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IMPROVING ROAD PAVEMENT — HOW WILL IT IMPROVE TRUCK PERFORMANCE?

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INTRODUCTION

All wood harvested in New Zealand is transported by truck, for part of the journey at least. Every truck driver has some idea of the effect that road characteristics can have on speed, comfort and fuel consumption. These characteristics are hard to quantify, but even harder to quantify is the saving that could arise from upgrading a section of road. Information on savings would be very valuable to the road designer and wood supply manager as well as the trucking contractor. It could make the timing of road improvements much more effective.

Figure 1 - Typical Rig Measured in Study

THE STUDY

From November, 1985 to February, 1986 a study was carried out in the Kinleith forests of N.Z. Forest Products Limited, in order to find out how road characteristics affect logging truck travel speeds and fuel consumption.

In the first part of the study, 37 sections of road were pre-selected and measured. Logging trucks were timed as they travelled over these sections. Without interfering with the driver's normal working pattern, 605 loaded trips and 484 unloaded trips were timed. The weight of each truck and its load was determined from the weighbridge at N.Z. Forest Products Limited Kinleith log yard (Table 1).

In the second part of the study, a 260 kW Mack E6-350 logging truck, equipped with a Model 115TC fuel meter, travelled over the test sections at various set speeds while the fuel consumption was recorded. One driver was used and he made two runs for each particular speed and load. In cases where the results varied significantly, a third run was made.

Table 1 - Statistics of the Log Trucks Observed

Item	*Statistics*	*Loaded Truck*	*Empty Truck*
Weight	*Measured trips*	*605*	*484*
	Maximum weight (t)	*67.24*	*25.16*
	Minimum weight (t)	*33.84*	*10.50*
	Mean weight (t)	*47.59*	*15.92*
Power to Weight Ratio	*Measured trips*	*605*	*484*
	Maximum ratio	*8.98*	*24.87*
	Minimum ratio	*3.86*	*11.50*
	Mean ratio	*5.93*	*17.95*
Power	*Measured trips*	*1089*	
	Maximum power (kW)	*354 (475 hp)*	
	Minimum power (kW)	*261 (350 hp)*	
	Mean power (kW)	*280*	

THE ANALYSIS

Not surprisingly, travel speed and fuel consumption were found to be related to a number of factors. The power-to-weight ratio of the trucks was found to have a major influence on mean truck speeds over the test sections. Of the sealed road characteristics, the horizontal curvature, the rise and fall over the test section were important to speed. On unsealed (dirt or gravel) roads, the depth of ruts, was also important. These factors were used to develop the mathematical models shown.

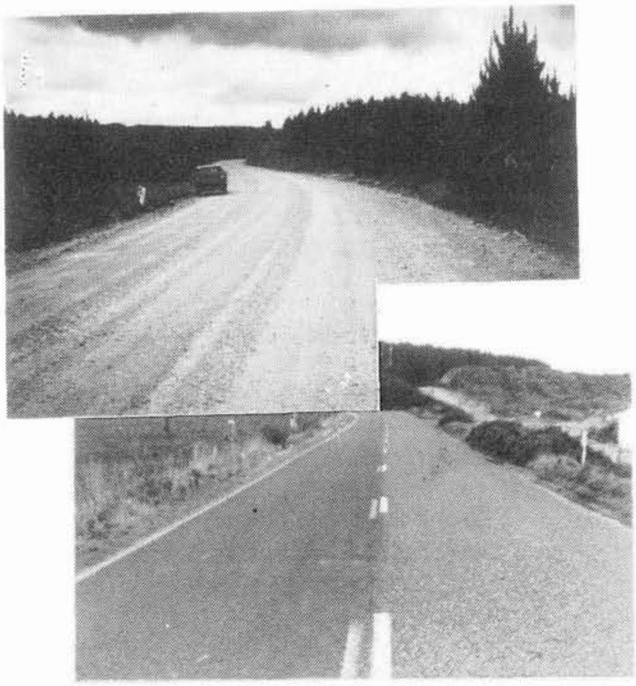


Figure 2 - Typical Roads in the Study Area

PREDICTION MODELS

Fuel consumption was found to be related to the same road factors as mean speed, along with the additional factors of speed and truck weight. For unsealed roads, road roughness was also found to influence fuel use. The power-to-weight ratio was not important since the loaded truck data was separated from the unloaded truck data during the analysis. The models relating these factors to fuel consumption are shown below.

The fuel consumption values given in the text and the graphs are derived from the study data. Other research has shown that there is a difference between measured steady conditions and real life. The models predicting fuel consumption allow an additional 13% but this needs to be verified.

(To change the models to give actual study results, change .113 to .100).

RESULTS OF PAVEMENT IMPROVEMENT

In order to determine the changes in truck performance made possible by improving the road pavement, specific examples must be looked at. Three cases are discussed here.

