand, because of its shorter-term and more flexible character, can more readily be altered to take advantage of technical improvements.

All road planning is directed towards achieving a network which conforms to the specification and spacings selected. In practice, topography, shape of forest blocks, etc., may require additional road length to that implied by the selected spacing, because of the need to provide link roads, reduce gradients to an acceptable limit, and so on; the presence of public roads may reduce the length of forest road required, if the highway authorities allow timber extraction to, and loading on, the public road verge.

Road Costs

When planning new roads, estimates of the costs of construction and maintenance should be based on the most reliable recent actual costs of comparable work, and must include labour on-cost. Road costs must include all construction work associated with the road transport of timber, such as:

Bridges, culverts, Irish bridges and fords.
Passing and turning places.
Stacking sites, where these have to be specially constructed because there is inadequate roadside space, and where the alternative of stacking on the carriageway is not possible because it impedes road haulage vehicles.

Certain construction costs should *not* be included in road cost for the purpose of determining road spacing. Thus, all costs concerned solely with timber conversion, e.g. conversion sites and lower landings,

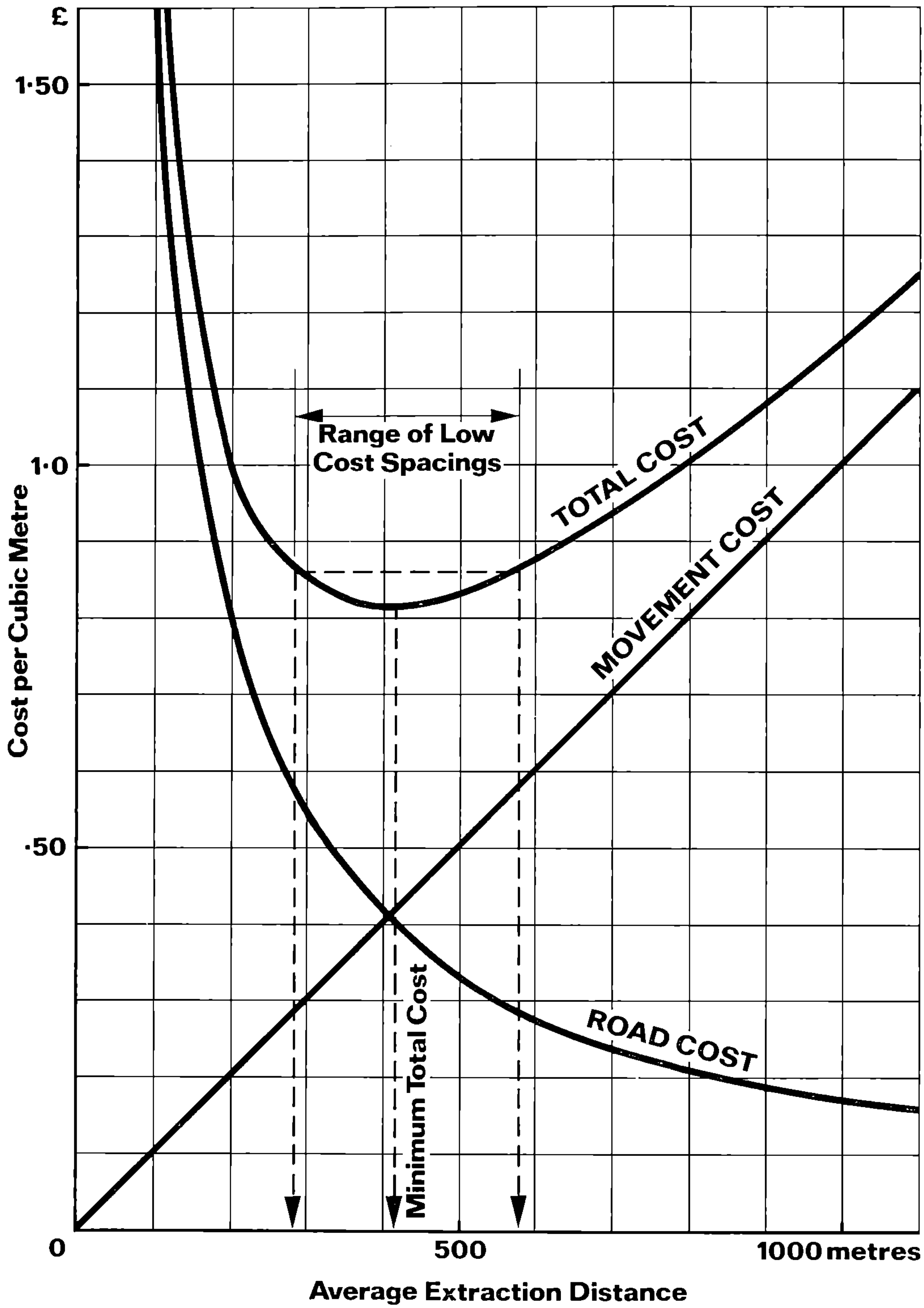

Figure 1. Relationship between cost of extracting timber and road spacing.

should be excluded, along with the cost of cattle grids. Large timber storage sites, other than roadside stacking sites, and transfer depots, should also be excluded. The conversion site costs, like the terminal elements of extraction and the actual conversion operations, are important features of the total harvesting system cost, and must be considered when comparing alternative methods of harvesting; but they have no direct influence on transport cost, and so are excluded when considering road intensity.

Given the best available estimate of construction cost, this is combined with annual maintenance cost for calculation purposes. Annual maintenance cost is most easily expressed as a single capital sum spent in the year of new construction, and is found by multiplying the estimated annual maintenance cost by a capitalization factor. These factors are given in Table 5 on page 29.

For example:

Construction cost per kilometre	£3,000
Maintenance cost: £40 per kilometre per year construction done at crop age 25 for final felling at age 50 years. Maintenance capitalization factor for 25 years at 10% (from tables) is 9·077	
Capitalized maintenance per kilometre = £40×9·077 (rounded off to nearest £10) =	£360
Total capitalized road cost:	£3,000+360 = £3,360 per kilometre

Road networks are not fully efficient, in that the length of road which has to be constructed to serve a given area, and to connect to the existing road system, is always longer than the length which road spacing requires. This extra length arises from several causes:

a. Road junctions cause local areas of over-roading; a T-junction, for example, reduces the average extraction distance by half in the area where the "extraction ribbons" of the two roads overlap, but the road cost per cubic metre is doubled.

b. In all but the most favourable terrain, roads seldom run straight. The need to conform to topographical features, the use of bends to gain height at acceptable road gradients, the limitations on stream and river crossings, all increase the length of road required to get from one point to another. Choice of the best combination of road alignment and length with construction cost is a civil engineering task. Forest roads must allow extracted timber to be handled easily at roadside. Road alignments and cross-sections should be selected so as to provide a high degree of access to the adjoining forest, and this may be reflected in increased road length. In some "knolly" terrain, the extra length due to road twisting may be considerable.

c. Even the most carefully planned road system has some areas where the road spacing is closer than optimum: this occurs where new roads are planned which must connect with existing roads, which will almost always have been laid out at closer spacings than those required by modern extraction equipment. Similarly, connections with public roads, and the constraints of rights of access to forests, result in road alignments which are not ideally situated. Finally, the topography and shape of many forest blocks causes road layout to be less than ideal. Narrow valleys are extreme cases.

The combined effect of these influences is to increase the length of road which must be built by 25–35% above that required by the optimum road spacing. In very difficult terrain the increase can be as high as 45%. This extra length must be taken into account when estimating the total road cost, because additional length increases the road cost per cubic metre extracted. In smaller blocks of woodland, the "network" may be very simple, often consisting of a single road through the forest. This is more efficient than a complex network because there are fewer junctions, and the extra length due to bends, etc., may be 20% or less.

Timber Volume

Correct assessment of volume of timber to be carried by the road is of the greatest importance. Volume assessments must be realistic. Calculations should not be based on broad assumptions of yield using average yield classes, *but on the best estimate of the volume which will actually be extracted.* Wherever possible, each proposed road should have attributed to it the volume from the area it is expected to tap, with due allowance made for areas of very good or very bad growth and unplantable patches. The actual productive area of a stand may be only 75% of the "map area" after allowance has been made for ground occupied by roads, rides, stacking bays, small gaps and windblows, etc. Where growth is uneven and several yield classes occur, as happens on morainic and similar irregular sites, the yield class used to give the road cost per cubic metre of the tapped area should be the weighted average yield class.

For example:

Figure 2 shows a proposed road in an area of variable crop. Weighted average yield class can be calculated, for all practical purposes, so:

Stand 1	30 hectares	at	YC 10,	then	30×10 = 300
2	40	,, ,,	YC 8	,,	40× 8 = 320
3	25	,, ,,	YC 10	,,	25×10 = 250
4	40	,, ,,	YC 8	,,	40× 8 = 320
5	50	,, ,,	YC 12	,,	50×12 = 600
6	60	,, ,,	YC 14	,,	60×14 = 840
7	50	,, ,,	YC 12	,,	50×12 = 600
	295 hectares				3,230
+unplantable	20 hectares	at Nil			
	315 hectares				

$$\text{Weighted average yield class} = \frac{3{,}230}{315} = 10$$

Timber volume assessment is specially important where yield classes are low, as small variations in the volume estimate can result in appreciable differences in road cost per cubic metre, and so affect optimum road spacing.

