FOREST ROADS: STANDARDS, DENSITY, TIMING AND COSTS

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SYNOPSIS

The question of when to establish roads formed to a standard suitable for logging is discussed on the basis of costs derived from forest operations in Southland and Otago, New Zealand. It is calculated that, for fast growing species, provision of tracks at time of establishment is false economy. It is concluded that for radiata pine crops roads should be established immediately before planting and that they should be on grades and alignments and to specifications (except for the running surface) suitable for use by logging trucks; initial density should be about one mile per 250 acres for easy topography and up to 200 acres for hilly land. For slower growing pines initial costs of road establishment should be lower, and for Douglas fir the lack of a suitable market for small thinnings makes any form of early access somewhat costly. This could be overcome in some instances by planting Douglas fir in mixture with pines.

INTRODUCTION

It is taken as axiomatic that a good roading system is essential to proper forest management. The question that exercises the forest manager is the economics of roading — how much, and when and where? In practice these questions might be determined largely by how much finance the owner, whether State or company, is prepared to allocate in the early establishment phases, and not by a study of the most economical expenditure in the long run. This matter, however, will not be pursued further, for the object of this paper is to present some analysis of roading as an aid to the sort of decisions that have to be made.

The study of the economics of forest roading began in Europe in about 1750, and from time to time it has received a good deal of attention. Of recent years, as exploitation has given way to management in country after country, the matter has become of great significance. In 1965, a major international stock-taking was arranged jointly by the United Nations Economic Commission for Europe and the Food and Agriculture Organization. A good many references will be made to this "Symposium on the Planning of Forest Communication Networks" in this paper, in which it will be referred to as the Joint Symposium. In New Zealand, the N.Z. Forest Service held a Logging Planning Conference in May 1964, and some of the matters raised then are also pertinent to the present enquiry; a contribution by Evans is of particular interest in relation to the timing of road establishment.

There is sharp disagreement on the timing of road establishment in New Zealand at present. Some contributors to the N.Z. Logging Planning Conference took the view that in the early stages of establishment all that was needed was a rough system of tracks;

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that more substantial roading would accumulate compound interest until used for harvesting, which would make its early establishment hopelessly uneconomic. On the other hand, many forest managers, forest protection officers, and those responsible for maintenance of vehicles (among others) contend that a good system of roads is essential from the earliest stage of forest establishment. The only country which parallels New Zealand's requirements is Britain, and there the Forestry Commission appeared at one time to have progressed within a few years from the ridiculous to the sublime. In 1948 the amount of roading being done in the establishment phase was minuscule, but by 1958 the standard density (which was based on requirements for horse thinning) was one mile to 80 acres (Grayson, 1965).

There can, however, be no hard and fast answer to the question of timing to fit all circumstances. If tracks can be put in for little cost, will remain negotiable whatever the weather, and require a minimum of maintenance, they could well be more economic than roads in the early phases of development. On the other hand, where road formation is costly, where metal is scarce but metalling is essential to keep either roads or tracks open, and where weather and soil are less favourable, a track system in the early phases might become an expensive luxury because, willy-nilly, money will be spent on maintaining whatever form of access was originally established. The cost of maintenance, over the period from land preparation to first thinning, can amount to a substantial sum.

This paper sets out to examine the question in the southern parts of the South Island of New Zealand. The relevant conditions are a moderate to high rainfall (30 in. per annum or more); mainly clay soils which, if used for tracks, cannot be kept in negotiable condition without metalling and regular maintenance; reasonable supplies of metal which, however, are not always close to forest areas; and topography which necessitates a certain amount of heavy side cutting for roads over about 30% or more of the afforestation areas, as well as tending to restrict the location of roads.

The importance of the question can be judged by comparing items of the Southland Conservancy budget for 1966–7. If planting and replanting are together taken as 100, the indices of other items are:

Land preparation	200
Releasing, blanking	55
Pruning, first log	86
Road construction	314
Road maintenance	77

These figures apply to an exotic forest of some 48,000 acres widely scattered in rather small units. Production from thinnings and clear-fellings amount to 3.3 million cu. ft annually. New plantings total about 2,700 acres and replanting some 600 acres per annum.

ROAD LOCATION, SPECIFICATIONS AND TIMING

Before dealing with costs, and at the risk of stressing the elementary (which, curiously enough, is often overlooked), it is desirable to analyse actual road usage. Several authors in the Joint Symposium note that, in the intensively managed forest, transport of men and materials accounts for more traffic than logging trucks (Samsat; Steinlin), and the matter is given some prominence in economic analysis of roading networks (Larsson, 1959). The Logging Planning Conference took the view that the principal use for roads was in the extraction of produce, and this would be so, in terms of tonnage at least, in the later stages of harvesting. In the fully developed forest it could also be the case for major roads, but it would not be true in the earlier phases of establishment and tending. Because of the amount of labour used in these early phases, up to the time of first exploitation at least, it is of considerable importance that men should be able to get to their places of work with the minimum loss of time and effort, especially when in conditions of full employment the most significant shortage in the means of production is manpower.

