Low-volume road grading maintenance management: New Zealand experience with a Canadian system

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Abstract

Like Canada, New Zealand leans heavily on a handful of primary industries. The health of those industries in turn depends on low volume roads (LVR). Over 45% of the national New Zealand road network carries fewer than 100 veh/day. About a third of the network is unsealed.

Only about a tenth of the network is designated State Highway, controlled by the national authority, Transit New Zealand. The rest, in district road networks of up to 4700 km, is controlled by 74 District Councils.

New Zealand has adopted a performance-based, contracted regime for road maintenance. Contractors make decisions on maintenance treatments, meeting specifications during and at the end of the contract. This has led to significant innovation in maintenance management practices.

In New Zealand, a leading forestry company and a major road contractor both experimented with a system called Optigrade, developed by the Forest Engineering Research Institute of Canada originally to manage the grading maintenance of unsealed forest haul roads. The system comprises accelerometer and GPS hardware mounted on a haul truck routinely traveling the road, and software designed to assist managers making decisions on grading frequency. The system schedules grading only for those road segments that need it, based on road roughness measurements.

To apply Optigrade to the management of public LVR networks laid out in grids rather than the dendritic road systems typical of forest operations required modifications to the hardware and the monitoring and analysis routines. Modifications to the system are described, together with the challenges and successes. A discussion of the implications for applying Optigrade to Canadian public LVR maintenance management practice is provided.

Background

New Zealand, as does Canada, relies heavily on the primary economic sector. In New Zealand's case, agriculture and forestry are the big drivers of the economy, along with tourism. All three in turn depend on low volume roads (LVR). The national network consists of nearly 100,000 km of roads (and an unknown amount of private haul roads), of which 75% carries fewer than 500 veh/day, and 45% carries fewer than 100 veh/day. About 1/3 of the roads are unsealed. Sealed or unsealed, unbound pavements predominate. Sealed LVR pavements have up to 40 mm of chipseal usually, rather than hot mix asphalt.

State highways amount to about 1/10 of the national road network and are administered by the national state highway authority, Transit NZ. Funds for road work flow from government to Transit NZ through Land Transport New Zealand, a Crown entity established under an act of Parliament in 2004, governed by a board appointed by the Minister of Transport. The rest of the country's public road network is administered by 74 District Councils. The vast bulk of these roads are LVR.

District road maintenance management in NZ

For district roads, New Zealand has adopted a performance-based maintenance regime. Maintenance is carried out by contractors. During the life of a maintenance contract, the contractor determines the maintenance treatments needed to keep the road network within specified conditions.

Over the life of a contract, both operating performance measures (OPM), measured monthly in the field, and network performance measures (NPM), measured annually in the field, must meet specified values. Examples of OPMs include:

- pavement, shoulders, detritus
- storm water structures, SWC and side drains
- bridges and minor structures
- vegetation control
- signs, marker posts, road markings
- furniture, litter, incident response

Examples of NPMs include:

- roughness
- major treatment quantities
- construction standards

The contract specifies criteria and maximum response times for the various performance measures while the contractor determines best practice and methodologies for carrying out the various activities. For example, pothole repairs on sealed pavements are a major activity in routine maintenance. In the contracts, potholes are defined with respect to area and/or volume, and the road authority's expectations of the performance of the repair is described, but the contractor selects the repair method most appropriate to correct the defect. In some contracts, the repair method may be specified. Typical response times are 5 days for a pothole, unless the pothole poses a danger to the road user, when appropriate signage must be put up within 4 hours of notification of the pothole and it must be repaired within 24 hours.

For gravel roads, typical performance measures for surface defects are "no defect with a depth greater than 75 mm" or " no corrugations more than 25 mm deep", and the specified response time depends on the road category; the response time could vary from 4 to 12 weeks, unless the defect poses a danger to the road user, when it must be repaired within 2 to 12 days, again depending on the road category.

In many of the contracts, the requirements for roughness for gravel roads have been subjective, based on either the number of grading cycles per time period or ride roughness based on user perceptions. The cost of meeting the requirements, of course, is difficult for the contractor to estimate and it is difficult to agree on what is an acceptable criterion for assessing performance.