Forest blocks with more uniform growth may still have to be divided into two or more growth zones for road planning purposes. For example, where there is a major change of growth pattern, perhaps because of altitude or soil change, and other costs (construction cost per kilometre, movement cost per cubic metre) remain the same, situations may arise as shown in Figure 3.

Low-yield forest not only requires careful volume assessment; evaluation of alternative transport methods is also vital. If planning is confined to consideration of high-specification lorry roads, it is possible to arrive at an optimum balance between high road cost per cubic metre (because of low volumes) and long, and therefore costly, extraction distance; the true optimum may lie in combinations of low-specification tracks, short stump-to-track extraction, and intermediate haulage to an existing lorry road.

Yields of timber occur at intervals in the future, from the series of thinnings and the final felling, and this makes for difficulties in road investment appraisal. It is more convenient to use discounted volume than actual volume yields. Just as the future expenditure on road maintenance can be expressed as a single lump sum of discounted expenditure in the current year, so the future volume yields can be discounted back to a single volume yield in the current year. A 10% discount rate is used, as in discounting road

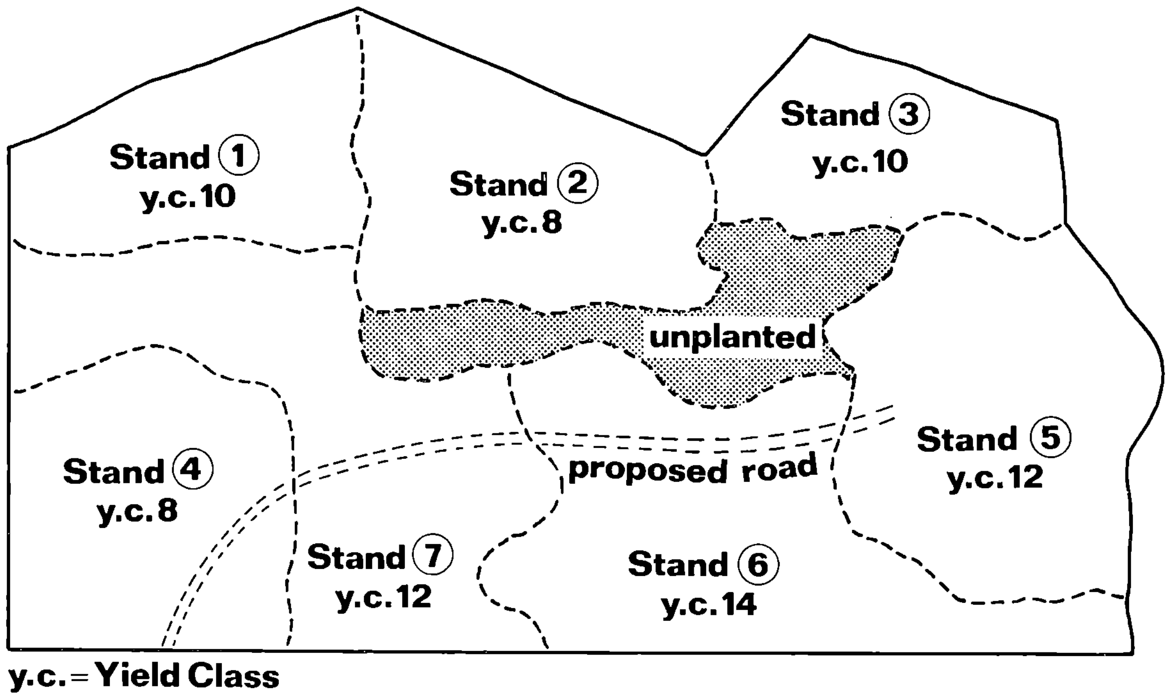

Figure 2. Siting a proposed road in an area of variable crop.

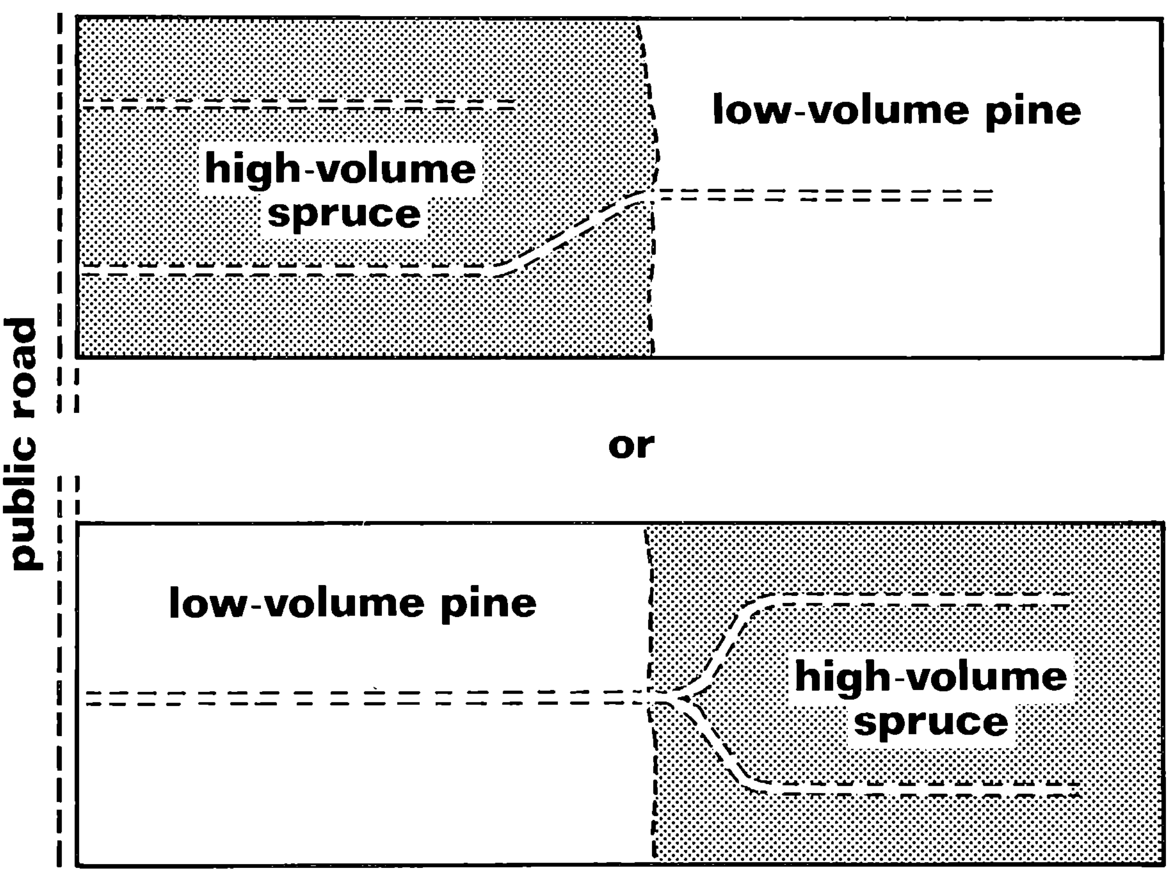

Figure 3. Road plans for areas of differing volume yields.

maintenance expenditure. Table 4 on page 28 gives discounted volumes for different species and yield classes. This table makes an allowance of 15% reduction from theoretical stocking, to allow for area of roads, rides, etc.

Extraction Distance

This term is conventionally used to describe the direct, straight-line distance from stump to roadside. It is generally read off maps, and where extraction is at right angles to the road, maximum extraction distance is taken as half the road spacing. Average extraction distance is calculated as one-half the maximum extraction distance, in these circumstances. Where extraction does not start at roadside, and timber must cross "dead ground", average extraction distance is the mean of maximum and minimum straight-line distance.

Only rarely does the timber actually move the straight-line distance above; normally the timber must be assembled into loads, by hand or by winch, before being pulled towards the road. This preliminary movement may or may not be in the direction of main extraction. Cable-cranes do the main extraction in a straight line, but most tractor extraction, either skidding or forwarding, involves some indirectness because of the need to lay out the extraction racks in relation to topography. The more uneven the land form, the greater the degree of indirectness. In the majority of tractor extraction operations there is also a certain amount of timber movement laterally, along the road, to conversion or stacking point. This last phase of movement on the road is independent of road spacing, and is properly part of the conversion or loading process; it does not count as movement distance for the purpose of determining road spacing.

Movement distance is the distance actually travelled by the timber between stump and roadside. For the purposes of road spacing calculations it is found by multiplying the extraction distance (as defined above) by 1·3, where tractor extraction is used. This additional length allows for the indirectness of rack layout and the longer route which tractors usually have to take on their journey back into the forest. For cable-crane extraction a factor of 1·1 is used, because the racks are straight, and indirectness arises only from the layout which cannot always be precisely at right-angles to the road.

Extraction Costs

Extraction costs comprise two main groups.

a. *Terminal Costs:* the costs incurred by the work elements of load assembly; load attachment to or placement on the transport machine; load removal and arrangement at the end of the extraction operation.

b. *Movement Costs:* Costs associated with the actual transport of timber, and which increase when road spacing, and extraction distance, increase.

Information on the time consumed during these phases of extraction is derived from time study data. Figure 4 illustrates a typical extraction cost structure, for skidders. Reliable information on movement time can be obtained from relatively few studies, as data are normally very consistent for a given machine and a particular set of operating conditions. It is particularly important that extraction costs are based on modern purpose-built forest machines, not on obsolescent equipment. Note that once the extraction system and road standard are chosen, terminal time does not influence the choice of road spacing, being independent of extraction distance.