Access then (taking the year 0 as being the year of planting) is required for:

Supervision and administration	Annually from year of purchase
Fencing and materials	0 minus 5 to 0 minus 1
Land clearing:	
Felling contractors	0 minus 7 to 0 minus 1
Machinery	0 minus 5 to 0
Burning off	0 minus 5 to 0
Planting	0
Fire control; protection	0 onwards, annually
Animal control	0 onwards (or earlier), annually
Biological observers	0 onwards, annually
Tree cleaning and blanking	0 plus 1 to 0 plus 2
Access to adjoining areas for similar operations	0 onwards (or earlier)
Pruning	0 plus 6 onwards; biennial or less frequently
Thinning to waste	0 plus 10 or later
Thinning with extraction	0 plus 10 or later

Not all of these facets of management are of equal importance, but the list does indicate that any road or track once established is likely to be used quite frequently every year. Therefore the questions asked in this section are: "Where should these roads be put?" "What specifications are we aiming for at this stage?"

The N.Z. Logging Planning Conference generally agreed to three classes of roads (Simpson and Spiers), defined as arterial, secondary, and spur or stab roads. This subdivision does not seem to be universally valid, for contributors to the Joint Symposium put forward a number of alternatives, depending largely on the current stage of management. Strehlke (East Germany), Lebrun (France), and Caragata (Romania) have arrived at similar conclusions to Simpson and Spiers and have a threefold classification into main, secondary, and skidding roads. Chtchiglovsky (U.S.S.R.) also has a threefold system aimed generally towards logging only but with some provision for a short regeneration period; his terms are main, branch, and spur roads. Cornides (Hungary) is more concerned with weather conditions; his Class I roads are for use for full log loads except in very wet periods or during the thaw; while his Class III roads are for use in dry frosty weather only (dirt roads). Klemencic (Yugoslavia) has only two classes — non-producing (equivalent to arterial roads), and producing (equivalent to secondary and spur roads). The declining sophistication of the classification appears to depend to some extent on the stage reached between early pure exploitation and degrees of management; thus the least viable classification is that of Tavsonoglu (Turkey) which is based solely on exploitable volume per acre. Some countries, notably Britain, have not apparently evolved this type of classification, although it is clearly of considerable importance.

The New Zealand classification is based entirely on logging requirements, but it does appear to fit the general requirements of forest management as well. In any case, at some stage in the history of the forest these types of roads, capable of accommodating varying densities and weights of logging vehicles, must be supplied. For radiata pine crops, roads for extraction of thinnings may be required within ten years of planting. For Corsican and other slower growing pines the period is likely to be about 20 years, while for Douglas fir (unless there is a suitable treatment plant) it will be 30 years or more. It is reasonable to suppose, however, that a roading system designed for logging could be equally well sited for other forestry purposes, and this is the view towards which several authors in the Joint Symposium are moving.

There seems to be general agreement in this country that arterial roads should be established to a high standard in the early stages of development (Evans; Simpson and Spiers). There is equal agreement that stab or spur roads should be put in to serve specific logging operations shortly before those operations are to begin. Doubts about timing and specifications devolve mainly on the establishment of secondary roads. The view of some loggers (Simpson, for example) is that we cannot hope to know what form logging will take ten, twenty, or thirty years hence, and that therefore roading should as far as possible be deferred until it is needed for logging. But in this connection it is necessary to make some distinction between roading planning and road formation. The consensus of opinion in the Joint Symposium and at the N.Z.F.S. Logging Planning Conference is that roading should be planned at the earliest possible stage either of exploitation (for wild forests) or of afforestation. It is far simpler to plan a roading network when the country is open than when crops have been growing on it for some time. Contour maps for hilly country carrying mature tree crops, taken from aerial photography, are often not accurate enough for road location and planning, and grade running in the field in dense crops with closed canopy is time-consuming and expensive. Moreover, in this type of country the roading layout is often determined largely by topography, so that there is little point in delaying planning.

Though there is general agreement on this point, there is some disagreement on whether these planned roadlines should be used for temporary or permanent access, or whether they should be planted. Those advocating planting do so on the basis that unplanted areas are non-producing. However, Kramer (1965) has studied beech and spruce stands in Germany, and has found that, provided roads are put in early in the life of the stand, there is no loss of increment in beech stands if the roads are less than 12 metres wide, and none in spruce forests if roads are five metres wide or less. He found that there can be serious losses when roads were cut through older stands, because of windthrow. This form of loss occurs also in Southland following roadline felling. It is also common experience that there is some financial loss in production from roadline felling; stumping is costly and disposal of spoil difficult in hilly country; and roads formed on stumped ground take time to consolidate, do not stand up well to logging traffic, and are therefore costly to maintain in the early period of use.

Those responsible for initial access for afforestation have fallen into two schools; those who have used the roading plan as the location for road or tracks, and those who have put in tracks as cheaply as possible, ignoring the roading plan and taking the view that tracks should be the most convenient or shortest route to the places of work, irrespective of grades, alignments, or other specifications. Evans (1966) strongly opposes temporary access on the planned roading alignments. He says that "first design should be final design" and points out that reformation of an existing road "could be between 1½ and twice the cost of earthworks of a road constructed initially to a high standard".

