A simple procedure is needed to control the quality and quantity of work, update and adjust the rate of production, and update maintenance needs and requirements for labor, equipment, and materials.

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Road Maintenance Costs and Research Directions of Low-Volume Logging Roads in New Zealand

D. M. ROBINSON AND P. J. FARLEY

Road maintenance costs are a significant consideration in the management of pavements for logging traffic. Cost and volume data have been gathered from a number of logging roads, within a common forest area, over a 15-yr period. Axle loads were usually close to the legal highway limits (8.2 tonnes equivalent single-axle) and volumes ranged from 2,000 to 250,000 tonnes/yr. A regression analysis of the data confirmed that maintenance costs on unsealed gravel pavements increase as the volume of logs carted over the road increases. A sealed road that was constructed to a standard that gives low Benkelman beam deflections showed an expected decrease in maintenance cost; this relationship is quantified. Overall, the data showed a wide range of maintenance costs versus volume hauled, with no strong statistical correlation between the two. The observations presented can be readily upgraded to allow for inflation (using a construction cost index). As more data become available, they can be used as one component in a multivariable model to optimize the design, rehabilitation, or reconstruction of a road, and improve the economics of a log transportation system. Even without this sophisticated modeling, they can provide valuable indicators for roading economies. Research directions within the New Zealand logging industry are detailed with particular emphasis on the means by which the industry can be effectively informed of known techniques in planning, economics, and construction. General comments are made on current and expected research and extension work.

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The New Zealand forest industry is becoming increasingly aware of rising costs as harvesting moves into plantation forests that were established on steep and difficult terrain. "Old crop" forests that were established on easy terrain during the early 1930s as part of the government's depression employment scheme have mostly been harvested. The "new crop" forests that were planted since 1950 are now coming into production. It is becoming apparent that the economic justifications used in the establishment of these forests were excessively optimistic, particularly in the state sector in which soil stabilization and employment opportunities were viewed as additional objectives. The requirement to provide an economic return on investment was not given primary importance.

New Zealand's economic philosophy is undergoing a major change, from a production base that is directly or indirectly subsidized to one that is unsubsidized and market-driven. The emphasis has been diverted from attempts by the government to assist industries or sectors that are seen as desirable, or successful, toward a situation of government neutrality. This change has led to alterations in the tax structure that now give

less relief to farming and forestry industries. The cost of all aspects of plantation forestry, particularly timber harvesting, is being closely examined.

Because roading and transportation may account for up to 50 percent of this harvesting cost, an appreciation of its components and their interrelationships is essential. Models for predicting cost, even if simple, are of importance in identifying an economic return, or at least, in minimizing the cost of logging transportation.

The present network of forest roads in New Zealand is approximately 26,000 km in length and a 50 percent increase is expected over the next 15 years as timber harvesting expands. The road types are as varied as the topography. Approximately 50 percent of the plantation forests are state-owned and the remainder are in private ownership. Of the major forest roads, the following two types are the most important:

- Gravel or aggregate pavement with no asphaltic or bitumen seal coat, and
- Chip-sealed pavement that consists of a compacted aggregate basecourse finished with a layer of competent, crushed aggregate (chip) held by a minimal application of bitumen.
  - The typical chip size is 7.5 to 12.0 mm, average least dimension, applied at rates of 60 to 80 m^2/m^3, and
  - The typical bitumen application rates are 1.3 to 1.7 liters/m^2.

Much of the current forest roading practice, both in terms of design and maintenance, has followed that of the national roading network. Forest roading, however, differs in emphasis from that of the national network, notably in regard to heavy vehicle distribution, traffic volumes, and available, or affordable, maintenance resources. Many traditional practices are now increasingly subject to investigation and change, including aggregate grading envelopes and specifications, resealing frequency, partial road width or wheel track only resealing.

Much of the roading in the forest industry is performed by personnel with little or no formal training in engineering or roading. This, and the realization that some practices have not been particularly cost-effective, means that more extensive planning and investigation of all aspects of forest roading is needed. Cost justification, cost-benefit analysis, and the economic realities of a market-oriented economy (i.e., profit or perish) put further pressure on traditional practices.