Movement Cost can be expressed as the cost per cubic metre for every 100 metres of movement distance. This is calculated as follows:

$$\begin{array}{c}\text{Movement cost}\\\text{per cubic metre}\\\text{per 100 metres}\end{array} = \frac{\begin{array}{c}\text{No. of standard minutes}\\\text{for tractor to move}\\\text{an extra 100 metres}\end{array}}{\text{Load size in cubic metres}} \times \begin{array}{l}\text{Cost per minute}\\\text{of tractor and}\\\text{operator}\end{array}$$

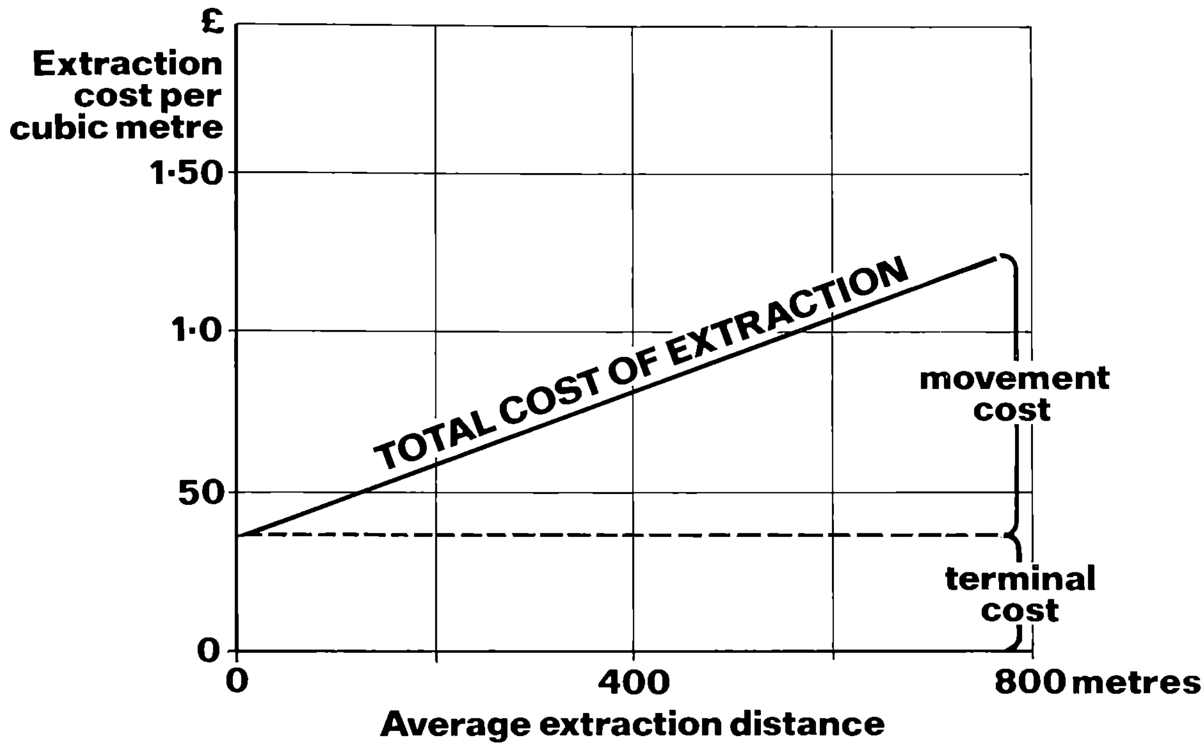

Figure 4. Relationship between terminal cost, movement cost, and total extraction cost over varying distances.

It is particularly important that movement costs should not be calculated from time study results from limited trials over short distances; road spacing determination is concerned with the *extra* cost involved in extraction over *extra* distance, i.e. marginal cost of movement, and this is accurately revealed when studies cover an array of extraction distances over several hundred metres.

Example: Extraction by Volvo SM 868 Forwarder

Movement time per load (from time studies)	=	4·04 standard minutes (SMs) per 100 metres
For average working loads of 10 cubic metres, movement time per cubic metre	=	0·40 SMs per 100 metres
Cost of Volvo SM 868	=	£7·12 per hour
Driver's wages, including incentive allowance and oncost	=	£1·50 per hour
Movement cost per cubic metre per 100 metres	=	$\frac{(7{\cdot}12+1{\cdot}50)}{60}\times 0{\cdot}40$
	=	£0·057

Note that this calculation uses standard time, which is a combination of actual time spent on the operation and time allowed for rest, other work and contingencies. Standard times are used in movement cost computation, because they are readily available and because they cover the minor delays and inefficiencies inherent in field operations. A full description of standard times and their uses is given in Forestry Commission Bulletin No. 47, *Work Study in Forestry*, edited by W. O. Wittering, HMSO, 1973.

Additional movement costs occur where improvements have to be made to the forest surface before extraction is possible. Work such as the bridging of a roadside drain, or providing access ramps on a roadside bank are "terminal" costs, and not included in movement cost because they are fixed amounts, independent of extraction distance. Work required along the extraction route, e.g. bridging or filling-in drains, removal of stumps, etc., does vary with extraction distance and the cost should be included in movement cost for the purposes of road spacing calculations.

It is impracticable to use the movement costs of many individual machines in road planning. The Forestry Commission uses two levels of movement cost in its road planning for tractor-extraction areas:

a. 6p per cubic metre per 100 metres: Used for all forwarder extraction, and easy conditions for skidders.
Applicable to lowland forests generally, and favourable upland terrain.

b. 10p per cubic metre per 100 metres: Used for skidder extraction on less favourable conditions.
Applicable to the more difficult upland areas and mountain forests.

These cost levels are the upper limits of ranges of movement costs of modern frame-steered forest tractors in mid-1975. The levels of cost are subject to alteration, as machine operating costs change. The Forestry Commission does not use movement cost in planning roads for cable-crane extraction: this is dealt with below.

One-way Extraction

Tractor extraction on steeper slopes, say 25 to 50%, may only be possible downhill. Because the timber only reaches the road from one side, the road cost per cubic metre is greater than for two-way extraction. The average extraction distance to the road should be also greater than for two-way extraction by about 40%. The actual increase is by a factor of $\sqrt{2}$.

It is often worth trying to continue to do uphill extraction with a reduced size of load, rather than accept more costly downhill-only extraction. For example, if the movement and road costs for optimally-spaced two-way extraction are each 50 pence per cubic metre, and total cost thus £1, a change to downhill-only extraction would increase this total cost to £1·40. If uphill extraction could continue with loads of half normal size, the movement cost for uphill extraction goes up to £1 per cubic metre, giving an average of 75 pence for uphill and downhill combined, and a total of movement+road cost of £1·25 per cubic metre. Movement cost could rise to 90 pence per cubic metre through reduced loads, before the "one-way" total cost of £1·40 is exceeded.

Cable-cranes can operate equally successfully up and down hill, and one-way extraction does not occur.

5. CALCULATION OF ROAD SPACING

The optimum road spacing can be calculated when road cost, discounted timber volume, and extraction movement cost are known, by working out the total of road and movement costs for various road spacings, as follows:

Example:

Assume average weighted yield class = 10
Timing of first thinning 25 years, according to Management Tables; Final felling at age 50
Discounted Volume per hectare 75 cubic metres
Road cost = construction £3,000 per kilometre
maintenance £50 per kilometre per year
discounted maintenance to final felling (over 25 years) £50 × 9·077
Total road cost £3,000 + (50 × 9·077)
= £3,450 per kilometre

Movement cost using skidders, two-way extraction = £0·10 per cubic metre per 100 metres

1. If road spacing is 400 m, average extraction distance is 400÷4 = 100 m
2. Average movement distance, for indirectness factor of 1·3, is 100×1·3 = 130 m
3. Average movement cost, at £0·10 per m^3 for 100 m is $\frac{130}{100} \times 0{\cdot}10$ = £0·13 per m^3
4. The area tapped by a kilometre of road at 400 m road spacing is $\frac{1{,}000 \times 400}{10{,}000}$ = 40 hectares
5. At 75 m^3 per hectare, the discounted volume reaching each kilometre of road is 40×75 = 3,000 m^3
6. Each kilometre of road costs £3,450; the inefficiency of the road network (junctions, bends, etc.) requires a greater length to be built, 35% more in this case, so road cost per km has to be increased to allow for this. Cost per km becomes £3,450×1·35 = £4,657
7. Road cost per m^3 is

$$\frac{\text{Road cost per km}}{\text{Volume reaching each km}} = \frac{£4{,}657}{£3{,}000} = £1{\cdot}55$$

8. Total of road and movement cost per m^3 is therefore: £1·55+£0·13 = £1·68

Repeating this sequence of calculations for other road spacings, the spacing at which total cost is minimized is shown in Table 1.