Some decision has to be made early in forest development on the roading needed (mainly for gang trucks) from shortly before planting up to the time of first utilization. Because of the value of labour, the roads must be reasonably safe; and this means that roads should have reasonable grades, alignments, and widths of formation; they must be negotiable in all weathers, indicating a weather-proof running surface; and they should have a reasonably smooth surface to save running time and to reduce wear and tear on vehicles which, as items requiring overseas exchange, are not always readily replaceable. Evans stresses that "travel time is influenced by grade, nature of the road surface, alignment, width of roadway, and psychological factors", while Byrne *et al.* (1960) state that "good surfaces result in greater savings in hauling costs than can be realized by increasing truck size with consequent increases in road construction costs".

There may indeed be a fairly fine line between acceptable gang truck roads and acceptable logging roads. The main additional need for logging is greater strength in the running surface. Thus a second distinction needs to be made in the early stages of the forest: that between formation and metalling. If the topography largely dictates the location of logging roads, it also tends to dictate grades and alignments, and the main variant within the scope of the forest manager is therefore width of formation. Evans advocates construction of all roads to high formation standards initially, but the application of metal only insofar as it is required by the type of traffic. Several authors in the Joint Symposium support this view. In Southland and Otago initial metalling is generally light (five or six, sometimes up to eight, cubic yards per chain), but some maintenance metalling is required from time to time under the frequent impact of light traffic. Usually by the time of first utilization the roads have absorbed a good deal of metal (up to 15 or even 20 cu. yd per chain) and have become well consolidated. If in the first place formation was suitable for logging trucks, the only extra cost at this stage is for additional metal. It is important to realize that sometimes the most punishing time in the life of a road is not at final felling, where large vehicles are used, but at first thinning, for which flat-deck trucks (which have a fairly high traction weight in lb/sq. in.) are often preferred owing to the type of produce. Moreover, where metal is expensive (for some areas in Southland the delivered price is $3.50 per cu. yd) the waste consequent upon reconstruction could be considerable.

The standards normally applying in State forests in Southland and Otago are given in Appendix 1. The general rules are:

(1) Roading layout for arterial and secondary roads should be planned before planting; the major consideration is their eventual use for logging and, where there is doubt, a logging expert should be consulted.

(2) Roads to be formed for access for silvicultural work are to follow the approved roadlines and for radiata pine stands are to be formed to logging standard. For areas in other species some reduction in formation widths and radii of corners is permissible, provided grades are satisfactory. Metalling is to be to light traffic standard.

(3) Roads not formed in the establishment phase are to be left unplanted; this does not include stab roads.

(4) Formed and metalled roads are to be regularly maintained.

(5) Stab roads are to be formed immediately prior to utilization.

The roading specifications may appear to beg some questions. It cannot be said with certainty what the future logging and extraction pattern will be. There is, for example, a tendency for logging vehicles to get bigger, but if vehicle weight increases, the remedy, applied at the appropriate time, is simple and will not affect roading in the early phases of development. As far as type of machinery is concerned, it can safely be taken that the logging vehicle powered with some form of internal combustion motor is likely to be operating for some time to come and to have economic advantages over other tentative alternatives (*e.g.*, helicopters). This prediction leads naturally to several useful guides: for example, the easier one can make adverse grades the better; it is usually quite clear which direction is adverse and hence this again will not affect planning in the early stages. The only doubt the forest manager might have is with curvatures. There is little doubt that he should aim at the widest curvatures in order to allow as much speed as possible (see Appendix 1), for time will remain costly far into the foreseeable future. The crux of the matter is minimum curvature; if logging trucks get bigger, will they get longer? The standard 16 ft log has been an acceptable article of commerce for several decades and appears likely to be equally acceptable for some considerable time. We should thus not be far out if we design curvatures to accommodate, as the absolute minimum, vehicles carrying logs of up to two lengths — say, 35 or

36 ft. In this connection it is worth noting that Larsson, in determining the roading system with the lowest cost per unit of wood extracted, established two important points. He found that financial loss due to a roading system of too high a standard was less than would be brought about by a roading system that was below standard to the same extent. This is confirmed by Klemencic. Larsson's general conclusion was that "a rationally planned motor truck haul road system in a forest might . . . be regarded as satisfactory even under materially changed future conditions". This holds true even when costs of timber extraction are substantially altered or when production per acre alters on a fairly major scale (Larsson, 1959).

ROADING DENSITIES

The eventual roading density in a forest, including spur roads, will depend mainly on practical considerations; the types of logging equipment used, the material being produced, the method of extraction, and especially the topography. Therefore, discussion of roading densities can become somewhat theoretical if a definite tract of land is not under consideration. Nevertheless, some discussion of the theoretical approach to roading densities is desirable in order to establish some guidelines. Overseas experience is valid since there is a growing tendency towards more detailed and intensive silvicultural management in most countries, and because extraction methods and machines are tending to be somewhat similar in scope and operation. For these reasons some of the findings of the Joint Symposium (where roading density has been dealt with exhaustively) will be discussed. There are generally two approaches, both with certain limitations, but both of some value in elucidating the essential points. The first group studies optimum roading densities in relation to timber extraction from a purely economic point of view. Larsson, for example, has built up elaborate mathematical models to study not only the optimum in relation to the minimum cost per unit of volume extracted, but also the effect of lowering or improving standards and densities. He has produced graphs showing the relationships between mean production per hectare, length of haul, and average speed at end point of haul. He also shows the relationship between roading density and roading standards, and establishes that, within certain limits, percentage losses are less for roads at too high a density than for roads at a correspondingly lower density; for example, if the optimum density is one mile to 250 acres, there is little loss if the density is one mile to 200 acres.