Thus the new regime has led to many innovations. Among other things, contractor Fulton Hogan Ltd., which manages 35% of the district road contracts, has been experimenting with unsealed road maintenance managed with the help of a maintenance management system called Optigrade.

Optigrade system

Following early concept development (Provencher and Méthot 1994, Provencher 1997), the Forest Engineering Research Institute of Canada (FERIC) developed a commercially viable system comprising hardware, software, and routines, for improving the management of the maintenance of haul roads. It is claimed that the use of the system can decrease road grading costs by as much as a third (FERIC, 2002).

In the development of the system, pavement outputs (Haas *et al.*, 1994) – distress, structural capacity, safety, and riding comfort (roughness) – were each considered in turn. Using any of the first three as a measure of pavement sufficiency was rejected for various operational reasons (difficulty in obtaining measurements, time, expense (Douglas *et al.*, 2004)), and the focus became road roughness.

In the Optigrade system approach, a roughness threshold is set as a trigger for road maintenance, particularly grading. Roughness is measured routinely using an accelerometer mounted on the suspension of a haul truck using the road (Figure 1). Alternately, some road owners mount the accelerometer on a pickup truck dedicated to that purpose. The accelerometer measures the vertical acceleration in G (gravities) of the suspension element at a frequency of 350 Hz, and a characteristic peak value[1] over a use-specified interval is recorded. Simultaneously, the position obtained by an on-board GPS receiver is also recorded. A file of roughness, position and instantaneous truck speed is written to a data logger on board the truck, to be downloaded and analysed later.

The system's software is designed to produce maps and reports. Colour coded maps of roughness or speed along the road can be displayed (Figure 2). Reports detailing road roughness and truck speed adjacent to user-defined marker locations can be produced. The data can be analysed, with respect to the user-defined roughness threshold, to produce grading reports showing which segments of the road are due for grading. The heart of the approach is that only those segments of the road which really *require* grading, based on road roughness, are *scheduled* for grading, thus increasing the efficiency of the

[1] the calculated average absolute deviation from the average value over the specified time interval is recorded, rather than the straight maximum value, expressed in G

maintenance effort. It should be noted that Optigrade was developed for long haul roads, circa 100 km, which receive very frequent grading, perhaps daily.

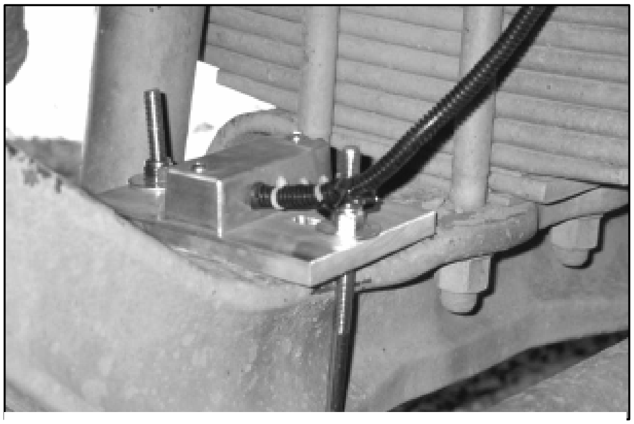

Figure 1. An accelerometer mounted on the front axle of a logging truck. (*photo: S. Mercier*)

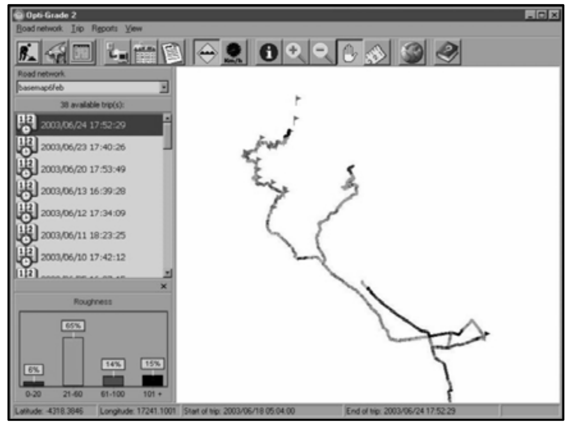

Figure 2. An Optigrade map on an output screen.

