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Contents

Using road-friendly technologies to extend the haul season on thawing roads

Abstract

During spring thaw, secondary roads can be weakened by water saturating the roadbed. Consequently, governments impose load restrictions to mitigate the impact of heavy haul traffic. As reduced payloads are not economically viable, large wood inventories are created at the mills to ensure continuous production. Recent truck technology improvements such as central tire inflation (CTI) systems and road-friendly axle configurations may reduce the loading applied to the roadbed and viable log hauling operations may be reinstated sooner than with traditional technology. This report documents the results of a field trial to explore the potential of these two road-friendly technologies to allow hauling operations during restricted periods.

Keywords

Load restrictions, Thawing roads, Log hauling roads, Central tire inflation systems, Logging trucks.

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Introduction

In many regions of British Columbia, load restrictions of 70–75% of maximum highway-legal axle weights are imposed on roads at the start of spring thaw and can last from six to ten weeks. These weight restrictions are based on regional temperature probes and are intended to prevent road damage from heavy haul traffic when the roads are at their weakest. The road restrictions are usually imposed on the lower-quality, secondary roads and not the primary roads or highways which are constructed to withstand heavier loads. The secondary roads become a bottleneck for the log haul, and the log haul is usually suspended because it is not economically viable to operate at reduced loads.

The strength of a roadbed is highest during the winter when it is frozen, but the strength drops quickly as it thaws (Figure 1). This weakening is due to the water from the melting frost becoming trapped in the

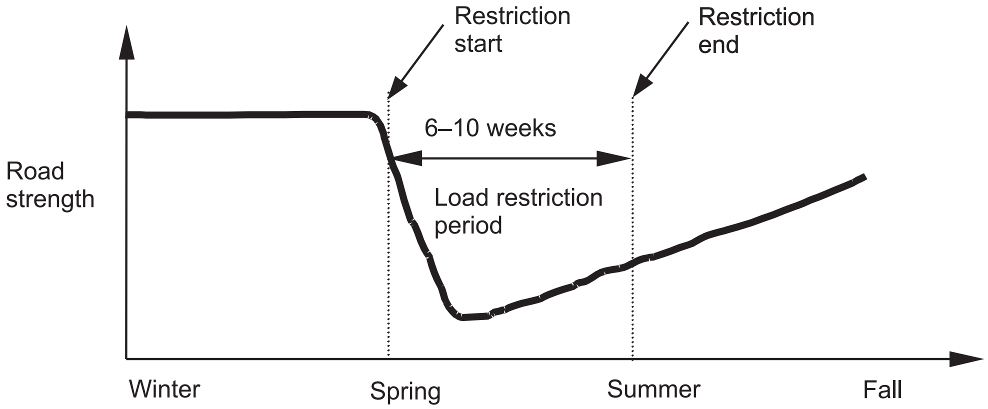

Figure 1. Seasonal fluctuations of road strength.

roadbed. As thawing continues, the water starts to drain from the roadbed and the strength begins to recover. Although the actual thaw period may be less than one week, the strength loss can occur over five weeks or longer. Once the road has recovered to an acceptable level of strength, the load restrictions are removed and all trucks are allowed to resume hauling at full axle weights.

A previous study (Bradley 1997) indicates that reduced tire pressures have the potential to mitigate damage to thawing thin pavements. For example, fully loaded trucks operating at lower speeds can safely reduce tire pressures to increase the footprint (i.e., tire contact area) which reduces the horizontal and vertical strains applied to the road structure. Central tire inflation (CTI) systems provide a convenient means for the driver to monitor and adjust tire pressures. As well, tridem axle groups have lower individual axle loads compared to single axle and tandem axle groups. Both of these technologies may provide opportunities to operate fully-loaded trucks during a portion of the traditional load restriction period.

As trucks equipped with road-friendly options impart less strain on a road than conventional trucks, they may be able to resume hauling earlier than the traditional end of the load restriction period. Benefits from an extended haul season can include reduced truck hourly ownership costs, reduced carrying charges for log yard inventory, end-product quality improvements from a fresher wood supply, and more flexibility for scheduling harvesting and hauling operations. Concerns that arise from an extended haul season include regulations associated with risks to the infrastructure and costs of monitoring both the road and the haul fleet for compliance.

During February and March of 2000, the Forest Engineering Research Institute of Canada (FERIC) undertook a field trial to evaluate the potential of extending the log haul season by using road-friendly technologies. The field trial took place near Kelowna, B.C. with the cooperation of Riverside Forest Products Limited and the B.C. Ministry of Transportation.