The authors working from the standpoint of economics suffer to some extent from lack of definition of some terms (notably "maintenance") and a lack of agreement as to whether roads have finite or infinite lives. Macmillan, for example, assumes an infinite life, while Strehlke gives prominence to amortization costs. The term "maintenance" has frequently been confused with what should more properly be termed "upgrading", but it is often difficult to distinguish where one stops and the other starts. In spite of this, and of some variation in the conclusions of the economists, the findings presented in the Joint Symposium for countries where the standard of management is fairly high should have some relevance for this country. Chesnau (France) concludes that the optimum density lies between one mile:330 acres and one mile:400 acres, but has to admit that the actual density in the forest being studied (Bousson) is one mile:250 acres, since terrain overrides any purely economic deductions. Grayson (Britain) has studied roading systems from the point of view of net benefit:cost ratio and has concluded that the optimum is between one mile:160 acres and one mile:180 acres. Strehlke (East Germany) equates minimum skidding costs with minimum costs of construction, maintenance and amortization and arrives at an optimum density of one mile: 210 acres.

These conclusions lie fairly close to one another. In Russia and Czechoslovakia more attention is paid to terrain. For example, Staud (Czechoslovakia) makes a distinction between easy, hill, and mountainous country and is concerned with silviculture as well as extraction. His figures are:

Level ground	from 1 mile:560 ac to 1 mile:500 ac.
Hilly country	from 1 mile:500 ac to 1 mile 280 ac.
Mountainous	from 1 mile:400 ac to 1 mile:220 ac.

Chtchiglovsky (U.S.S.R.) comes to opposite conclusions, taking into consideration the aim of minimizing the cost of extraction. In mountainous country his optimum density is 1 mile:660 acres, while on other terrain the range is 1 mile:400 acres to 1 mile:140 acres. The economists all stress, however, that mathematically determined optima should be considered only as guides to practice; indeed some of their findings give distances between roads that would be too great for practical logging.

The second and larger group in the Joint Symposium are what can be termed the field men. They are concerned mainly with the practical aspects of logging. Silversides (Canada) considers that road density must be based on experience; formulae can be properly applied only in conjunction with logical deductions from costs and other field data. His conclusion for eastern Canada is that roads that climb between levels should be reduced to a minimum, and that the major length of roading should be spaced horizontally at economic intervals (meaning optimum haul for specified equipment). Seheult, in the same country, carries this further for pulpwood logging with rubber-tyred skidders, and advocates roads spaced some 22½ chains apart for "one side only" skidding.

Macmillan (Britain) takes into consideration not only silviculture but also fire protection and concludes that, in the early stages of afforestation, roading density should be between 1 mile:320 acres and 1 mile:240 acres. Kramer advocates a density of 1 mile:250 acres for managing spruce stands in East Germany. Cornides (Hungary) bases his conclusions on topography, type of logging equipment, and increment of stands, and advocates densities from 1 mile:160 acres to 1 mile:260 acres.

While the economists came to opposite conclusions concerning mountainous country, the field men seem to be thinking in the same direction. Pestal (Austria), from the study of the use of skyline cranes, considers a haul of 35 to 50 chains is suitable for hilly country, but for mountainous country this must be reduced to 15 to 25 chains. His compatriot Hafner agrees, and in Czechoslovakia Dressler comes to a similar conclusion (15 to 30 chains). Schonauer gives practical examples and maps of forests in Austria with road densities from 1 mile:120 acres to 1 mile:170 acres, but his compatriot Vyplel takes the view that current densities of 1 mile:200 acres should be improved to 1 mile:100 acres. The implication from these studies is that the more rugged the country the denser must be the roading system for efficient logging.

Several authors in the Joint Symposium discuss the increment loss in taking land out of production for roading. Kramer has calculated that roads 30 ft wide at a density of 1 mile:250 acres gave an increment loss in a Norway spruce forest of about 0.8%. Strehlke gives a table which indicates that in European beech forests roads 45 ft wide (stump to stump) at a density of more than 1 mile:200 acres result in an increment loss of 1%. It appears that loss is related to the radius of tree crowns. It is therefore possible that in radiata pine stands there would be little loss of increment if roads are not more than 30 ft wide (stump to stump); similar widths would possibly cause little loss in Douglas fir stands, but for Corsican and other pines reduced widths would be preferable. The question needs evaluation for these species.

Although there are obvious discrepancies, the general consensus in the Joint Symposium is that the density of logging roads in easy terrain where silviculture is important should be to the order of 1 mile:200 acres. For practical reasons, roading density in hilly and mountainous country must be increased. These conclusions are closely related to the capacity of logging equipment in use at present. What then of the future? The major criteria will always be logging needs and costs, and although there is some controversy about future logging gear and methods, two general elementary principles are always likely to be overriding:

(1) A machine (or rarely now an animal) is taken to the log, which is then attached and dragged out to a roadline, and

(2) A stationary machine is set up on a roadline from which a rope is taken out to the log, to which it is affixed; the machine then drags the log to the roadline.