TRANSPORT COSTS

The following are the three main components of transport cost:

- *Road construction costs.* The traditional engineer's estimate or a variation of construction costs is well-understood and likely to be backed up by historical cost records from either contract or in-house construction (*1*).
- *Road maintenance costs.* The true, historical background costs are often unreliable or hidden for a number of reasons that may include tax avoidance, capital cost charged to maintenance; area costing instead of road-by-road costing.
- *Transport or trucking costs.* The relationship of truck owning and operating costs to the total harvesting cost is well-understood. Much less understood in any readily quantifiable form are the interrelationships between the following:
  - Road roughness and operating costs;
  - Geometric standards, gradients, and travel time;
  - Operating costs and road type (i.e., increased brake, tire, and general maintenance caused by unsealed roads).

As will be described later, the National Roads Board (NRB) and the Logging Industry Research Association (LIRA) of New Zealand are performing trials in some of these cost categories. Recent work by the NRB is useful in relating road roughness to vehicle operating costs (*2*).

Whether an analysis of logging transport systems is performed through network analysis or by use of conventional cost-benefit analyses of road improvements or upgrading, the single, most uncertain item is maintenance cost (*3*). Although it is not the major cost in harvesting, the fact that it is not adequately quantified is a hindrance to a realistic assessment of its position during a rational analysis.

ROAD MAINTENANCE COSTS

In an attempt to find reliable historical costs for road maintenance, the following items had to be considered, because historical road maintenance costs often included capital construction costs for various reasons.

- Uncertainty exists as to what is maintenance and what is capital expenditure.
- Taxation benefits may be greater from maintenance than from capital expenditure, and it is often difficult to apportion them accurately at a later stage.
- Road maintenance is often performed on a wet day as a substitute for regular work, and is performed regardless of its need.
- In small forests, road maintenance is often used as a justification for purchasing or keeping plant, such as graders, bulldozers, and trucks; this also leads to maintenance being performed regardless of its need.

When considering these points, the most reliable information, in fact the only information that is readily available on a road-by-road basis, is that used in this analysis.

In May 1971, the New Zealand Forest Service Head Office required the establishment of a record of maintenance costs and volume of timber carted on the main roads in state forests. Useful data were accumulated in the only place in which this was done by adding the road number to the accounting code for all maintenance expenses.

Timber Volumes

All harvested timber volumes are recorded in detail by compartments. The total volume extracted from each compartment was recorded against the roads that were used to transport the timber in the particular time period. In this case, the task of assigning compartment volume flow to a particular road was straightforward, because in almost all cases only a single road link was available.

In addition to forest timber, a substantial volume of other timber has been carted over some of the roads used in this analysis in recent years. This additional traffic used these roads

in preference to the state highway system to minimize the cartage distance and national road user charges. These operators pay a fixed fee per load for the use of the forest roads. The volume of timber that was generated outside the forest and transported on these roads has been reliably estimated from the record of payment. This fixed-fee system is unrealistic in accounting for the cost of road maintenance, but is easy from an administrative standpoint and does not lead to substantial losses. Other traffic that comprises agricultural and general transportation, and overweight vehicles that were diverted from an inadequate state highway, has not been fully recorded. This traffic, which mainly travels over Roads 1 and 20, is not likely to significantly affect the results of this study. No account was taken of conventional light traffic.

Road Details

ROAD 1, Valley Road, is a 13.8-km, two-lane road situated on well-drained alluvial river flats adjacent to the Motueka River. It had been used for many years before an overlay was applied and it was resealed in March 1972. Benkelman beam deflections that were taken after it was resealed ranged from .3 to .6 mm.