TABLE 1

CALCULATION OF OPTIMUM ROAD SPACING

Road Spacing metres	Average Extraction distance metres (1)÷4	Average Movement distance metres (2)×1·3	Average Movement cost £/m^3 (3)×$\frac{0{\cdot}10}{100}$	Area tapped per km of road hectares (1)×$\frac{1{,}000}{10{,}000}$	Discounted Vol. per km. of road cubic metres (5)×75	Road cost £ per cubic metre $\frac{3450 \times 1{\cdot}35}{(6)}$	Total, road + movement cost £/m^3 (4)+(7)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
400	100	130	0·13	40	3,000	1·55	1·68
600	150	195	0·19	60	4,500	1·03	1·22
800	200	260	0·26	80	6,000	0·77	1·03
1,000	250	325	0·32	100	7,500	0·62	0·94
1,200	300	390	0·39	120	9,000	0·52	0·91
1,400	350	455	0·45	140	10,500	0·44	0·89
1,600	400	520	0·52	160	12,000	0·39	0·91
1,800	450	585	0·58	180	13,500	0·34	0·92
2,000	500	650	0·65	200	15,000	0·31	0·96

This example indicates a road spacing of 1,400 m as giving the lowest total of road and movement cost per cubic metre. But if spacing is increased to 1,800 metres the increase in cost per m^3 is only 3 pence, and one would in practice try to lay out the road system with spacings of 1,800–1,900 metres.

Calculations of this type are most useful when considering road networks in fairly large blocks of forest, and where the lengths of road are substantial. The roading of small blocks of woodland is best considered differently, and an example of the latter type is given on page 24, Case C.

The calculations above may be speeded up by using formulae to work out movement and road costs, as shown below:

$$\text{Movement cost £ per m}^3 = \frac{1 \cdot 3\, Sh}{400} \quad \text{for two-day tractor extraction}$$

$$= \frac{1 \cdot 3\, Sh}{200} \quad \text{for one-way tractor extraction}$$

$$\text{Road cost £ per m}^3 = \frac{10\, RW}{SV} \quad \text{for both one- and two-way extraction}$$

Where S = Road spacing in metres
h = Movement cost in £ per m^3 per 100 metres
R = Capitalized road cost (construction and maintenance) in £ per kilometre
W = Network inefficiency factor = 1·35 in most lowland forests
V = Discounted volume per hectare (average) in cubic metres

The optimum road spacing can also be found by formula:

$$\text{Optimum } S = \sqrt{\frac{4\, RW}{1 \cdot 3\, hV}} \quad \text{for two-way tractor extraction}$$

$$= \sqrt{\frac{2\, RW}{1 \cdot 3\, hV}} \quad \text{for one-way tractor extraction}$$

Where S = Spacing in *thousands* of metres
R = Capitalized road cost in *thousands* of pounds per kilometre
W = Network inefficiency factor
h = Movement cost in £ per cubic metre per 100 metres
V = Discounted volume per hectare (average) in cubic metres

Note that the units for spacing and road cost in the optimum-spacing formulae are in thousands of metres and pounds, unlike the Movement and Road cost formulae above.

While the optimum-spacing formulae are quick to use, they do not give an indication of the effect of using "greater-than-optimum" spacings which might well be adopted in practice to reduce the level of road investment.

6. TIMING OF CONSTRUCTION

The aim is to construct roads as near as practicable to the time they are required for use. This will generally be one to two years before planting or harvesting starts. The timing of much new road construction is thus closely related to the timing of first thinning, which will normally be within the span of years defined in *Forest Management Tables* (Forestry Commission Booklet 34, HMSO). Delaying thinning results in loss of discounted revenue and some gain in deferring road investment, and the two more or less balance where delay is short, say, up to five years. The extreme case of delay is a no-thinning regime, which may be the best alternative where plantations are of low yield class and the costs of road construction are disproportionately high. These cases need careful evaluation: some areas where thinning cannot be justified because of high-specification road costs may possibly be viable thinning prospects if low-specification roads can be built. Road planning in such cases follows the same principles as for normal areas.

7. ROAD SPACING FOR CABLE-CRANE EXTRACTION

Harvesting roads in terrain where only cable-crane extraction is possible are best planned at present on the basis of a maximum cable-crane range of 600 metres. The economic balance of road and movement costs normally lies beyond this, but 600 metres represents a practical limit to the present generation of cable-cranes in current use in this country. This limit may be extended as a result of further research.

8. PRE-PLANTING ROADS

Pre-planting roads enable men and materials to travel more quickly across country. Supplies such as fencing materials, plants, etc., must be carried in some form of cross-country vehicle, e.g. crawler tractor and sledge, "Muskeg", "Argocat", or forwarder with half-tracks, and the first possibility to consider is whether these vehicles can do all material transport from existing roads to the new planting area without the necessity to build further access roads, or with the minimum of track construction and improvement.

The aim in planning pre-planting roads must be to achieve the largest net benefit possible, i.e. savings in operational costs must exceed road costs to the greatest possible degree. All road costs are shown against the establishment operations, because of the long time before the roads are used for harvesting. Road alignments should be chosen with care to ensure they are well-sited to serve as harvesting roads in due course.

When the existence of a road is expected to have a large benefit in terms of reduced fire loss, the extent of these savings should be quantified (even though the precision of estimate may not be high) and used in the appraisal of whether to build a road and if so to what standard.

Only large blocks can justify pre-planting roads. Appraisals should be based on the savings in cost of materials haulage and in the cost of walking by industrial workers for all establishment operations. The cost of walking by supervisors, and all subsequent advantages for inspection, protection and maintenance operations, are best omitted from appraisals as these are relatively minor items of expenditure occurring at irregular intervals.

Roads to Isolated Blocks

Appraisal of alternatives should be made by comparing the costs of operations with a road with other alternatives.

Example:

An isolated block of 600 hectares would require a road of 1 kilometre to reach it, if this were built. The alternatives are as follows:

a. *Build 1 kilometre of Category II road to block:*	£3,500
Subsequent maintenance and marginal cost of haulage of materials, plants and men are negligible	
Total of option (a):	£3,500

b. *Improve stream crossings and some side slopes to allow transport of men by Land Rover:*

Cost of improvement:	£1,000
Haulage of fencing material, plants and fertilizer, including loading at public roadside and unloading in forest. 450 tons in all:	£400
Transport costs of workers by Land Rover	

Continued overleaf

Continued from page 13

Labour input 10 man-days per hectare	
×600 hectares = 6,000 man-days	
@ 6 men per Rover = 1,000 Rover trips	
lasting 0·1 hours per day = 100 hours	
Wages @ £0·78 per hour for 600 hours	£468
Land Rover marginal cost, 2,000 kilometres	£75
Total of option (b):	£1,943

c. *Minimum improvement to stream crossing to allow use of forwarder for transport of materials:*	£200
Haulage of fencing materials, etc., as in option (b)	£400
Walking time by workers	
2 km per day or 40 minutes per man-day	
£0·52 per man-day × 6,000 man-days	£3,120
Total of option (c):	£3,720

If the choice lay only between (a) and (c), the road should be built; not only are there savings—a road has additional benefits in ease of protection and supervisory inspection. It could be maintained that one could "afford" to spend up to the full limit of (c) and still have a sound investment. The weakness of this argument is apparent when (b) is considered; this option has all the benefits of (a) at roughly half the cost.

There are practical limitations to alternatives based on a high degree of walking by workers. When walking exceeds two hours per day, i.e. where the walking distance is greater than three kilometres out in the morning and the same distance back at night, the effective working day becomes reduced. At four hours per day walking, the effective working time is reduced to two to three hours, and labour input per hectare rises sharply. This may be acceptable for very small amounts of work, but in most cases some form of worker transport is necessary when walking distance is three kilometres or more.

Roads Within Blocks

As with roads to blocks, the savings which roads provide are chiefly savings in walking time. The savings are largest in large blocks. Evaluation of the best alternatives must take into account:

a. the effects of different lengths of new road construction
b. the costs of different standards of construction, e.g. low-specification roads, with possibly some restriction on use in adverse weather conditions, should be considered as alternatives to high-specification all-weather roads
c. the speed of travel of vehicles over the different standard of road or track, or cross-country.

Example:

A 900 hectare block is considered for roading, and field survey shows that the following alternatives are possible:

a. Build no pre-planting roads in block: rely on walking and cross-country vehicles to provide for all access and haulage of materials.

b. Build a road from an existing access road on the boundary, penetrating the area for a distance of 0·8 kilometre.

c. As (b), but penetrating area for 1·6 kilometres.

From known travelling speeds, average travelling times from the forest reporting point were calculated, and the time available for work each day. See tabular statement following:

Alternative	Average time per man-day	
	travelling	working
(a)	84 mins	6 hrs 36 mins
(b)	60 mins	7 hrs
(c)	46 mins	7 hrs 14 mins

The estimated outputs per man-hour on establishment operations on this block were as follows:

Planting	0·08 ha
Ploughing	0·20 ha
Cross draining (mechanical)	1·00 ha
Cross draining (hand)	0·25 ha
Weeding	0·22 ha

From these data and the length of the working day given by the three alternatives, the number of man-days for operations with each alternative can be calculated, and costs attached to them, as shown below:

	Alternatives		
	(a)	(b)	(c)
Total labour input for establishment operations on this block, man-days	3,678	3,487	3,351
Reduction in labour input through roads (alternatives b and c), man-days	—	191	327
Value of reduction at £8·70 man-day (including oncost)	—	1,662	2,845
Road cost estimate: £1,540 per km.			
cost of constructing 0·8 km.	—	1,232	—
cost of constructing 1·6 km.	—	—	2,464
Residual saving (Value of reduced labour input—Road cost)		+430	+381

Alternative (b) was selected, and 0·8 kilometres of road built. Though the savings were modest in comparison with the total labour expenditure of £30,000 or so, there are other unquantified benefits in better utilization of ploughing machinery, savings in travel on protection, survey and inspection, etc. The road could be built with these in mind, knowing that the construction costs were already fully covered by "hard cash" savings in labour input.