Objective

The primary objective of this project was to investigate the potential for fully-loaded log trucks to operate during the traditional spring load restriction period by using road-friendly technologies. The following tasks were identified to complete this objective:

- Determine if road-friendly technologies for loaded logging trucks can sufficiently reduce the impact of hauling on thawing roads.
- Assess the economic benefits of extended haul seasons as they relate to this case study.
- Collect and analyze roadbed temperature, moisture content and strength data to explore any trends or relationships.
- Propose an implementation strategy for forest companies to use when considering haul season extensions on thaw-weakened roads.

This objective was accomplished using techniques developed in cooperation with the Ministry of Transportation for assessing spring road strength recovery and road damage.

Study methods

The road test

Philpott Road, located east of Kelowna along Highway 33, was selected as the test

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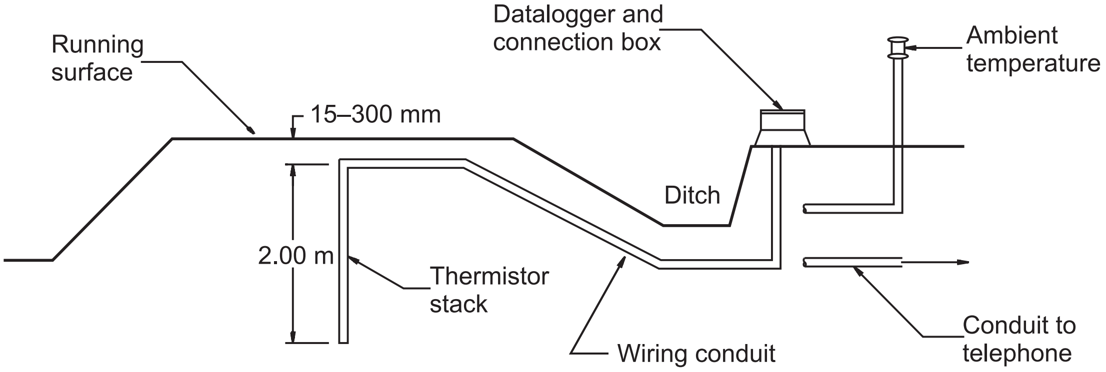

Figure 2. Road cross section with frost probe.

road as it has historically been a log haul bottleneck for Riverside during spring break-up. Road core samples showed that the two-lane rural road was constructed by cutting and filling a side slope from the indigenous material (glacial till). Originally, the surface was gravel but it was later capped with a 25-mm-thick seal coat for dust control.

The road was instrumented with a frost probe (Figure 2) composed of twelve temperature and three moisture sensors to monitor the roadbed during the thaw and recovery periods. The junction of Philpott Road and Highway 33 was marked as km 0.000, and the end of the test section was at the end of the pavement at km 5.750. The frost probe was located near the midpoint of the test section at km 3.385. The frost probe installation (Figure 3) and initial Benkelman beam[1] (Figure 4) measurements for road strength were completed prior to the onset of frost in the preceding fall period, in November 1999.

Monitoring methods acceptable to the Ministry of Transportation were needed to ensure that operating road-friendly configurations before the end of the load restriction period would not cause unacceptable damage to the road. The first method used surface distress surveys (Aderichin 1994) to monitor the surface condition before, during and after the trial (Figure 5). Five representative sections 50 m in length were observed for signs of surface distress, including pavement cracking, lifting and pothole development. If areas outside of the survey sections were noticed to be breaking up, they were added to the survey sections. As well, the rutting

Figure 3. Collecting data from frost and moisture probe data logging station on Philpott Road.

Figure 4. Taking Benkelman beam measurements.

Figure 5. Measuring crack length in a surface distress survey.

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[1] Benkelman beam is a device used to measure the road surface deflection rebound to a standard axle which can then be related to the road strength.

rate of the road was assessed using before and after measurements of the road cross-section profile from three 25-m sections.

FERIC personnel were onsite throughout the entire field trial to monitor the road strength and surface condition. The road strength, evaluated with Benkelman beam readings taken every second day, determined when the log trucks could return to hauling, based on their road-friendliness ranking. FERIC personnel also verified the tire pressures and axle loads on the log trucks for conformance to the test parameters.

Determining road friendliness

A road-friendliness ranking was determined for the various log haul configurations available for this trial (Figure 6) by modelling the road structure using ELSYM-5 and determining the stresses and strains imparted by each axle group within each configuration type. See Appendix I for more information on ELSYM-5 and its application in this study.