ROAD 20, Stock Road, is a 7.2-km, two-lane road situated on weathered glacial outwash gravels that cross a low saddle between the Motueka and Wai-iti Rivers. It follows the general line of an old road but was constructed on a new alignment from 1973 to 1975. Approximately 40 percent of the road was sealed in March 1973; the balance was sealed in March 1975. Benkelman beam deflections that were taken after it was sealed ranged from 1.0 to 1.5 mm. Some maintenance problems associated with poor subsurface drainage have been evident since shortly after construction.

ROAD 2, Kerrs Hill Road, is an 11.4-km, established, one-and-a-half-lane road situated on weathered glacial outwash gravels that cross a ridge between the Motueka and Motupiko Rivers. In 1978, 4.5 km of the road was realigned and upgraded to two lanes; the balance was realigned and upgraded in 1980. The road was partially sealed in 1982 and was completed by March 1983.

ROAD 8, Blows Road, is a 4.0-km, one-and-a-half-lane road situated on a mixture of alluvial and glacial outwash gravels. It runs adjacent to a tributary stream of the Motueka River and provides access for logging that catchment area.

Cost Data

Typical cost data for Road 1 are summarized in Table 1 and Figure 2. All costs have been adjusted using the Ministry of Works and Development Construction Cost Index (CCI) to allow for inflation. A standard computer spreadsheet package was used to allow the cost information to be easily updated using the CCI, which accounts for cost increases in labor, plant, and materials. Maintenance costs are plotted against volume for all four roads in Figures 1 to 4. The costs and volumes are for 6-month periods. The unit cost (cost/volume) is not time-dependent and can be used for direct comparison with other costs. An allowance has been made for the fact that some of the costs on any given road are for both aggregate and sealed surfacing and for sealing costs charged to maintenance (i.e., Road 1: 1971 to 1972; 1985).

RESULTS OF THE ANALYSIS

Sealed Roads

Analysis of Road 1 shows no good linear correlation, either single or multiple, between cost and volume or time. The unit cost (cost/volume) shows no good correlation with time. However, the unit costs that are plotted against time since sealing in Figure 5 provide some indications that may be of practical value.

No statistically significant correlation exists in Road 20 between cost and volume or time (Figure 2), and unit cost and time since sealing (Figure 5). However, the plot of unit cost against time since sealing (Figure 5) gives some practical indication of the expected range of maintenance costs.

Unsealed Roads

The simple linear correlation between cost and volume is not good (R^2 = 12 to 16 percent), as shown in Figures 3 and 4. When costs and volumes were smoothed over three periods better correlations were obtained for Roads 2 and 8, as shown.

Cost of Road 2= \$NZ537 + \$NZ0.020 × volume (tonnes)
(R^2 = 51.2 percent)
Cost of Road 8= \$NZ466 + \$NZ0.038 × volume (tonnes)
(R^2 = 28.5 percent)

Although the second equation does not have great statistical weight, these results provide an indication of road maintenance costs in the absence of anything better.

COMMENTS

The data for the sealed roads show considerable scatter. This is to be expected because sealed road maintenance in particular is characterized by two features. First, the need for maintenance often can only be seen months after the concentration of loads has passed. Second, sealed road maintenance work is generally not urgent. It is also usually performed by off-site contractors, which results in a further delay between damage and repair.

The two roads do not show the same cost relationships. This may be accounted for in the differing initial construction standard and the differing maintenance requirement that results from topography and generally poor drainage of Road 20.

The initial Benkelman beam deflections that were taken on Road 1 were considerably less than those on Road 20. The indications are that this has resulted in lower maintenance costs and less sensitivity to the volume of heavy traffic.