Developments

While about 50 Optigrade systems had been installed in Canada including one in use on a provincial road, it was unknown in New Zealand. The first system was implemented by one of New Zealand's largest forestry companies in 2002, under a research agreement with FERIC and the Forest Engineering Programme, New Zealand School of Forestry, University of Canterbury, in 2002. Subsequently, systems were implemented by two of New Zealand's largest road construction contractors.

The forestry company requested a field trial of the system from November 2002 to June 2003. Roughness data was collected by the system over the period, and a subsequent roughness vs. speed study performed in September of 2003.

In November of 2003, Fulton Hogan Ltd., began experimenting with the system to determine if it could be successfully applied to the management of the maintenance of unsealed public LVR. In June of 2005, a second contractor purchased a system, but did not do any research with it.

Forestry study

The forestry study was carried out in Okuku Forest approximately 50 km north of Christchurch, in New Zealand's South Island. An unsealed working haul road 18 km long was selected for the trial. The road rose 600 m above the elevation of its entrance into the forest then fell again to an elevation 100 m above the entrance at its end in the forest. The gross gradients of the four main pitches that can be identified in Figure 3 ranged from 7 to 10%.

Plots of instantaneous speed against road roughness for the unloaded and loaded directions indicated that haul truck speed was independent of roughness: the operator drove at speeds dictated by the road geometry rather than the road's roughness, with speed data clustering around 40 or 70 km/hr for the unloaded direction, and 30 or 62 km for the loaded direction (Figure 4). Average trip speeds both unloaded and loaded were also independent of average road roughness (Figure 5).

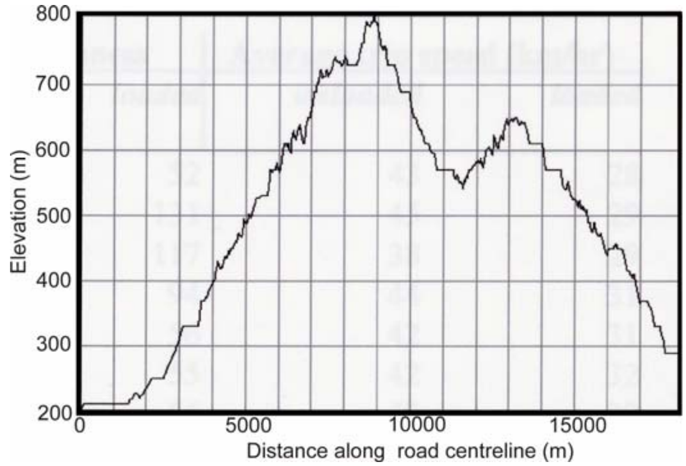

Figure 3. Profile along forestry test road.

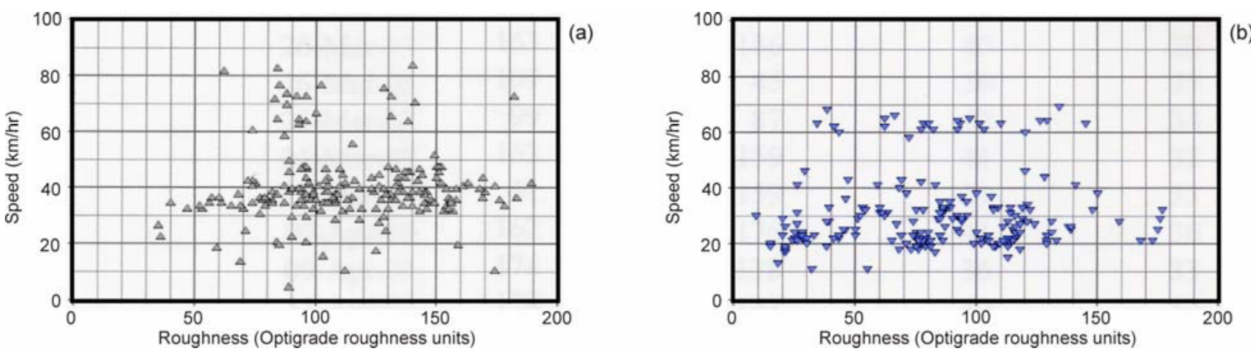

Figure 4. Instantaneous speeds, (a) unloaded direction, (b) loaded direction.