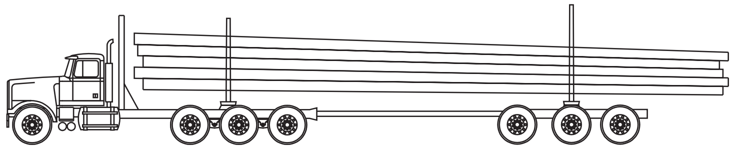
Based on previous work by Mahoney et al. (1994), it was assumed that the road would fail through fatigue cracking rather than rutting. Therefore, the amount of horizontal tensile strain imposed at the bottom of the seal coat by a given configuration formed the basis of its road-friendliness ranking.

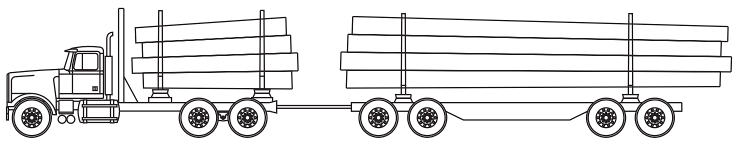
Each configuration's rank was determined by its limiting axle group, i.e., the axle group that imposed the largest horizontal tensile strain. For example, a tandem tractor/jeep/tandem pole trailer has both tandem axle groups and a single axle. Under B.C. regulations, the individual axles of the tandem group each carry 8 500 kg (17 000 kg per group) while the single jeep axle is allowed 9 100 kg. The 9 100 kg single axle will impart the largest horizontal tensile strain and was therefore the limiting axle for this configuration.

Historically, the Ministry of Transportation has used a maximum allowable road surface deflection[2] of 1.25 mm to identify when the load restriction period should end. ELSYM-5 modelling was applied to determine the road strength that corresponded to the maximum expected deflection of 1.25 mm for the particular test road. Holding the road strength constant at this level, ELSYM-5 was used to determine the horizontal tensile strains that resulted from the three types of axle groups (single, tandem and tridem) by applying their respective maximum legal loads to the road. The largest strain was then set as the maximum allowable strain for the road.

To determine at what weakened road strength levels the more road-friendly axle groups can operate, the ELSYM-5 modelling process was again used. In addition to 100% maximum legal loads, 90% loading was also evaluated as an interim loading to potentially speed re-introduction of configurations.

ELSYM-5 was also used to estimate the potential tensile strain differences between normal highway and optimized tire inflation pressures. The most road-friendly configurations were allowed to resume hauling earlier but only once the thaw-weakened road had sufficiently recovered. As the road strength continued to recover, configurations with less road-friendly combinations subsequently resumed hauling, provided


Tridem tractor/tridem pole trailer


Tandem tractor/quad-axle wagon

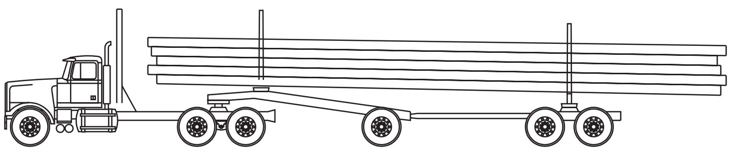

Tandem tractor/jeep/tandem pole trailer

Figure 6. Log haul configurations used in the field trial.

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[2] Maximum allowable deflection is the mean plus two standard deviations calculated from a set of Benkelman beam readings.

they imposed less than the maximum allowable strain.

CTI systems, which permit the operators of heavy trucks to optimize each axle group's tire inflation pressure for the vehicle speed and/or loading condition, were used to improve a configuration's road-friendliness. Travelling at lower speeds (e.g., 30–60 km/h) typical of secondary roads allows more opportunity to reduce the tire pressure for a given load. Operating at optimized tire pressure has been shown to decrease road fatigue damage (NCHRP 1997) compared to operating at normal highway tire pressure.[3] A radial tire's footprint will lengthen as the tire pressure is reduced, reducing the average contact pressure and thus the strain imparted on the road. To model the CTI-equipped trucks, data previously collected by Weichel (1995) were used to verify the ability of the ELSYM-5 computer program to accurately model the effects of reduced tire pressure (Appendix I).

Economic benefits

An assessment of the economic benefits of extending the haul season was made using FERIC's Foothills Log Transportation Cost Model (Blair 1999). The haul costs for a log haul fleet hauling over 320 000 m^3 annually were estimated for both the standard log haul season (i.e., no hauling during the load restriction period) and for a log haul season that was extended by hauling during the latter part of the load restriction period. The haul season extension used for these calculations was the same haul season extension that was realized during the field trial.