Those in charge of a forest where labour is scarce might well have chosen alternative (c), which cut the labour input on the establishment operations by 10% and released a man-year of skilled labour for work elsewhere, at no added cost. For general guidance, the following table gives figures for road densities which are most likely in practice. These figures are based on studies by Work Study Branch of the Forestry Commission:

Block size hectares	Road density, metres per hectare	
	Tracks (£1,000 per 1 km.)	Lorry Roads
Below 300	none	none
300–800	1	none
800+	2	1

9. ROAD IMPROVEMENT

Roads which were designed in earlier years may be inadequate for the large road haulage vehicles now in general use, and improvement of these existing roads may be necessary. Improvement can range from relatively inexpensive work, such as widening the road width on bends, to major reconstruction when pavement strength has to be improved, or extensive realignment is necessary.

Road improvement is best planned on the same lines as new construction.

a. From the existing roads, select a "skeleton system" at the feeder-road spacing which would have been chosen if this were new construction. Realignment should seldom be necessary.

b. The remaining roads can be improved when the cost of improvement is less than the resultant savings in extraction cost.

c. Improvements may also be justified by savings in timber haulage costs, both on forest roads and on public roads, to customer.

There are a number of possible alternatives to road improvement which should be examined. Because each case is different, no general rules apply, but the following tables give examples of alternatives and the elements of cost associated with each. If it is found that no one alternative is clearly better than the others (at least 10% cheaper, say) the best choice is usually that which gives greatest flexibility and ease of future management.

10. ROADS FOR SMALL BLOCKS OF WOODLAND

The problems of small woods are those of low volumes of timber per cut. This makes harvesting more expensive through a higher cost of fetching-in equipment per cubic metre handled, and the cost of any road at all may be prohibitively high. The development of high-capacity forwarders in recent years allows timber extraction over agricultural land at comparatively low cost, with minimum damage to fields, and this has eliminated the necessity of building roads to outlying blocks of woodland.

The decision whether to build a road to a small wood or group of woodlands can best be taken by following the same procedure as for road improvement decisions. The alternatives given in Table 2 are of general application, though road construction work will consist of full construction, not merely improvement. The cost elements in Table 3 similarly apply.

TABLE 2

ROAD IMPROVEMENT AND SOME POSSIBLE ALTERNATIVES

Alternative	Transport method		Construction Work required	Remarks
	On forest road to high standard or public road	On high standard or public road to customer		
(a)	Large lorry (e.g. 32 tonne GVW) direct to customer		Improve forest roads to high standard	Imposes no limitation on future transport arrangements, e.g. with contract haulage or standing sales
(b)	Restricted range of lorries, i.e. less than 32 tonne GVW direct to customer		None	Haulage contractors or merchants may not possess lorries of appropriate size
(c)	Large lorry, part loaded on forest road; topped up later	Large lorry with full load	Stacking site for topping-up timber?	Limited to roads which are inadequate in gradient or pavement strength
(d)	Forest tractor and road trailer (e.g. artic trailer) to transfer point on high standard road	Large lorry, e.g. artic tug and trailer	Trailer park at forest road end?	Best with owner or merchant doing own haulage
(e)	Small-medium lorry to transfer point on high standard road	Large lorry, loaded at transfer point	Construction of load transfer depot?	Most efficient where forest-road lorries unload direct onto large lorries or road trailers at transfer point
(f)	Forwarder from roadside to transfer point on high standard road (Forwarder extraction from rack to transfer point is more efficient)	Large lorry loaded at transfer point	Construction of load transfer depot?	Most efficient where forwarders unload direct onto large lorries or road trailers at transfer point

TABLE 3

COST ELEMENTS IN COMPARISON OF ROAD IMPROVEMENT AND ALTERNATIVES

Cost Element	Alternatives involving cost element					
	a	b	c	d	e	f
EXTRACTION AND ROAD HAULAGE: Extraction cost, stump or rack to forest road (full extraction cost/m³ × area × discounted vol./ha)	×	×	×	×	×	×
Loading transport at forest roadside (loading cost/m³ × total discounted volume)	×	×	×	×	×	× ?
Transport on forest road (average haulage distance × full transport cost per m³ per km. × total discounted volume) by:						
large lorry	×		× part load			
small or medium lorry		×			×	
tractor + road trailer				×		
forwarder						×
Load transfer at transfer point on high standard road						
road trailer collection cost				×		
unload onto large lorry or trailer					× ?	× ?
unload in depot: load large lorry					× ?	× ?
travel/fetch-in and load "topping-up" timber			×			
Main road haulage cost	×	×	×	×	×	×
FIXED COSTS: Cost of improving forest roads to high standard	×					
Maintenance of high standard roads: total capitalized cost	×					
Maintenance of existing roads: total capitalized cost		×	×	×	×	× ?
Construction cost of stacking bays on forest roads	× ?	× ?	× ?	× ?	× ?	
Construction cost of load transfer depot on high standard road			× ?		×	×
Construction cost of road trailer park at high standard road				× ?		
(Total Cost = sum of the above)	—	—	—	—	—	—

11. FOREST ROAD SPECIFICATIONS

The following brief specifications are those which the Forestry Commission has found to be generally appropriate for forest roads:

1. Type of Road Vehicle for which High-Specification Roads are Designed

a. *Articulated*

Gross vehicle weight:	32 tonnes
Maximum axle load:	10 tonnes
Maximum overall width:	2·5 metres approx.
Maximum overall length:	15 metres
Minimum distance between outer axles:	
4 axles:	11·6 metres
More than 4 axles:	9·75 metres approx.

b. *Fixed platform*

Gross vehicle weight:	28 tonnes
Maximum axle load:	10 tonnes
Maximum overall width:	2·5 metres approx.
Minimum distance between outer axles:	7·9 metres approx.

These two vehicle types are the largest normally used on public highways in Great Britain.

2. Road Line Clearance Width:

Variable. This must accommodate all road works and associated drainage, assure tree stability at road edge and allow road to dry out.

3. Road Formation:

See Figures 5 and 6.

Firm subsoil conditions:	Formation width: 4·7 metres Formation camber: 75 millimetres On flattish ground camber is increased to 90 millimetres Upper batters: As steep as possible Lower batters: Normally 1 in 1·25
Deep peat:	Formation width: 5·6 metres Formation camber: 100 millimetres Distance of side drains from road centre line: 5·8 metres

On steep side slopes crossfall replaces camber. Crossfall is at least 150 millimetres towards inner edge, but does not exceed 190 millimetres. Change from camber to crossfall is made over a transition length of 15 metres.

4. Longitudinal Gradient:

Maximum 10%
Minimum 1% in flat country, for efficient drainage.

5. Pavement Width:

3·2 metres standard width, but increased on sharp curves.

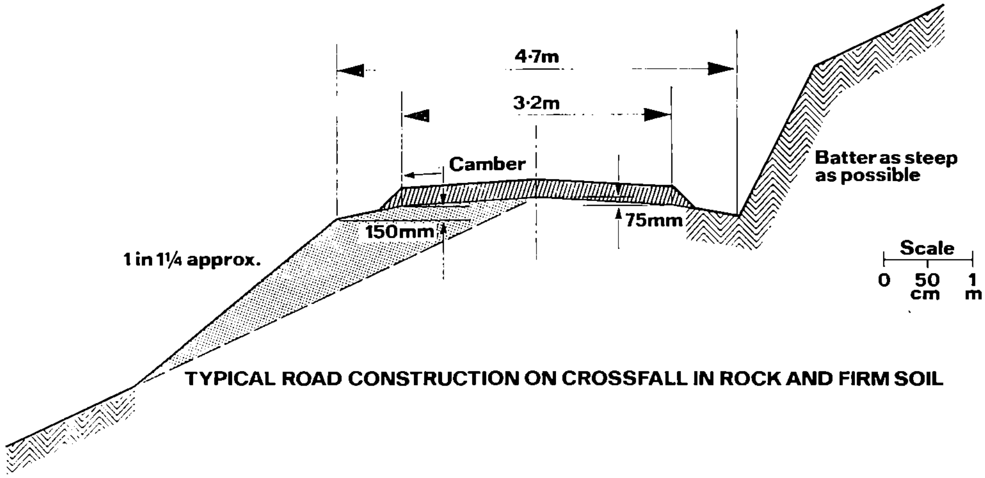

Figure 5. Cross section through a typical road on a crossfall in rock and firm soil.