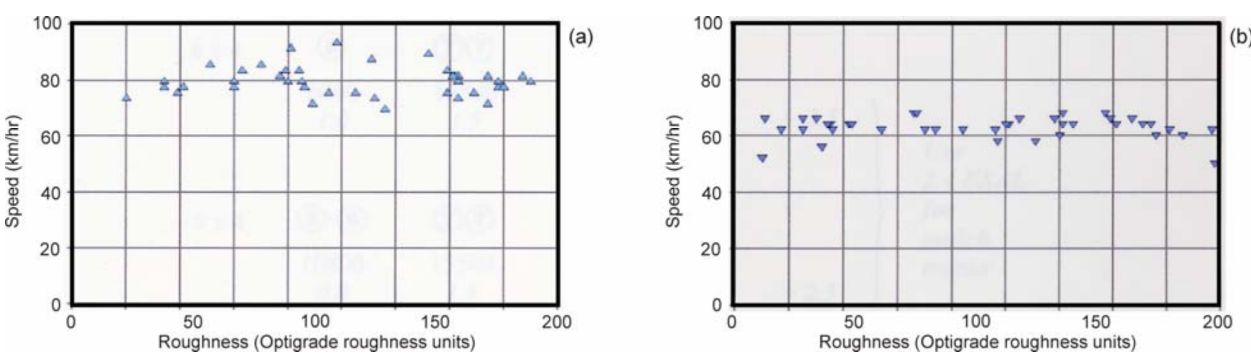

Figure 5. Average speeds, (a) unloaded direction, (b) loaded direction.

The haul truck traffic consisted of 6 different configurations. These are detailed in Table 1 by configuration, gross vehicle mass, and ESAL.

Table 1

Forestry trial truck configurations

Configuration	Gross vehicle mass (tonnes)	ESAL
Rigid frame trucks		
6 x 4	21.5	2.5
8 x 4	26.3	2.3
Truck, full-trailer combinations		
3 F3	43.8	4.5
4 F3	43.9	3.5
3 F4	44.0	3.7
4 F4	44.0	2.8

An attempt made to relate periodic road roughness measurements to truck traffic measured in accumulated equivalent single axle loads (ESAL), the actual grading of the road, and rainfall (Figure 6) was unsuccessful for a number of reasons:

- weather data had to be obtained from a weather station in another valley nearby, and it is known that valleys in this mountainous region can have substantially different micro-climates
- there were gaps in the rainfall record when precipitation may have been missed
- the forestry company operations foreman elected to grade the road at times not prompted by the roughness measurements
- there were at times long gaps in the roughness record.