Road temperature and moisture content analysis

Once the field trial was completed, the temperature and moisture content data collected from the frost probe and Benkelman beam measurements were analyzed to determine trends or relationships between the datasets. As part of the post-trial data analysis task, the development of a simplified method was explored. See Appendix II for additional research in this area.

Results and discussion

The road test

Past Ministry of Transportation experience in this region indicates that spring thaw begins when the temperature in the top 450 mm of the roadbed rises above –1°C. Accordingly, 70% load restrictions were initiated on Philpott Road on February 25, 2000. The road had sufficiently recovered to lift the restriction to 100% legal axle loads by April 7 and then the restrictions were completely lifted on May 9.

At the end of the trial, there were no significant changes in the surface distress survey sections due to trafficking during the load restriction period. The sections were surveyed three times: once pre-trial (March 7–8, 2000), once at the end of the trial (March 28, 2000) and once post-trial (May 23, 2000). No substantial changes between the pre-trial survey and the end of trial survey were evident. One or two new potholes appeared in each survey section and some of the potholes increased in size. As well, no changes in the post-trial surface distress conditions occurred between March and May. The condition of the post-trial road was considered to be no worse than a typical year when hauling had been suspended for the load restriction period.[4]

No catastrophic failures of the road inside or outside of the survey sections occurred, although there were two localized failures of the road at stations km 3.69–3.70 and 2.80–2.82. The first section (km 3.69–3.70), about 10 m in length, was located at a corner on a slope, and consisted of severe alligator cracking and lifting that ran across the entire road but predominantly along the centre line. As well, shoulder cracking occurred in the loaded lane.

Note:
Much research by other organizations has already taken place and is ongoing in the area of thawing roads and load restriction practices. This research may be applicable in developing relationships between road strength and an easily measured value, e.g., between Benkelman beam measurements and temperature. If so, a simpler methodology may be developed to predict when to allow road-friendly configurations to haul on thaw-weakened roads without having to take Benkelman beam measurements for each road.

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[3] Optimized tire pressure as recommended by the Tire and Rim Association (1999) is dependent on vehicle load and travel speed. This can be as low as 172 kPa (25 psi); this trial used 275 kPa (40 psi). Normal highway tire pressure is typically 690 kPa (100 psi).

[4] John Hallam, Area Manager (Kelowna Management Area), B.C. Ministry of Transportation, personal communications, May 11, 2000.

It appeared that water tended to drain across this road section. The second section (km 2.80–2.82), about 20 m in length, was located in a straight section of road, in an area with noticeable potholes and cracking before trafficking. Severe alligator cracking occurred in both lanes and moderate block cracking was located along the outer wheelpath of the loaded lane. There was also moderate rutting along the wheelpaths of both lanes. Upon returning to the road in May, it was noted that these localized failures had not worsened. These two failures were likely due to excess water in the roadbed and once the water drained from these sections, the deterioration stopped.

The three rutting test sections showed no visible change in road profile during the trial. In addition, no visible change in rutting was noted in other sections of the road. Performing an Analysis of Variance (ANOVA) of the before and after profiles confirmed that there was no significant change in the profiles within a 95% confidence interval.

The Benkelman beam test data were gathered and then the maximum expected rebound[5] was calculated for each test (Figure 7). Early in the trial, Philpott Road was saturated, resulting in a weak road structure and the dual tires of the test truck leaving an imprint in the road surface. A steel plate, approximately the size of the dual tire footprint, was used to prevent the truck from leaving an imprint in the road. Initially, when the road structure was weak, the plate worked well but as the road strength recovered, the plate would shift under the beam truck leading to erroneous data. For the remainder of the trial, Benkelman beam tests were performed with and without the steel plate, with the latter readings forming the basis for the analysis.

The measured rebounds increased to a maximum of 3.5 mm on March 5, 2000 and then recovered to a rebound of 1.52 mm on March 25, 2000. The maximum expected rebounds for both post-trial Benkelman beam tests were 1.48 mm and 1.51 mm in May and June, respectively. The Benkelman beam test from November 1999 had a maximum expected rebound of 0.9 mm. The summer deflection of about 1.5 mm was slightly greater than one and a half times the fall deflection, while the maximum spring deflection was almost four times greater than the fall deflection.