Considerable data scatter is inevitable on unsealed roads as a result of the following factors:

- The influence of the time of the year at which loads are transported (also true for sealed roads);
- The specific weather conditions during periods of particularly heavy logging (also true for sealed roads);

TABLE 1 TYPICAL ROAD MAINTENANCE COSTS AND TIMBER VOLUMES

ROAD NO. 1					
DATE	C.C.I.	VOLUME	COST	ADJ COST	REMARKS
		(000 tonnes)	$NZ/Km	$NZ/Km	
July-Dec 1971	981	12	1723	4277	Includes some sealing cost
Jan-Jun 1972	981	65	1631	4048	Includes some sealing cost
Jul-Dec 1972	981	82	143	355	
Jan-Jun 1973	981	114	2	5	
Jul-Dec 1973	981	79	2	5	
Jan-Jun 1974	981	91	92	228	
Jul-Dec 1974	981	120	163	405	
Jan-Jun 1975	981	104	163	405	
Jul-Dec 1975	981	99	71	176	
Jan-Jun 1976	981	51	51	127	
Jul-Dec 1976	981	21	377	936	
Jan-Jun 1977	981	38	367	911	
Jul-Dec 1977	981	91	31	77	
Jan-Jun 1978	981	75	102	253	
Jul-Dec 1978	981	81	143	355	
Jan-Jun 1979	1027	55	39	92	
Jul-Dec 1979	1119	47	288	627	
Jan-Jun 1980	1318	32	178	329	
Jul-Dec 1980	1450	34	154	259	
Jan-Jun 1981	1590	35	29	44	
Jul-Dec 1981	1750	37	97	135	
Jan-Jun 1982	1870	37	204	266	
Jul-Dec 1982	2000	30	500	609	
Jan-Jun 1983	2030	52	75	90	
Jul-Dec 1983	2030	54	155	186	
Jan-Jun 1984	2060	32	50	59	
Jul-Dec 1984	2195	28	213	236	
Jan-Jun 1985	2365	45	1363	1403	Includes some reconstruction cost
Jul-Dec 1985	2435	42	584	584	

- The influence of the construction standard on subsequent maintenance (also true for sealed roads); and
- The fact that periodic cumulative maintenance, especially the replacement of top course aggregate, does not necessarily coincide with periods of heavy loading.

TRENDS

Data are sufficient to indicate the existence of (a) a weak positive relationship between tonnes of timber carted and maintenance costs for unsealed roads, (b) a very definite divergence in the costs for sealed and aggregate roads, and (c) the general cost level of sealed road maintenance.

Relationship Between Tonnes of Timber and Equivalent Design Axles

An average logging truck carries about 20 to 25 tonnes of payload and is assessed as being equivalent to 2.5 equivalent design axles (EDAs). One-thousand tonnes of timber is therefore equivalent to 100 to 125 EDAs. (1 EDA = 8.2 tonnes on a twin-tired single axle.)

This assessment compares with the NRB standard assessment method using commodity factors: 1.35 EDAs per logging truck. However, this method counts both full and empty trucks. Therefore, EDAs/truck are equal to 2.7 (allowing for two-way travel). There are therefore approximately 135 EDAs/1000 tonnes of payload.

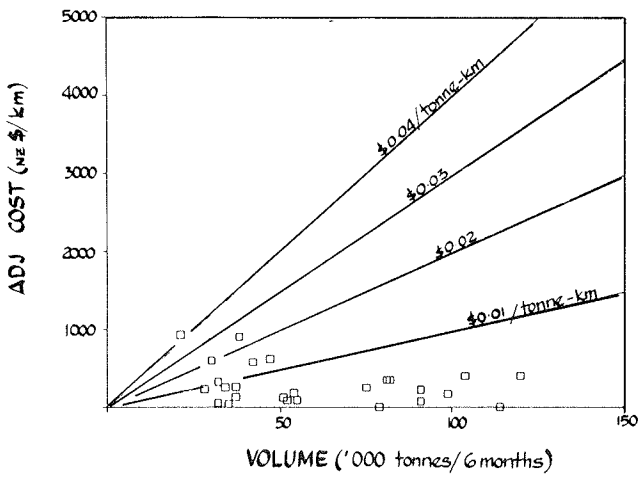

FIGURE 1 Relationship of cost and volume on Road 1 (sealed).