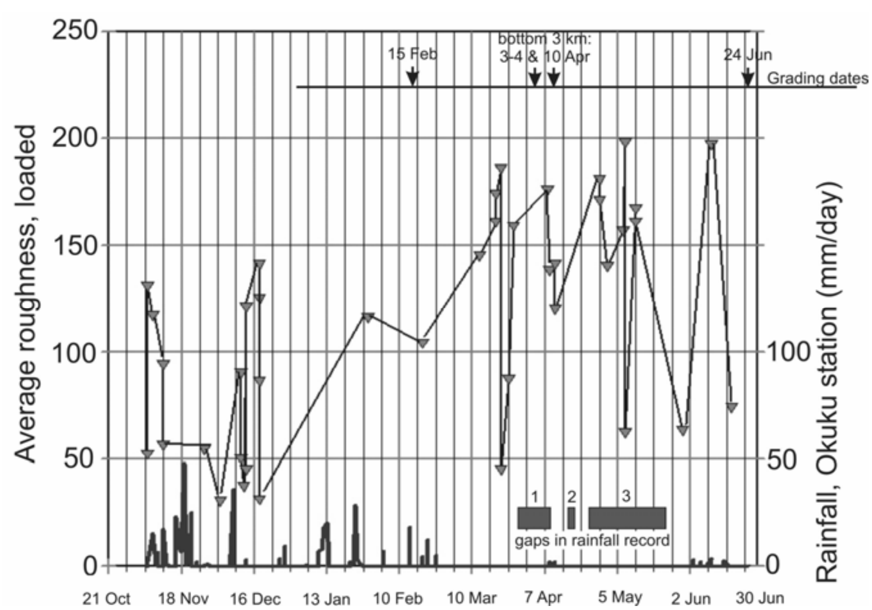

Figure 6. Average roughness in the loaded direction vs date, with grading notes and rainfall data. (Roughness in Optigrade roughness units)

An issue for the forestry company was the claim by FERIC that roughness readings are essentially independent of the speed at which the haul vehicle is running. A trial was devised where the haul truck was run over the same stretch of unsealed haul road at target speeds of 20, 35 and 50 km/hr. The statistics of the trial are shown in Table 2.

Table 2

Forestry haul truck speed trial

Observations	Speed			Roughness*		
(n)	Mean (km/hr)	Std dev (km/hr)	Coefficient of variation (%)	Mean	Std dev	Coefficient of variation (%)
19	20.6	1.8	8.8	34.9	1.7	4.8
19	37.7	3.3	8.6	40.8	4.0	9.9
6	54.2	2.3	4.3	37.8	5.0	13.3

* roughness reported in Optigrade roughness units (characteristic peak acceleration in G).

The complete results are plotted in Figure 7. The slope of the regression, which is the sensitivity of the roughness measurements to speed, was 0.132 Optigrade roughness units/(km/hr).

<u>Research by Fulton Hogan Ltd.</u>

Fulton Hogan's proposed use of Optigrade for public road maintenance management represented a substantial change from what FERIC originally designed the system for (Douglas *et al.*, 2004). Two key differences arose in this new application: identifying and isolating the data for specific road segments within a large district grid network proved to be a challenge, and mounting the hardware on the rear axle differential of a pickup truck rather than a heavy haul vehicle generated technical differences.

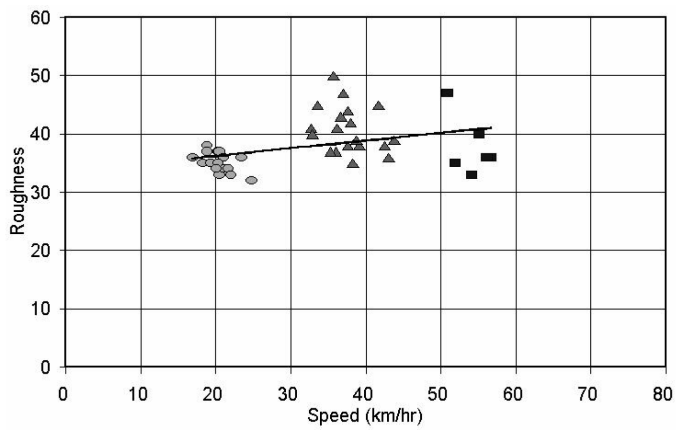

Figure 7. Combined roughness / speed data for all three passes. (Roughness in Optigrade roughness units)

Optigrade's software works from a basemap generated from waypoints. At the start of a forest road project, the locations of the waypoints are recorded with separate GPS equipment, and relatively few are needed along a single haul road. However, such an approach confuses the system when applied to a grid network of public roads. It became clear during the research that a spacing of 1000 m between waypoints was the maximum limit, and that at an absolute minimum points were needed at each end of a road segment (Douglas *et al.*, 2004). It was also desirable to record the locations of intermediate points between the end points, to delineate features such as bridge approaches and driveways, where anomalous roughness observations would be otherwise unexplained. FERIC rewrote the software code to cause the maps to display on demand the identification number of each observation point on the map, so analysts could identify ranges of relevant points in the data file for particular road segments (Douglas *et al.*, 2004).