Case 1: Change from Unsealed to Sealed Pavement — Level Straight Road

For this example, suppose we want to turn a level straight section of unsealed road with a roughness of 63 counts per 100 metres *(1)* and a rut depth of 31.75 millimetres, into a

Prediction Models

Speed :

Formula 1 : $Y1 = 55.5 + 1.671\,(P/W) - 0.0335\,(C) - 0.413\,(RS) - 0.207\,(FL)$

Formula 2 : $Y2 = 54.6 + 0.691\,(P/W) - 0.435\,(RS) - 0.326\,(FL) - 0.578\,(DR)$

Fuel Consumption :

Formula 3 : $Y3 = .113\,(330.1 + 3763/V + 0.0796\,(V^2) + 0.6935\,(RS*W) - 20.9\,(FL) + 0.163\,(FL^2))$

Formula 4 : $Y4 = .113\,(242.7 + 3318/V + 0.6895\,(RS*W) - 7.5\,(FL) + 0.0385\,(FL^2))$

Formula 5 : $Y5 = .113\,(201.2 + 3317/V + 0.0884\,(V^2) + 0.6760\,(RS*W) - 18.25\,(FL) + 0.114\,(FL^2) + 6.07\,(R))$

Formula 6 : $Y6 = .113\,(216.5 + 3509/V + 0.0196\,(V^2) + 0.5984\,(RS*W) - 8.92\,(FL) + 0.044\,(FL^2) + 1.57\,(R))$

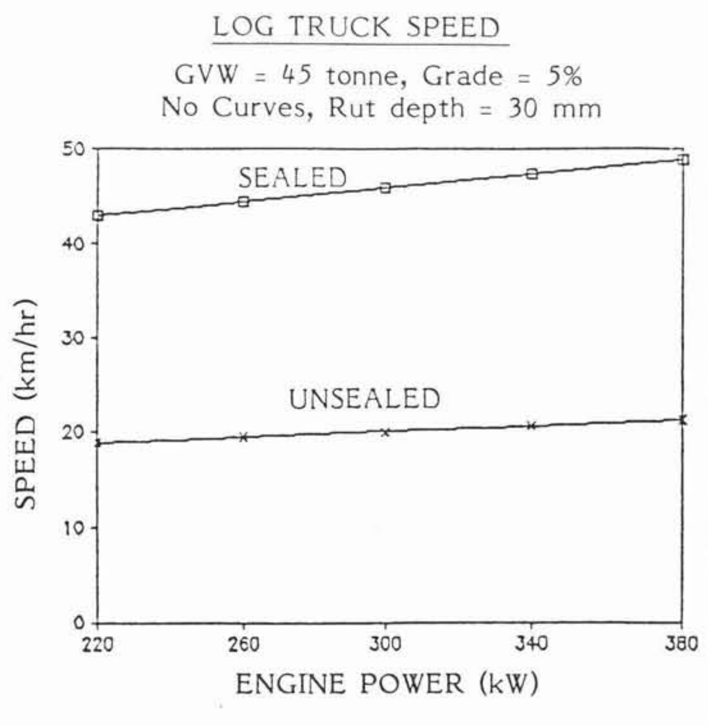
Where:

Y1 = Mean speed of trucks on sealed roads in km/hr
Y2 = Mean speed of trucks on unsealed roads in km/hr
Y3 = Fuel consumption of loaded trucks on sealed roads in litres/100 km
Y4 = Fuel consumption of unloaded trucks on sealed roads in litres/100 km
Y5 = Fuel consumption of loaded trucks on unsealed roads in litres/100 km
Y6 = Fuel consumption of unloaded trucks on unsealed roads in litres/100 km
P/W = Power-to-weight ratio in kW per tonne
C = Horizontal curvature in degrees per km
RS = Vertical rise in metres per km
FL = Vertical fall in metres per km
DR = Depth of rut on unsealed roads in mm
V = Speed of the truck in km/hr
W = Weight of truck in tonnes
R = Roughness of road surface in counts per 100 metres

sealed road with a roughness of 4 counts per 100 metres. How much can the speed increase, and what will the change in fuel consumption be?

For loaded trucks, with a power to weight ratio of 5.93 kilowatts per tonne (the average during the study), the achievable speed calculated using Formula 2 is 40.4 kilometres per hour. Under the same conditions but with a sealed pavement, the achievable speed calculated using Formula 1 is 65.4 kilometres per hour, an increase of 62%. Fuel consumption drops from 81.4 to 72.8 litres/100 kilometres, a saving of 10.2%, according to Formulae 3 and 5.

For empty trucks, using the average power to weight ratio of 18 kilowatts per tonne, the achievable speed on unsealed roads is 48.7 kilometres per hour, while on sealed roads the achievable speed is 85.5 kilometres per hour, an increase of 76%. The fuel consumption was calculated as 43.4 litres/100 kilometres for unsealed pavement and 28.2 litres/100 kilometres for sealed pavement, a decrease of 35.1% (using Formulae 4 and 6).