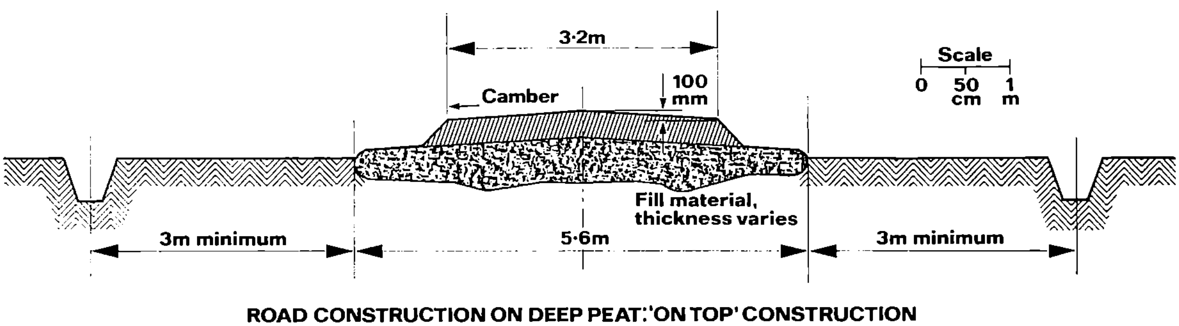

Figure 6. Cross section through a typical road built over deep peat using the "on top" construction method.

6. Horizontal Curves:

60 metres radius

Road pavement is widened on the inside of sharp curves, with a straight transition of 15 m length to the inner radius, as follows:

Curve radius 45 metres:	Pavement width	3·5 metres
30 metres:		4·0 metres
20 metres:		4·5 metres
15 metres:		5·0 metres

7. Road Pavement: Dry-bound Macadam Construction

Thickness of base course + "surfacing" course

or combined base and surfacing course: From 150 millimetres to 450 millimeters or more.

8. Road Pavement: Bituminous Macadam Surfacing

Base course of bitumen macadam of 30 millimetres final thickness using 20 millimetres nominal size aggregate.

Wearing course of dense bitumen macadam of 25 millimetres thickness using 10 millimetres nominal size aggregate.

Bituminous surfaces are only provided on certain selected main forest roads and some amenity roads.

9. Road Pavement: Roadstone Specification

i. Base course: 25–30 (Stewart Aggregate Impact test)

ii. Surfacing course: less than 25 (Stewart Aggregate Impact test)

Aggregate impact figure given is the percentage of fines (i.e. passing the No. 7 (2·36 mm) sieve) to original sample after test.

10. Turning Places

See Figure 7.

Width 4·0 metres
Length 21·0 metres

Normally in the form of a T with 11·0 m radius curves.

11. Passing Places

See Figure 8.

Width 4·0 metres
Length 15·0 metres at full width; 33·0 metres including approaches and exits

Passing places are located at intervals depending on sight lines.

12. Design Speeds

Road standards have been based on design speeds of 30 kilometres per hour on straights and easy curves, 16 kilometres per hour on sharp curves, for road vehicles at (1) above.

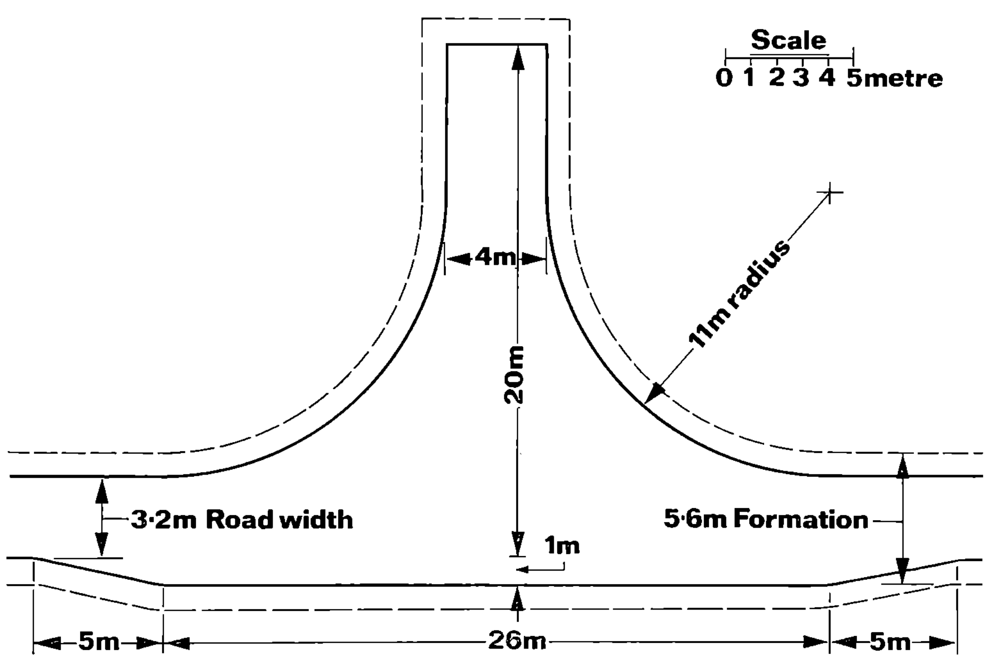

Figure 7. Plan of a typical turning place.

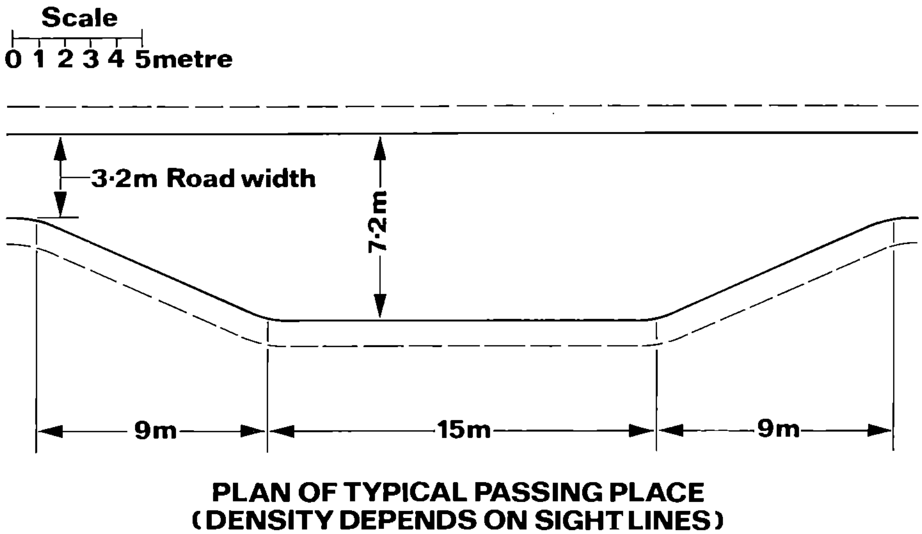

Figure 8. Plan of a typical passing place. The density, or frequency, of such passing places will depend on the sight lines that enable each driver to see the approach of another lorry.

12. ILLUSTRATIVE CASES

Case A. Determining the Correct Spacing for Roads in a Block of Forest

The forest area is a block of 600 ha, roughly 2 km by 3 km with an existing access to the public road system at the eastern end. Topography is a valley with a small stream in the bottom. See Figure 9.

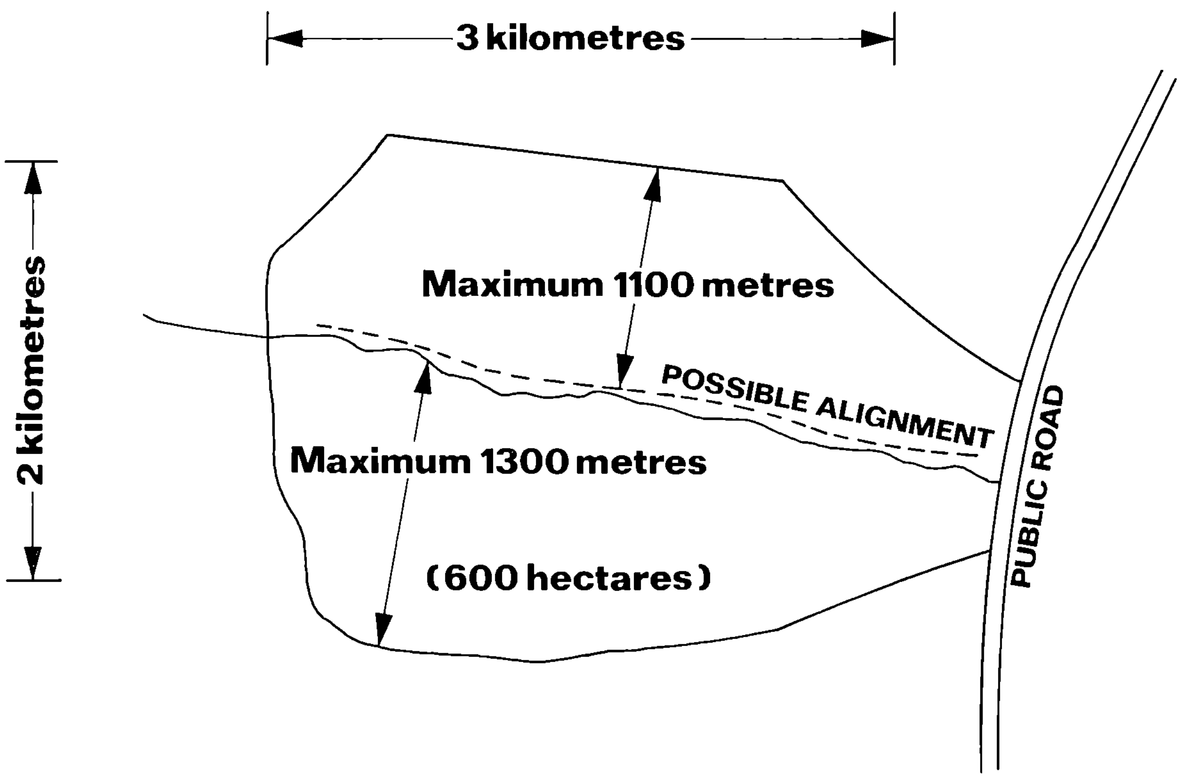

Figure 9. Possible alignment for a road to serve a forest block in a valley.

a. Average weighted yield class of stands = 10
b. Thinning regime: according to *Forest Management Tables* (Forestry Commission Booklet No. 34) by G. Hamilton. HMSO, 1971.
c. Thinning to start at 25 years, with all stands coming into production within 2 years or so
d. Proposed final felling age: 60 years
e. Terrain all suitable for tractor extraction, downhill only
f. Long-term marketing pattern likely to be sawlogs and pulpwood
g. Road haulage considerations: distance to customers is great enough to make 32-ton GVW lorries the only practicable means
h. Current road costs for this area are assumed to be:
   High-specification lorry road = £3,000 per km construction cost
   £50 per km annual maintenance cost

The harvesting system is assumed to be based on tree-length extraction using frame-steered skidders. A movement cost of 10 pence per cubic metre per 100 metres of movement distance is used for planning purposes.