The real question is: what distance is it convenient or economic to move logs from stump to road? Some examples are given above and these tend to confirm that the tendency in recent years has been for this distance to shorten. Current figures (Simpson and Spiers) are:

Tractors: Optimum 8 to 10 chains; maximum for corners about 15 chains.

High lead haulers: Optimum, about 12 chains; maximum, 20 chains.

Skyline haulers: Optimum, 16 to 20 chains; maximum, 35 chains.

Mobile haulers and spars: Optimum, under 8 chains; maximum, 12 chains.

Thinning haulers: Optimum, about 6 chains; maximum, possibly 10 chains.

Skyline cranes in Europe and Japan have been used up to 120 chains, but their operation depends on type of slope. In mountainous country in Europe the tendency is to reduce length of haul and in some cases the optimum is defined as between 15 and 25 chains, with a maximum of about 50 chains.

Much of the country in Southland and Otago will eventually be logged by hauler systems, and it can safely be concluded that the optimum distance between roads will be to the order of 30 to 40 chains. Since it is generally desirable, especially from the point of view of fire protection, to have through roads in the secondary system, it must be concluded that these roads cannot be laid directly through all hauler locations, which in due course will be placed at the end of stab roads. Thus, the sort of espacement that can reasonably be considered, excluding spur roads, would be to the order of 40 chains between roads of the arterial and secondary system.

The simplest case to consider would be flat land. Parallel roads at 40-chain intervals, with a connecting road at right-angles every two miles would, for large rectangular areas, give a density of 1 mile:256 acres. In hilly country such an ideal arrangement is not possible; roads have to be established where suitable grades and alignments can be found, and in practice roading density planned for forests in Otago and Southland (omitting spur roads) is fairly close to 1 mile:200 acres. In easy country density can be as low as 1 mile:300 acres, while in difficult conditions it can be as high as 1 mile:160 acres. Viewed against the practice in other countries, these figures appear to be reasonable, and in addition the Forest Service standard for roading density for fire protection is 1 mile:200 acres.

It may be felt that such a density in the establishment phase is a luxury, but it should be borne in mind that the fully-established roading density at Kaingaroa Forest for thinning extraction lies between 1 mile:64acres and 1 mile:80 acres. Initial densities at the levels considered above are thus very much less than the density for intensive harvesting. But it is of some importance to examine the economic implications of the initial density, particularly in relation to additional costs and labour. A decrease in roading density from 1 mile:200 acres to 1 mile:400 acres adds approximately half an hour per man-day to all operations owing to extra walking time. This may sound small enough, but for all operations in Southland Conservancy in 1965–6 the loss of labour would have amounted to some 11,000 man-hours. Allowing for wet and other lost time, a man-year is about 1,850 man-hours of actual work, so the additional labour to make up for the additional walking time would have been about six men. Staff and specialists would also have lost time, but are not included in this total.

With roads at 1 mile:400 acres, when compared with a density of 1 mile:200 acres, the financial losses on various operations, based on weighted mean costs in Southland for the year 1965–6, are shown in Table 1.

These are direct costs. If one assumes overheads of 35% on labour and takes all costs forward at 5% compound interest to the time of first exploitation indicated by the asterisks in the table, the total additional costs per acre will be:

For radiata pine at 12 years old	\$10.05
For Corsican pine at 20 years old	\$10.45
For Douglas fir at 30 years old	\$18.56

TABLE 1

Year	*Operation*	*Costs in \$ per acre (to nearest 5c) for:* P. radiata	Ps. menziesii	P. nigra
— 1	Preparation	0.40	0.40	0.40
0	Planting	0.80	0.80	0.80
+ 1	Cleaning — 50% of area at	1.05	1.05	1.05
+ 1	Blanking — 30% of area at	0.20	—	—
	10% of area at	—	0.20	—
+ 6	Pruning 0/6	1.45	—	—
+ 8	Pruning 6/12	1.05	—	—
+10	Pruning 12/18	1.05	—	—
	Pruning 0/6	—	—	1.00
+11	Pruning 0/8	—	1.60	—
+12	Thin	*	—	—
+15	Prune 6/12	—	—	0.80
+16	Prune 8/18; thin to waste..	—	1.20	—
+20	Prune 12/18; thin	—	—	0.80*
+30	Thin	—	*	—

ROADING COSTS

Some representative roading costs, incurred in the years 1964–6, in Southland Conservancy, are given in Appendix 2. Over this period the weighted mean cost of new roads formed and metalled shortly before planting was slightly below \$38 per chain. This is a convenient figure to use in the models to be discussed below, and will thus be adopted. It covers both arterial and secondary roading, with formation normally 24 ft wide or more and metal restricted to 9 ft lane at a rate of about 6 cu. yd per chain. Roading to this standard at a density of 1 mile:200 acres costs \$15.20 per acre.

Where, in the past, tracks have been put in for establishment, the tendency is for the density to be higher than 1 mile:200 acres. Costs have varied from as little as \$4.00 per chain, to over \$8.00 for formation, and from \$5.00 to \$10.00 per chain for initial metalling. For the purpose of this discussion, a density of 1 mile:180 acres at a cost of \$12.00 per chain has been adopted; the cost per acre is then \$5.30.