With the hardware mounted on a pickup truck, the issue of speed sensitivity arose again. Two trials were performed with the unit mounted on a supervisor's pickup, and the roughness / speed coefficients were found by linear regression to be 0.31 and 0.42 Optigrade roughness units/(km/hr) (Douglas *et al.*, 2004). Thus on average, the "livelier" suspension of the pickup truck resulted in a roughness measuring system about 2 ½ times more sensitive when compared to mounting the hardware on the heavy logging truck (recall the sensitivity was 0.132 Optigrade units/(km/hr) in the forestry trial).

This led to a consideration of testing protocols. Speed sensitivity could be eliminated in comparative testing, done on the same segments of road repeatedly through the year, if the truck speed was kept constant. So what speed should be selected? Speed should be relatively high, so field work productivity would be high. On the other hand it would be limited by safety considerations – obeying speed limits, meshing with any traffic that might be encountered, and the speed limitations presented by the geometric design of the roads. For the rural district under test, which had very flat terrain and long straight roads with relatively few stop signs, a speed of 80 km/hr was feasible. A technique of modifying the observed roughness was adopted for observations taken at speeds more than about 10 km/hr above or below this standard speed, using the regression coefficient obtained in the speed trial.

Beyond speed, the testing protocol took account of the mechanical characteristics of the "platform" – the pickup truck. Because the testing vehicle suspension characteristics affect the recorded roughness, the protocol required the operator to ensure that the pickup truck's weight was held constant (no throwing a half dozen bags of cement in the truck to be dropped off while in the vicinity of the day's roughness testing!). Tire pressure was to be checked and restored to the norm before testing was to start. Worn tires and shock absorbers were to be replaced. It became important to make field staff aware that their trusty daily workhorse of a pickup truck became a scientific instrument when being used for roughness testing.

Calibration of the system on perhaps a monthly basis, possibly anywhere in the country, was considered, particularly as tire and shock absorber deterioration, along with any spring deterioration that might occur, are difficult to assess. A conceptual "portable calibration road" was contemplated. A solution thought to be practical yet reliable where 2 x 4 timbers, temporarily nailed crosswise on a smooth pavement at some suitable interval over perhaps 100-200 m was considered, but never tried.

New Zealand presented unique logistical challenges. Roughness testing was needed on both of the main islands, which are connected by a ferry. To tie up a pickup truck needed on one island to perform roughness testing on the other island would be very inconvenient. A dedicated trailer, which could be shipped from site to site, was considered (but by the time of writing, not implemented). Using such a trailer would also permit easier adherence to the testing protocol's requirements for constant weight, and tire, shock absorber and spring condition.

Application to Canadian practice

It would appear that use of simple roughness measuring systems in Canadian public LVR road maintenance management would be fruitful. The changes needed in the Optigrade system are within grasp.

The identification of particular road segments in Fulton Hogan's research, while handled in a satisfactory way for the research trial, is not convenient for day to day production work. More work needs to be done on the software interface. At present, Optigrade software outputs maps which show strings of colour-coded observation points along the routes followed by the truck, drawn on a blank background (Figure 2). It would be desirable to superimpose the colour-coded roughness symbols onto topographic maps of the network's region, and to be able to highlight and isolate individual road segments, bringing their roughness and speed data along with them into individual analyses. The features shown on topographic maps are particularly needed for public road networks, to make it easier to find and isolate individual road segments. It is important to be able to isolate individual road segments because sealed and unsealed segments are interspersed, and the very essence of the Optigrade system is that attention is paid to only those parts of a road network that need it.

For Canadian practice, the logistics problem would be even more acute, because of the distances involved. The solution would be to equip a suitable number of purpose-built trailers to cover a family of districts or a region to be monitored.