Expressed as a capital sum, the total of road costs is:

Construction: £3,000 per kilometre.

Maintenance: If road is built when thinning begins, at age 25, and continues to felling at age 60, maintenance is done over 35 years.
At a 10% test discount rate, the capitalization factor for annual payments made over 35 years is 9·644. So capitalized maintenance costs of £50 per km per year are (50×9·644) = £482 per kilometre.

Total capitalized construction+maintenance costs are £3,000+£482 = £3,482.

Using the formula given on page 12 for calculating the optimum road spacing,

$$\text{Optimum spacing} = \sqrt{\frac{2\,RW}{1{\cdot}3\,hV}}$$

$$= \sqrt{\frac{2\times3{\cdot}48\times1{\cdot}35}{1{\cdot}3\times0{\cdot}10\times75}}$$

$$= 0{\cdot}98 \text{ thousand metres}$$

This optimum spacing of 980 metres can be checked for sensitivity by using the formulae given in page 12 for movement and road cost per cubic metre, as follows:

Road Spacing S metres	Movement Cost £/m³ $\frac{1{\cdot}3\,Sh}{200}$	Road Cost £/m³ $\frac{10\,RW}{SV}$	Total Cost £/m³
800	0·52	0·78	1·30
900	0·58	0·70	1·28
1,000	0·65	0·63	1·28
1,100	0·71	0·57	1·28
1,200	0·78	0·52	1·30
1,300	0·84	0·48	1·32
1,400	0·91	0·45	1·36

The above figures indicate that there is a range of spacings, from 800 to 1,200 m, where the total of movement and road cost per cubic metre hardly varies. This means that a single road along the valley bottom would tap the whole area, giving maximum extraction distances generally around 1,000–1,100 m. Even at the maximum of 1,300 m, the total cost only rises 4 pence per cubic metre above the minimum total cost. Figure 9 shows the probable alignment.

Case B. Layout of Road Networks at Desired Spacing

In a great many cases the choice of road layout is restricted by topography or the position of existing roads. But in forests on less difficult terrain there will be instances when choice can be exercised, and when the shape of the forest block allows some latitude. A problem frequently arises when the desired road spacing does not fit the dimensions of the forest block very well.

Figure 10 shows a block of forest, approximately 1,700 m wide, with a single access at the south end to the public road system. We wish to lay out forwarder tracks in this block, and calculations of road spacing indicate a spacing of 700 m, with a maximum off-track haulage distance on either side of 350 m.

If the most obvious layout of parallel tracks is attempted, the choice lies between 3 tracks spaced at 570 metres, giving a total track length of 6·1 km (Figure 10a) and 2 parallel tracks spaced at 850 metres giving a total track length of 4·2 km (Figure 10b).

A layout nearer the desired spacing can sometimes be obtained as follows:

a. Mark off on the forest map, the maximum extraction limit of 350 metres around the boundary (Figure 10c).

b. This limit gives a position for the outer portion of the track system; mark in the alignments (Figure 10d).

c. Mark off the maximum extraction limit of 350 metres around the inner side of these tracks, so defining their catchment area. This leaves a central area still untapped (shaded on diagram) (Figure 10e).

d. Mark in possible spur roads to tap this central area (Figure 10f). The solution shown has one spur, marked ×, which is less efficient than the other two, but if we assume that this is accepted, the total track length is 5·45 kilometres, and the track layout gives extraction distances equivalent to a track spacing of 700 metres over practically the whole area.

This solution must obviously be subject to modification when laid out on the ground; but it does provide an indication of the type of layout one should try to achieve.

Case C. Choosing the Cheapest Combination of Road and Road Haulage Method

The woodland area is a block of forest, 30 hectares in extent and roughly 1,000 m by 300 m, running along the lower slope of a hill. The only possible road alignment is just inside the lower boundary of the wood. This is a fairly common "narrow valley" or "loch-side" situation (Figure 11). The nearest public road is at *A*, 500 metres from the end of the block.

Crop and other factors are as in Case 1, except that the terrain is steep, and extraction must be downhill, by cable-crane: road costs for a high-specification lorry road are £4,000 per km for construction, and maintenance per kilometre costs £50 per year. A low-specification track, suitable for forwarders, can be constructed on this site for £1,500 per kilometre, and will cost £100 per kilometre annually for maintenance.

The cost of moving timber by forwarder from the foot of the cable-crane racks along a track to point *A* on the public road system (where it can be collected by lorry), is assumed to be £0·55 per cubic metre. The average haulage distance from cable-crane rack to point *A* is 1,000 metres.

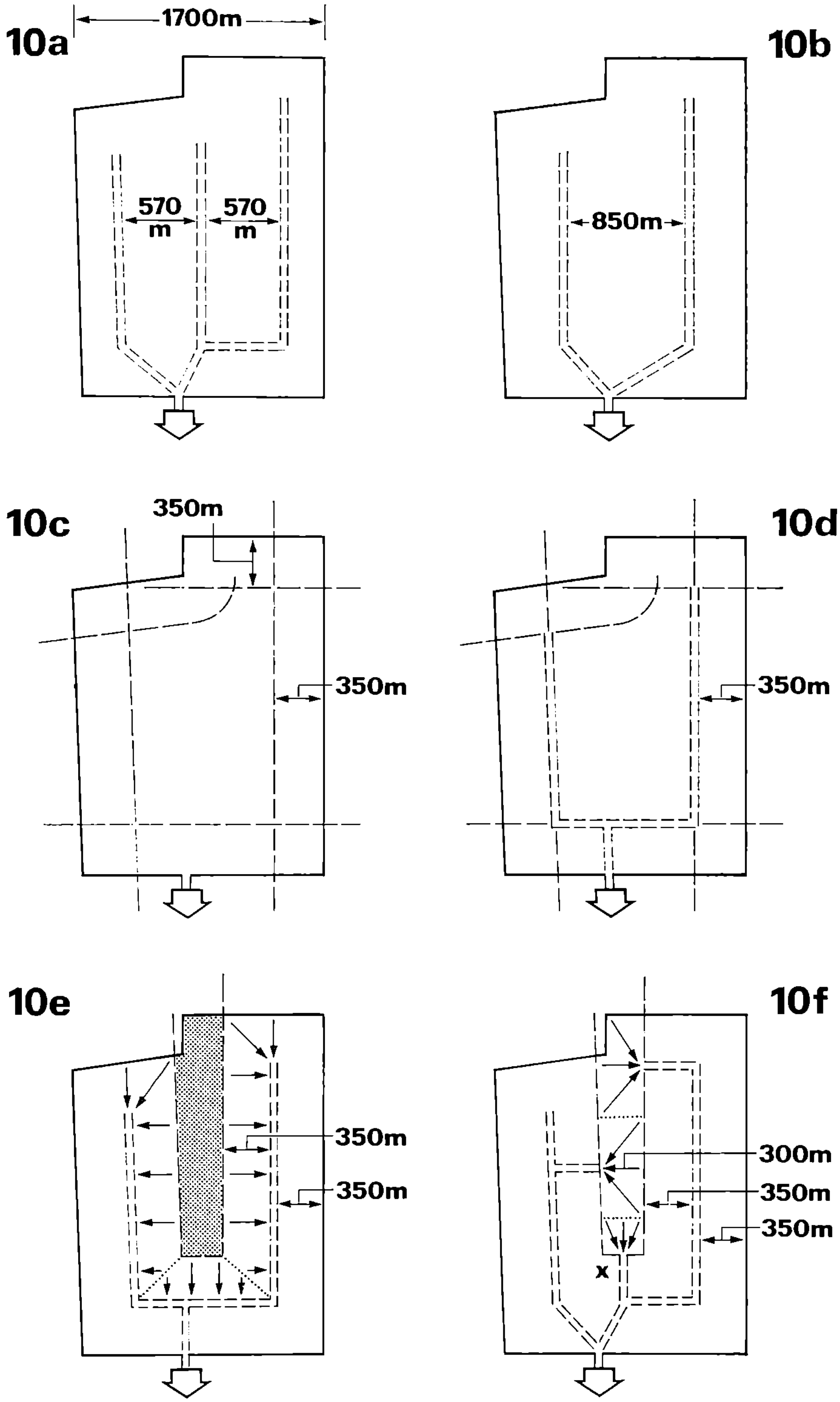

Figure 10. Steps in planning forwarder tracks in a forest block to secure maximum economy. See p. 24, Case B.