A critical cost is that for reconstruction of tracks or low-grade roads immediately before logging. A mean cost in Southland is \$60.00 per chain, but the cost is usually higher where stumps have to be removed; this operation alone can cost up to \$50.00 per chain in difficult conditions. Reconstruction at \$60.00 per chain at a density of 1 mile:200 acres amounts to \$24.00 per acre. If, however, roads are put in initially to a standard of formation suitable for logging, the cost of upgrading amounts to only \$24.00 per chain or \$9.60 per acre. New roads put in especially for logging cost from \$48.00 to \$140.00 per chain; a reasonable mean cost (which does not allow for stumping) is \$70.00 per chain, equivalent to \$28.00 per acre; this does not include spur roads.

A most difficult figure to assess is that for maintenance. The difficulty is not confined to Southland, as several authors in the Joint Symposium met with the same problem. Grayson quotes a British Forestry Commission figure of £50 per mile per annum, which seems somewhat high. Volkert came to the conclusion that there are scarcely any relationships between construction costs and maintenance costs relative to the type of road, but maintenance costs will always be high if the standard of metalling is low relative to the traffic use. One difficulty recorded in the Joint Symposium has been overcome in the figures presented here, which distinguish between annual maintenance (for example, grading and some re-metalling) and upgrading for logging. In other respects, examination of costs in Southland Conservancy leads to the same conclusion as that of Volkert: annual costs of maintenance, whatever the type of road, do not vary appreciably per unit of length. The weighted mean cost is $70.00 per mile per annum (although in practice costs are not incurred for any particular length of road every year). This is equivalent to $0.35 per acre per annum for a density of 1 mile:200 acres.

DISCUSSION

In the report of the N.Z.F.S. Logging Planning Conference, in the summing-up on layout and timing of logging roads, appears the statement: "any minor roads constructed [meaning secondary and spur roads built well before they would be required for logging] should pay for themselves by actually reducing the cost of establishment, silvicultural or protection operations enough to pay for the road". One difficulty of determining the validity of this statement is that nowhere did the Conference define what precisely was meant by the three terms used to classify roads. How much land should an arterial road actually serve? Would this be determined by topographical units — for example, one arterial road per valley? Where does an arterial road cease and a secondary road begin, and what are the bases for determining the proper classification? A somewhat imprecise definition is given in Appendix 1; arterial roads are expected to serve 5,000 acres or more and secondary roads about 1,000 acres: but when these criteria are examined against actual pieces of land they do not always prove helpful. It is not the purpose of this paper to do more than draw attention to the need for clarification; its main purpose is to show that, in certain circumstances, the statement above is highly misleading, and that, in any particular set of conditions, it needs to be examined critically.

For this purpose five mathematical models, using the data already presented, are given in detail in Appendix 3. The models compare the following possible courses of action:

(1) Establishment of tracks two years before planting to a density of 1 mile:180 acres, followed by logging roads put in at the time of first thinning.

(2) Establishment of roads two years before planting to a density of 1 mile:200 acres, on proper alignment but to half standard (that is, at a cost of $7.60 per acre). These roads are reconstructed immediately before first thinning.

(3) Establishment of roads two years before planting to a standard represented by $38.00 per chain at a density of 1 mile:400 acres; remainder of area made accessible by tracks at a

density of 1 mile:180 acres. Tracks are reformed, and roads are upgraded, immediately before thinning.

(4) Establishment of roads two years before planting to a standard represented by \$38.00 per chain, but at a density of 1 mile:400 acres. Additional roads are established immediately before thinning to make up a density of 1 mile:200 acres, and original roads are upgraded at the same time.

(5) Establishment of roads two years before planting to a standard represented by \$38.00 per chain at a density of 1 mile:200 acres, and upgraded before thinning.

It has been assumed in the models that the roads and tracks are all located by logging experts, and that no major technical changes occur in the interim to make these roads obsolete. Comparative costs are shown in Table 2.

TABLE 2

Specifications	*Costs in \$ per acre at 5% C.I. for:* *Radiata pine*	*Corsican pine*	*Douglas fir*
(1) Tracks	45.48	57.50	80.98
(2) Roads at ½ standard	45.28	58.74	84.96
(3) Roads at ½ density, tracks	45.56	61.92	93.56
(4) Roads at ½ density	47.00	57.74	85.94
(5) Roads at full density	45.88	66.56	106.78

These costs do not include certain incalculable items. These include the proportion of costs which could reasonably be considered an insurance premium for ease of access in case of fire; access for animal control, noxious weed control, disease inspections and control, research, investigations, inspections, supervision, compilation of working plans, mensuration (especially assessments), survey, timber sales, ground control for aerial photography, and public relations; wear and tear on vehicles and additional delays and costs on movement of personnel. All these items, if they could be reliably assessed, would, on strictly economic grounds, favour a well-formed roading system rather than a "cheap" system of rough tracks.