Case 2: Change from Unsealed to Sealed Pavement – Curved Steep Road

Suppose there is a section of road with the same roughness and rut depth as those of the section in Case 1, but with a curvature of 200 degrees per kilometre and a vertical rise of 72 metres per kilometre *(2)*. If the unsealed section is then sealed, speeds of the trucks may increase by 222% and 188% for laden trucks and empty trucks respectively, and fuel consumption may decrease by 11.9% and 10.4% for laden trucks and empty trucks respectively.

Figure 3 - Roughness testing vehicle

Case 3: Improvement of Unsealed Road Surface

To calculate the effect of improving an unsealed road, say by the use of a grader, let's assume that the original road section had a vertical rise of 54.51 metres per kilometre, a roughness measurement of 63 counts per 100 metres, and a rut depth of 31.75 millimetres. The road has now been improved to a roughness measurement of 21 counts per 100 metres and a rut depth of 5.8 millimetres. If the grade is not changed, how much may we increase the speed and decrease the fuel consumption of the logging truck?

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(1) Counts/100 metres : a measure of road roughness used by the Ministry of Works and Development. It is measured by a NAASRA roughness meter mounted in a Mitsubishi L30 van. For further information contact the authors.

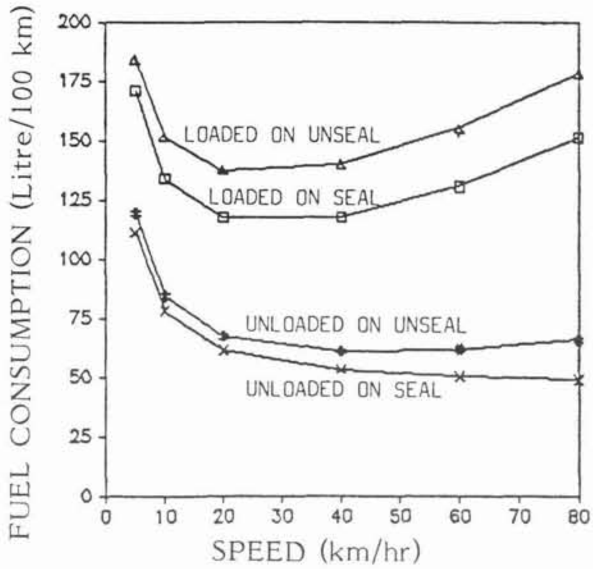
(2) Vertical rise (fall) : The model uses the total gain in altitude (and/or fall). Variations in gradient to achieve this are not recognised.

For loaded trucks, the achievable speed before grading was calculated to be 16.6 kilometres per hour, an improvement of 90%. Using these speeds in the fuel consumption formulae shows that, before grading the fuel consumption would be 246.6 litres/100 kilometre. After grading the rate drops to 218.0 litres/100 kilometre, a savings of 11.6%.

For empty trucks, the models indicate a pre-grading speed of 24.9 kilometres per hour, while after grading the achievable speed is 39.9 kilometres per hour, an increase of 60.2%. Fuel consumption would decrease by 10.6%, from 94.5 litres/100 kilometre to 84.5 litres/100 kilometre.

LOG TRUCK FUEL CONSUMPTION

GVW = 45 tonnes, Grade ≒ 2%
No Curves, Unsealed ruts = 30 mm



DISCUSSION

The predictive models relate the important road characteristics to the resultant speed and fuel consumption of logging trucks. They are limited to the range of truck configurations and road characteristics found in the study area. Other elements, such as climatic conditions and driving technique (Ljubic and Michaelsen*, for example)(1) can influence speed and fuel consumption, and these have not been included in the models.

(1) Ljubic, D. and Michaelsen, J.E. 1986. "How driving techniques affect energy consumption." British Columbia Lumberman 70(4):B38-B39.

Thirdly, it must be recognised that these models are derived using a great variety of axle and trailer configurations, and the results, which reflect the average of the factors measured, may not be applicable to any one particular truck. Nor have the models been verified by field experimentation (upgrading particular sections and assessing the results).

However, the models are based on a very large sample of trucks operating under normal conditions, and the relationships developed are very significant statistically. The influence of operator driving technique is thought to have been averaged out because of the large sample. The study assumes that, because of the highly productive nature of the operation, the changes in travel speed are a reflection of road characteristics.

What does become apparent when looking at the results is the magnitude of the impact of road characteristics on truck performance, and the large potential for improving logging truck transport efficiency by improving the road pavement.

The models give the road planner a tool which can help him decide on what design to follow when initially constructing a road, and when to upgrade that road. This is possible because the savings in time and fuel can be calculated and compared with the cost of construction or upgrading.

While we have concentrated here on road pavement, the influence of grade and curvature has also been assessed. More information can be supplied by the authors on request.

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