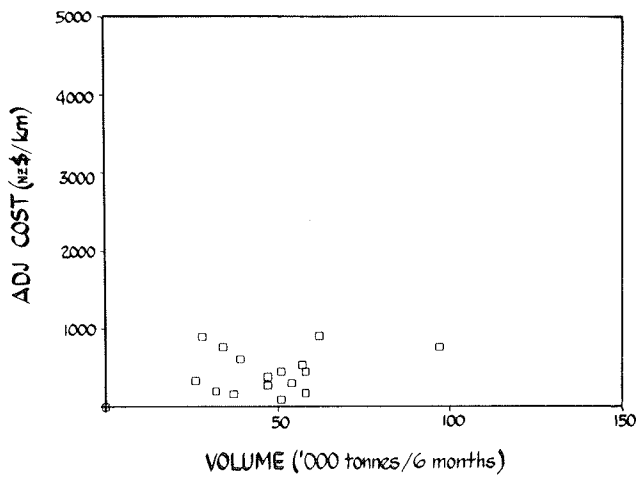

FIGURE 2 Relationship of cost and volume on Road 20 (sealed).

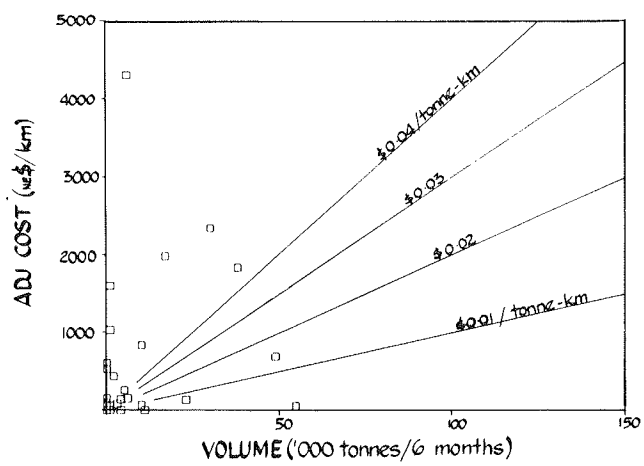

FIGURE 3 Relationship of cost and volume on Road 8 (unsealed).

Application to Other Areas

Maintenance costs will vary throughout New Zealand but the divergence between sealed and aggregate road costs will remain. Because the region studied has a reasonable supply of low-cost aggregate, it is probable that there will be a greater divergence in other areas.

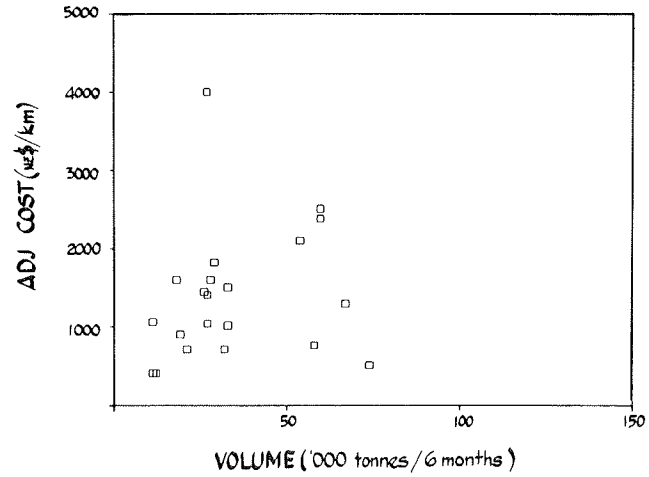

FIGURE 4 Relationship of cost and volume on Road 2 (unsealed).