Two alternatives can be considered.

a. Build a high-specification road from *A* to a point at the far end of the block so that the whole area at the far end can be extracted by cable-crane. Timber haulage would be by large lorry, assumed to cost £0·03 per cubic metre per km for movement only. (Lorry loading cost is common to all possible alternatives here, and so is excluded.)

b. Build a low-cost forwarder track on the same alignment and use a forwarder to move timber from the cable-crane to lorry loading point at *A*.

A third alternative is to build a lorry road to a lower standard than in (a), and run lighter lorry loads over it. This is not considered here, as the cost of constructing such a road is usually nearly as much as for a high-specification road and resultant savings are generally small.

Comparing the two alternatives above:

	(a) High-specification road and lorry haulage	(b) Track and forwarder haulage
	£	£
Road cost per km capitalized £4,000+(50×9·077)	4,454	—
Road cost for 1·5 km length of road	6,681	
Track cost per km, capitalized £1,500+(100×9·077)		2,408
Track cost for 1·5 km length		3,612
Lorry haulage: £0·03 per km ×1·0 km average haul to A ×75 m³/ha average discounted volume ×30 ha area of wood	67	
Forwarder haulage £0·55 per m³×(75×30)m³		1,237
Total road+haulage cost for comparison purposes	6,748	4,849

Extraction costs from stump to track or road are common to both alternatives, and so are ignored. In this example, alternative (b) is substantially cheaper than alternative (a), and would therefore be chosen.

If the cost of track construction were £2,500 per kilometre instead of £1,500, the total cost of alternative (b) would rise to £6,349; while still cheaper than (a), the advantages are slight and it is a matter of judgement on non-financial grounds as to which is chosen. If the haulage pattern from the rest of the forest is by lorries operating on high-specification roads, it would be better to choose this for the wood in question, even if the financial comparisons indicate a slight disadvantage. This type of assessment is highly dependent on the accuracy of the cost estimates.

Case D. The Effect of Road Improvement on Transport Cost

A number of forests have road systems which were adequate for the type of lorry transport in use at the time of construction, but not for the larger lorries now being used. Should an existing road system be improved to allow access by large lorries?

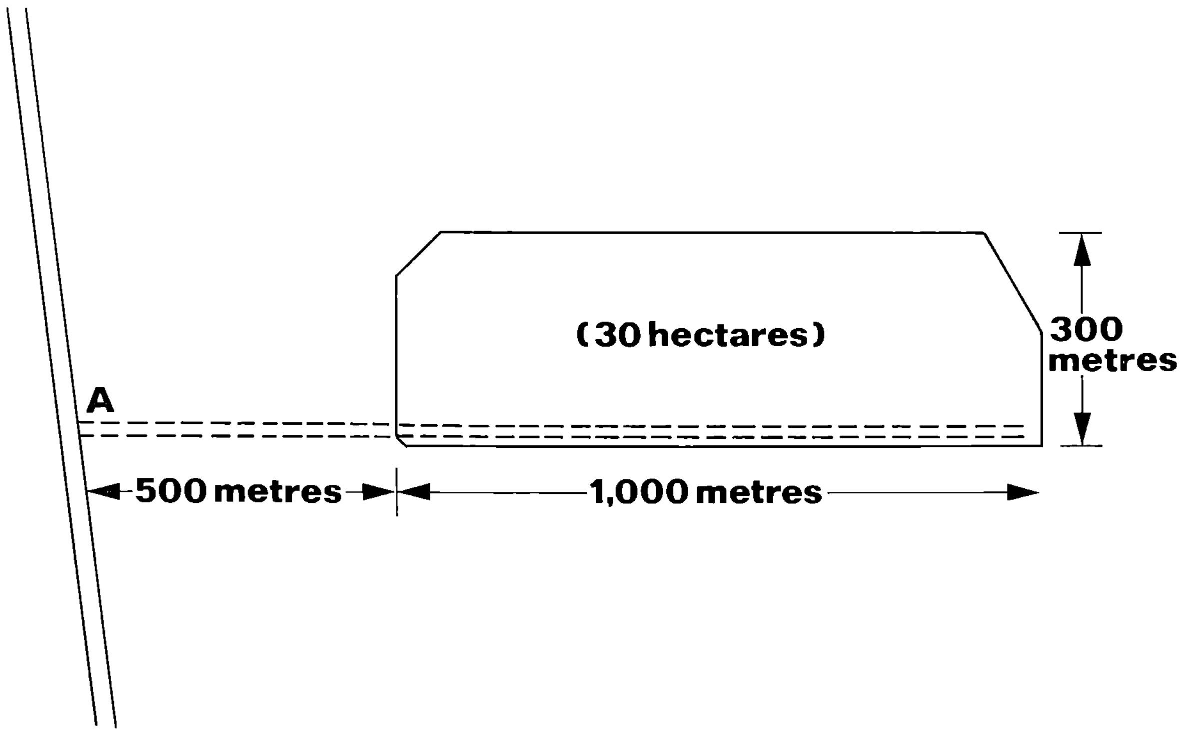

Figure 11. Sketch plan for choosing the cheapest combination of road and road haulage method for an isolated forest block. See p. 24, Case C.

Assuming that the use of large lorries is desirable from the point of view of transport costs, costs of improvement can be compared directly with resulting savings. Consider a block of 160 hectares of forest, served by 2 kilometres of road not of high enough specification to allow access by 32 tonne Gross Vehicle Weight lorries. Assume crop and other conditions are the same as for Case 1, except:

Current cost of improvement to high specification is £500 per kilometre.
The annual cost of road maintenance is unaltered by improvement.
Road haulage by large lorries, following improvement, is expected to cost £0·12 per cubic metre less than at present.

Costs and savings of improvement are as follows:

1. Cost of improvement: 2 kilometres at £500 per km: £1,000

2. Savings:

Discounted Vol. per hectare:	75 cubic metres	
×Area of block	×160 hectares	
×Savings per cubic metre	×£0·12:	£1,440

Savings exceed cost by a substantial margin, so the road should be improved, provided that there is some certainty that savings will continue at the rate assumed.

The greatest difficulty in this type of problem is accurate assessment of savings. Where transport costs are well known the benefits of changing to large lorries can be calculated with reasonable accuracy. Hired haulage quotations may or may not reflect the true operating costs of transport.

It is sometimes argued that improvement is essential, so that large lorries can be used and so delay a rise in contract haulage costs: this may well be true, but it is difficult to verify whether this is really the case, or whether the haulier gratefully accepts a larger margin of profit and omits to pass any of the savings to the grower.

The same difficulty arises where all the possible hauliers use large lorries only, and the choice seems to lie between road improvement and not getting the timber out. Improvement should not be carried out without investigating other possibilities, as in Case C.

TABLE 4

VOLUMES PER HECTARE DISCOUNTED TO TWO YEARS BEFORE AGE OF FIRST THINNING

(See text: Timber Volume, page 6)

Yield Class	Discounted Volume (cubic metres per hectare)										
	First thinning at normal age (Table 3 of *Forest Management Tables*)*					First thinning delayed for 5 years			First thinning delayed for 10 years		
	Standard Conifer	CP	LP	SS	EL	Standard Conifer	LP	SS	Standard Conifer	LP	SS
4	30		40		35	40	55		45	75	
6	45	50	50	50	50	55	70	65	65	90	85
8	60					75	85	85	90	100	105
10	75					95			110		
12	90					115			130		
14	105					135			155		
16	120					150			175		
18	135					170			200		
20	150					190			220		
22	165					210			240		
24	180					230			265		
26	195					245			285		
28	210					265			310		
30	225					285			330		
Rule of thumb:	YC×7·5					YC×9·5			YC×11		

Notes

Roads are generally put in at two years before first thinning.

Columns headed "standard" refer to all conifer species, other than those listed separately. Actual discounted volumes fall within 10% of the standard figures.

CP = Corsican Pine. LP = Lodgepole pine.

SS = Sitka spruce. EL = European larch.

* Forestry Commission Booklet 34, HMSO.

TABLE 5

DISCOUNTING FACTORS FOR 10% TEST DISCOUNT RATE

(See text: Road Costs, page 3)

Years	Compounding factor	Discounting factor	Capitalization factor
5	1·611	0·621	3·791
10	2·594	0·386	6·145
15	4·177	0·239	7·606
20	6·728	0·149	8·514
25	10·83	0·0923	9·077
30	17·45	0·0573	9·427
35	28·10	0·0356	9·644
40	45·26	0·0221	9·779
45	72·89	0·0137	9·863
50	117·4	0·00852	9·915
n	$(1\cdot10)^n$	$\frac{1}{(1\cdot10)^n}$	$\frac{1\cdot10^n-1}{0\cdot10(1\cdot10)^n}$

Compounding factor: A sum spent or received in year 1 becomes:

$\text{sum}\times(1\cdot10)^n$ in *n* years

Discounting factor: A sum spent or received in year *n* in the future is worth:

$\text{sum}\times\frac{1}{(1\cdot10)^n}$ in year 1

Capitalization factor: Sums of so much per year for *n* years are worth:

$\text{sum}\times\frac{1\cdot10^n-1}{0\cdot10\,(1\cdot10)^n}$ in year 1

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