Asset condition profiles

Analysis techniques need to be developed to keep pace with the sophistication of the hardware, and to facilitate any moves towards performance-based specification of unsealed LVR maintenance. One technique that holds promise is the concept of asset condition profiles (Engelke 2003, Douglas *et al*. 2004). At any given time, there is a distribution of roughness values across the road network. The application of maintenance treatments (e.g. grading) alters that distribution. A roughness-based asset condition profile is a plot of the percentage of the network smoother than each value of roughness. Figure 8 is an example, drawn from the data collected by Fulton Hogan Ltd. on two separate dates (Douglas *et al*. 2004). The curves show that over four months, the smoother parts of road network (less than about 80 Optigrade roughness units) became somewhat rougher, but that the rougher parts of the network (greater than about 80 Optigrade roughness units) became somewhat smoother. The implication is that contractor had targeted the rougher

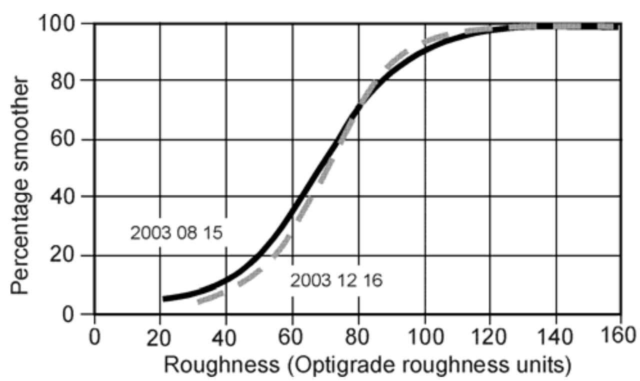

Figure 8. Asset condition profiles for FH roughness data.

parts of the network for maintenance, and during that time, the smoother parts had naturally deteriorated under traffic.

These asset condition profiles can become an extremely useful tool, if adopted. They resemble aggregate sieve analysis grain size distribution curves. In a manner similar to aggregate specification, envelopes of acceptable asset condition profiles could be set, and the current condition profile of the road network or parts of it compared (Figure 9). If the profile falls within the envelope, the maintenance regime is acceptable. If it falls outside on the rough side of the envelope, maintenance would be seen not to be keeping up and if it falls outside the envelope on the smooth side, the contractor would be considered to be wasting money and resources, doing too much maintenance.

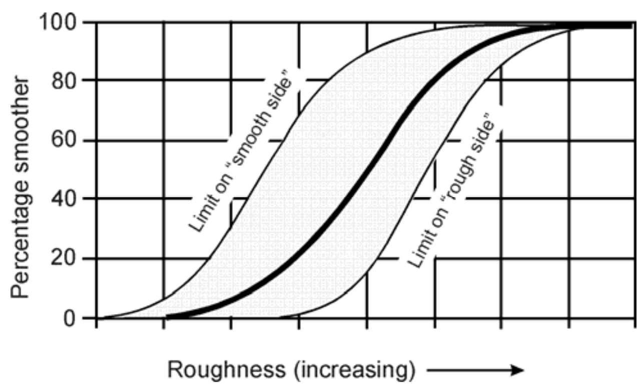

Figure 9. Prototype asset condition profile for roughness within conceptual specification limits.

Before asset condition profiles are to come into widespread use, a great deal of thought needs to go into the limits on them. How rough is tolerable? What is the desirable distribution across the network? How much maintenance is too much? What are public expectations? Are those expectations changing? Which way? Road authorities, contractors and road-user groups should confer to set the limits.

Conclusions

Based on the work described in this paper, the following can be concluded:

- Optigrade, an established, commercially viable road grading maintenance management system originally designed to cater to the needs of forestry haul roads, proved amenable to the management of the maintenance of unsealed public low-volume road networks
- adaptation was required before the system could be used in this new application
    - new methods of identifying specific road segments had to be devised
    - attention had to be paid to the greater sensitivity of the system’s measurement when the hardware was mounted on a pickup truck rather than a heavy haul truck: pickup trucks’ suspensions are “livelier”, hence the system is more sensitive to truck speed
- careful attention must be paid to test protocols in this new application: the truck’s weight, tire condition and inflation pressure, spring condition, and shock absorber condition must be kept constant from one test to another as the testing season proceeds

- in order to assist in calibration of the system over time at different sites across the region or country, a “portable calibration road” consisting of 2x4 timbers temporarily nailed to a smooth road at the testing site should be considered further
- the concept of asset condition profiles holds promise as a way of portraying and analyzing low-volume road roughness, particularly on a network basis.

Acknowledgements

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