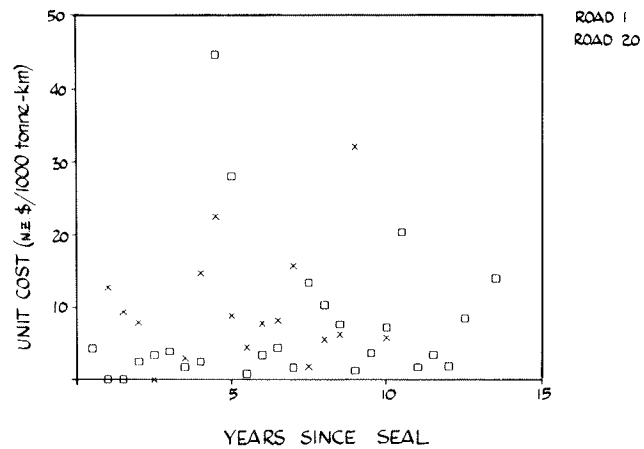

FIGURE 5 Relationship of unit cost and time on sealed roads.

When an attempt is made to apply these results to other areas, it is important to analyze the basic maintenance cost components, such as routine grading, routine gravel application, culvert and watertable maintenance, marker posts, and grass and vegetation control. These cost components should be analyzed on a rational basis as a starting point for the application of volume- and time-related variable costs.

When the results of this study are used to estimate road maintenance or to analyze and plan costs, an allowance should be made for both the initial sealing and periodic resealing and rehabilitation costs. These costs were not included in this study. An allowance can easily be made for both costs in a conventional, rational analysis or estimating procedure.

Comparison With Other Logging Road Maintenance Costs

Average road maintenance costs were obtained from two other forests for the sake of comparison. These are true road maintenance costs, gathered on an area basis, with 200,000 to 300,000 tonnes/annum/road. These costs vary between $NZ0.02 to $NZ0.035/tonne/km for annual maintenance and include both sealed and unsealed roads. The relationship of these costs to the analysis costs can be judged from the plotted lines of Figures 1 and 3.

Unfortunately, a wealth of information could have been available from these areas over a long period of time if costs had been kept on a road-by-road basis instead of an area basis.

ROAD MAINTENANCE RESEARCH

The NRB and LIRA are jointly undertaking funded, detailed trials into road maintenance for both sealed and unsealed roads.

Sealed Road

The sealed road trials are in two sections on a conventional, chip-sealed road. The first section is on a public road and has normal highway weight restrictions. The weight restriction for a single axle/twin tire is 8200 kg; that for a tandem axle/twin tire, at 1.2 m spacing, is 14 500 kg. The restriction on gross vehicle weight is 39 000 kg.

Monitoring of this section commenced in June 1986 and is expected to run for at least 5 years. The second section is an off-highway logging road. Although it currently only carries highway-weight road traffic, a strong possibility exists that this will be increased by a factor of 1.25 to 1.4 in the future.

The major work at this stage of the trials consists of the regular monitoring of roughness by NAASRA meter reading; Benkelman beam deflections in both summer and winter; pavement surface condition (visual rating and groundwater observations); maintenance effort and cost; climate records; and total heavy transport tonnage by way of weighbridge tallies for all heavy vehicles. A total of approximately 200,000 (net) tonnes is expected each year. Light vehicles can be estimated with sufficient accuracy from spot checks. Accurate records of construction methods are at hand.

Unsealed Road

This trial commenced in November 1986 and is expected to run for at least 2 years. The main work at this stage of the trial consists of the regular monitoring of roughness by NAASRA meter readings; Benkelman beam deflections in both summer and winter; pavement surface condition (visual rating); maintenance effort and cost; total heavy transport from weighbridge records; dust loss; aggregate loss; climate records; and total heavy vehicles by weighbridge tally. Loads heavier than those permitted on the highway may also be carried in the future.

Both of these trials provided an opportunity for the NRB, LIRA, and the local road controlling authority to work together on a project of mutual interest.

FURTHER RESEARCH

In 1984 and 1985, LIRA undertook an industrywide review of logging road standards, methods, and techniques. The review was discussed at a workshop of selected participants and the following research needs and directions were defined. Most of the research work is of a practical nature and is expected to produce immediate returns by the industry that oversees and directly funds the work.

Education and Training

LIRA's work in this field is directed toward encouraging people with civil engineering knowledge and training into the industry, and providing technical support to those who are already in the industry and have roading responsibilities. These responsibilities may often be shared with forestry, logging, and transport functions. There are signs at the university level that cooperation between the forestry and engineering schools will eventually strengthen engineering skills within the industry.