It is considered that savings due to adequate roading (both in quantity and quality) in these fields could amount to a considerable sum over a period of time. Two examples (both suppositious but both likely) can be given. They refer to a small forest of 10,000 acres with an average employment of 12 men. It is assumed that arterial roads have been formed to good standard, but that all other access is by rough track. The amount of truck running is taken to be 40,000 miles per annum and additional wear and tear on vehicles amount to 1 cent per mile; this is likely to be well below actual additional costs, and is equivalent to 3 cents per annum per acre. On this basis approximate additional costs for radiata pine stands would be 60 cents per acre at time of first utilization, for Corsican pine it would be \$1.20, and for Douglas fir \$2.35.

For the second example, it is assumed that one-way travel time is lengthened on each trip by five minutes (that is, 10 minutes per return trip). In the given circumstances, the annual cost per acre would be 5 cents. At time of first utilization thinning the additional cost for radiata pine would be 75 cents per acre, for Corsican pine $1.75, and for Douglas fir $3.42.

None of these additional costs are particularly startling, but if the whole range given above were accurately costed the savings could amount to a sum in excess of the difference between the cheapest and the most expensive alternative given in Table 2. Even without these unknown items, the models indicate that a system of tracks in the conditions described is not a cheap substitute for an adequate roading system established shortly before planting. For radiata pine there is little to choose between the various alternatives; the most costly is roading at half density. But the models are probably not sufficiently sensitive to distinguish real differences when the total spread from the cheapest to the most costly is only 86 cents per acre. It is, however, a reasonable assumption that roads in radiata pine areas should be constructed to a standard of formation suitable for logging, at about the time of planting, and that at this stage density of roading to the order of 1 mile:200 acres is acceptable on economic grounds.

The situation is not so satisfactory for Corsican pine (and by inference for other pines with a similar rate of growth). The most costly alternative is roading to a density of 1 mile:200 acres and to the standard normally aimed at in Southland. But even here the differences are not large, the total spread being only $9.00 per acre between the cheapest and the most costly. A saving of $8 per chain in initial roading costs for alternative (5) in Table 2 would bring the total compounded cost down to $57.20, and it would be simple to achieve this saving with a slight reduction in density or, where appropriate, a slight lowering of standards. Simpson is adamant that "economy should be in the matter of road length or density, not in quality, for the latter can easily become false economy indeed". Because of topography in many forests this precept is not generally easy to follow, and therefore if standards are to be lowered in certain circumstances there should be some definition of what is acceptable. The main saving in Corsican pine areas would be curvatures; it is estimated that the amount of re-alignment necessary to bring these roads up to logging standard would not exceed twice the initial saving — that is, about $6.00 per acre.

In Douglas fir stands the spread of costs between the cheapest and the most expensive roading alternative is too great to ignore. This is largely a reflection of the lack of markets for small round produce in Southland and Otago. Although it would be theoretically cheaper to serve Douglas fir areas with tracks during the establishment and tending phases, the point is often academic, since areas of this species are likely to be contiguous to stands of other species, including radiata pine. Alternatively, access to Douglas fir areas often gives access to other species beyond them. The position would be alleviated by planting Douglas fir in mixture with Corsican or other appropriate pine, to be thinned out (say) at 20 years old, leaving the Douglas fir for later thinnings and as the final crop.

CONCLUSIONS

The principal conclusion to be drawn from the studies discussed in this paper is that several current opinions on the matter of early access to afforestation areas are questionable; economic comparisons between practical alternatives can show that, in certain circumstances, the most expensive operation can in the long run be the most economical. In addition, the following managerial guides are indicated:

(1) In view of the high investment in roading for timber extraction, a good deal of time and effort should be devoted to good planning, in which the forester, roading engineer, and logging expert should all have a hand. The best time to do this planning is in the very earliest stages of forest development.

(2) Any form of access put in for establishment and tending cannot be considered in isolation. Accumulated costs of forming and maintaining poor access can well be equal to the cost of high-grade roading, but this will depend on soil, topography, and weather. All aspects must be closely examined before arriving at decisions.

(3) Any roads established in the early stages of development should be formed to final standard, and should be planned as part of the final roading network. Substantial savings are made if good roading is provided for all establishment and tending operations in the forest.

(4) Initial roading up to a density of 1 mile:200 acres is justified for radiata pine where thinnings are to be removed at an early age. For slower-growing species, some relaxation of standards can be permitted. Where there is no outlet for thinning before 30 years of age, early provision of high-density roading cannot be economically justified.

The conclusions in this paper are generally in close agreement with findings in countries where intensive silviculture and management has been, or is being, introduced; especially with those in Britain, where conditions most closely resemble those in New Zealand.

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APPENDIX 1

Suggested Standards for Forest Roads

Designation	Class I Arterial		Class II Secondary		Class III Stab	Class IV
To serve units 1,000 ac per unit	5 units or over		1 unit or over		under 1 unit	Landrover access
Continuous use or spasmodic	Continuous		Continuous		Spasmodic	Spasmodic
Topography	Rolling	Mountainous	Rolling	Mountainous	N.A.	N.A.
Number of traffic lanes	2	2	2	2	1	N.A.
Minimum design speed for curves	40 mph	30 mph	30 mph	15 mph	15 mph	N.A.
	9 ch	4.5 ch	4.5 ch	1.5 ch	1.5 ch	
Desirable maximum gradient	1 in 20	1 in 10	1 in 15	1 in 10	1 in 10	1 in 5
Roadway width	30 ft	27 ft	27 ft	20 ft	18–20 ft	8 ft
Lane width	2 at 11 ft	2 at 10 ft	2 at 10 ft	2 at 9 ft	1 at 12 ft	N.A.
Minimum loose metal depth	6 in.	6 in.	5 in.	5 in.	4 in.	—
Camber	½ in. per ft	½ in. per ft	½ in. per ft	½ in. per ft	½ in per ft	—

In Classes I, II and II, proper road construction practice should be adhered to, although on difficult country curve design and grade may have to be sacrificed.