Effective Extension

The effective extension of information that is already available has been identified as a most necessary and productive endeavor. In early 1986, LIRA began distributing two, brief 4- to 6-page publications on a more or less monthly basis. *Road Notes* covers topics of interest to roading specialists in the forest industry (*4*). *Road Books* covers available books, pamphlets, and manufacturers' literature that may be of interest to roading specialists in the forest industry.

A booklet on compaction has also been distributed, and various computer programs have been made available to the industry. These programs cover machinery costing, estimating construction costs, network analysis, and the geometrics of vertical and horizontal curves. Although little of this material is original, its dissemination is believed to be most productive. Reaction from the 45 people on the mailing list has been enthusiastic. The 4- to 6-page format seems to be appropriate. Further work on the production of a forest roading terminology guide is proceeding well.

Compaction

Little compaction is performed on most forest roads, unless they are to be sealed. Adequate compaction, and appropriate gravel specifications that allow a clay binder fraction, would yield the following improvements: reduced maintenance grading requirements, reduced corrugation or washboarding, reduced potholing, and reduced infiltration of water (*5*). A clay-bound aggregate is often a cheaper roading material than an inappropriate, though high-quality, aggregate.

Compaction data from various published reports and trials can serve as a basis for practical requirements on forest roads (*6, 7*).

Soil Testing

Emphasis has been placed on simple tools to measure soil strength that preferably correlate with the traditional CBR tests. The Scala penetrometer and the Clegg Hammer have both been studied and used (*8, 9*). They can be used in most forest roads in which the full CBR testing procedure simply cannot be justified. The recent Technical Recommendation on soil testing that was published by the National Roads Board has been well-received (*10*).

Pavement Design

Emphasis has been placed on the extension of existing pavement design techniques and information to field engineers. Standard

New Zealand highway design techniques are not always the best economic choice for forest roads, but because little other information has been readily available, they have been used by default (*11*).

The various design methods and techniques of the U.S. Forest Service are being evaluated for use in the New Zealand forest industry together with other research that has appeared in various publications (*12-14*).

Alternate Log Transport Options

The potential use of six-wheel-drive trucks by civil engineers on steep roads is being investigated. The initial research is limited to a quick economic study, in which manufacturers' data and known cost and topographic information are being used. The results are promising enough to suggest that six-wheel-drive trucks and roads constructed with steep grades and minimum width may become part of New Zealand's logging transport scene. The limitations of double-handling at the transfer yard, and reservations about the size of the cartage must be overcome. The break-even point for this option to be economically feasible varies with the terrain and the transport distance. Each use of the technique also needs to be individually evaluated. This is not difficult with the ready availability of spreadsheet modeling and network analysis techniques on personal computers. A major limitation may be the difficulty of transporting conventional truck- or track-mounted yarders to the necessary landing sites on such roads (*15*). Another advantage of the type of road used in this alternate transport system is that trees can be planted in the road again until the next harvesting operation.

Transportation

In addition to the work outlined in the roading field, LIRA is performing work in the trucking field. Particular areas of interest are vehicle simulation by personal computer; vehicle gradeability in traction-limiting conditions; truck and road interaction, and the effects of road geometrics on vehicle performance; vehicle dimensions, legal limits (both weight and size), load securing, and cab guards; and extension of safe, sound techniques to the industry.

Seminars

The major forum for the presentation of project work and studies is at LIRA's annual seminar. The topic of the June 1987 seminar was "Logging Roads and Trucks."

The budget for roading and transportation is 25 percent of LIRA's total budget of NZ$900,000. The effective use of this budget is of paramount importance. Although fundamental research is useful and stimulating, the main emphasis must be to ensure that the industry gets value for its money. Industry contributes 50 percent of the total budget directly and this proportion is expected to increase over the next 3 years to possibly reach 70 percent of the budget.

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