No culvert pipe to be smaller than 9 in., and when a size has been calculated for a creek, 20% should be added to the diameter.

Length of vehicle and axle weight have been taken into account in curve design and metal depth.

APPENDIX 2

Representative Roading Costs — 1964–6

The following items are total costs, including overheads at 35% rounded to the nearest $ per chain.

	Cost per Chain $
(1) *Formation Only*	
(a) Main access to Woodlaw Forest from the south-west. (Fairly steep, with side-cutting over the greater portion.)	44
(b) Access to Island Bush (Woodlaw Forest). (Secondary road through cutover and second growth forest on moderately easy topography)	26
(c) Secondary roading in Otago Coast Forest. (Much side-cutting in rock, including some blasting)	70
(2) *Formation and Metalling*	
(a) Some arterial, but mainly secondary roading in Otago Coast Forest. Some fairly steep grades and heavy cut and fill in gullies, but majority of formation on ridges. Metal to light traffic standard	38
(b) Mainly secondary roading at Berwick Forest. A certain amount of side cutting, but rather more than half on easy ridges. Metal to light traffic standard	36
(c) Beaumont–Rongahere Road from Rankleburn to Beaumont Forest H.Q. Rock blasting, heavy stumping in parts; several wet areas. Weather throughout very adverse. Road constructed to heavy logging standard, being a main logging route and a public road	140
(d) Logging roads in Rowallan Forest. Much side cutting often with difficult soil and weather conditions; stumping and log disposal. Metal to heavy logging standard	49 to 110
(3) *Re-formation and Reconstruction*	
(a) Re-formation, widening, and minor re-alignment at Pebbly Hills Forest; mainly metalling to upgrade to heavy logging standard	36
(b) Re-alignment in Dusky Forest. Fairly steep grades and mostly side-cutting in rock. Metalling to heavy logging standard	60
(c) Re-alignment in Rankleburn Forest. Work made more difficult owing to condition and layout of original road. Metalling to heavy logging standard	60

APPENDIX 3

Costs of Access to Year of First Commercial Thinning

Costs shown for five alternatives, as follows:

(1) Establishment of tracks two years before planting to a density of 1 mile: 180 acres, followed by establishment of logging roads put in at time of first commercial thinning; this is taken as 12 years for radiata pine, 20 years for Corsican pine, and 30 years for Douglas fir.

(2) Establishment of roads two years before planting to a density of 1 mile: 200 acres, on proper alignment but to half standard (that is, at a cost of $7.60 per acre). These roads are reconstructed immediately before thinning.

(3) Establishment of roads two years before planting to a standard represented by $38.00 per chain at a density of 1 mile: 400 acres; remainder of area made accessible by tracks at a density of 1 mile: 180 acres. Tracks are re-formed and roads are upgraded immediately before thinning.

(4) Establishment of roads two years before planting to a standard represented by $38.00 per chain, but a density of 1 mile: 400 acres. Additional roads are established immediately before thinning to make up the density to 1 mile: 200 acres; original roads are upgraded at the same time.

(5) Establishment of roads two years before planting to a standard represented by $38.00 per chain in a density of 1 mile: 200 acres and upgraded immediately before thinning.

	Costs in $ per acre for:		
	P. radiata	*P. nigra*	*Ps. menziesii*
1. *Tracks—Initial Cost $5.30/acre.*			
Cost to first thinning	10.54	15.50	25.24
Maintenance to first thinning	6.94	14.00	27.74
Construction — logging roads	28.00	28.00	28.00
Total	45.48	57.50	80.98
2. *Roads at Half Standard — Initial cost $7.60 acre.*			
Cost to first thinning	15.04	22.24	36.20
Maintenance	6.24	12.50	24.76
Reconstruction	24.00	24.00	24.00
Total	45.28	58.74	84.96
3. *Roads at Half Density: Tracks — Initial cost $10.24/acre.*			
Cost to first thinning	20.26	29.96	48.78
Maintenance	6.50	13.16	25.98
New roads on half area	14.00	14.00	14.00
Upgrading original roads	4.80	4.80	4.80
Total	45.56	61.92	93.56

4. *Roads at Half Density — Initial cost $7.60/acre.*

Cost to first thinning	15.04	22.24	36.20
Maintenance	3.12	6.26	12.38
Extra walking time	10.04	10.44	18.56
New roads for half area	14.00	14.00	14.00
Upgrading original roads	4.80	4.80	4.80
Total	47.00	57.74	85.94

5. *Roads at Full Density — Initial cost $15.20/acre.*

Cost to first thinning	30.04	44.46	72.42
Maintenance	6.24	12.50	24.76
Upgrading	9.60	9.60	9.60
Total	45.88	66.56	106.78