Determining road friendliness

The road core samples showed that Philpott Road had a 25-mm-thick seal coat surface with a natural, glaciated soil base and subgrade. Since there was no distinct difference between the base and subgrade, the test road was modelled as a single layer in ELSYM-5. The ELSYM-5 model of Philpott Road was calibrated with Benkelman beam data taken in November 1999 when the maximum recorded rebound was 0.9 mm. Once calibrated, the model was then used to determine the road strength (represented by modulus) for a maximum expected surface deflection of 1.25 mm and then used to compare the road-friendliness of the axle groupings with different combinations of tire pressure and load (Figure 8).

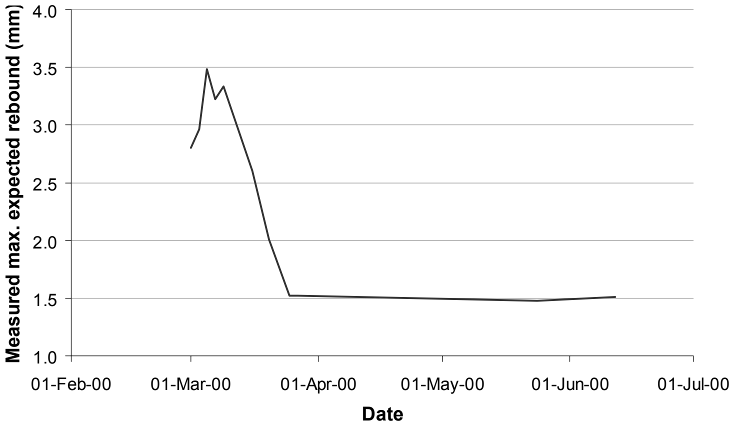

Figure 7. Measured maximum expected rebound results from Benkelman beam tests.

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[5] Maximum expected rebound is the mean plus two standard deviations calculated from a set of Benkelman beam test data.

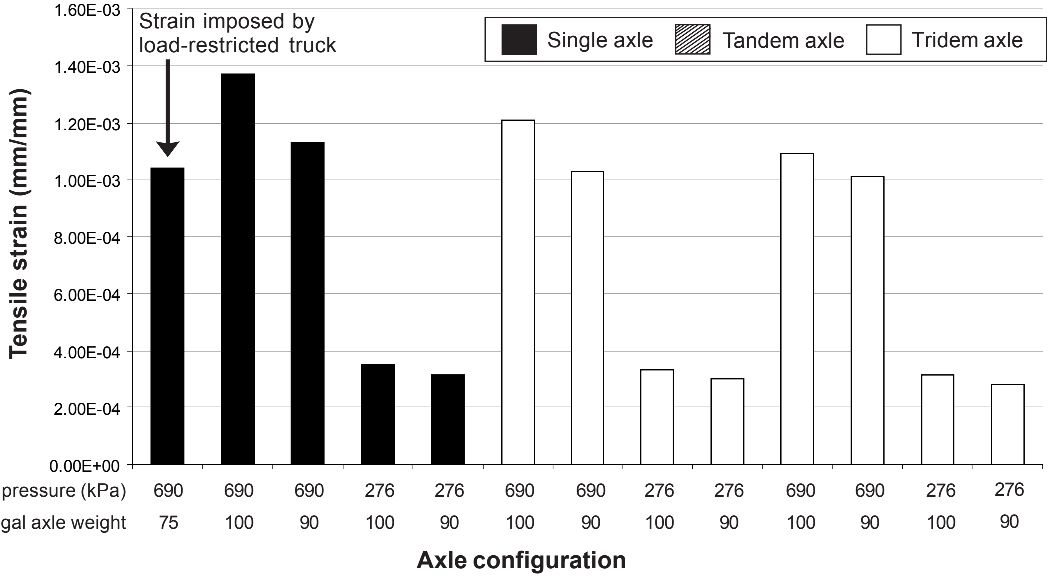

Figure 8. Horizontal tensile strain as a function of axle configuration, load and tire pressure.

The road strength for a maximum expected deflection of 1.25 mm was determined to be about 55 000 kPa (8000 psi), and the tensile strain for each configuration was determined for this road strength. The single axle with normal highway tire pressure imposes the largest strain (1.37×10^{-3} mm/mm) and is therefore the least road-friendly of the axle groups. This strain was then defined as the maximum allowable strain and used to determine when the other configurations could resume hauling. As well, the comparison shows that tire pressure has a larger influence on strain than the axle load.

A fully-loaded axle group with optimized tire pressure causes less strain than the same partially-loaded axle group with normal highway tire pressure. Therefore, the full load/optimized tire pressure combination could resume hauling sooner. Further examination of Figure 8 reveals the left to right trend of least road-friendly to most road-friendly combinations for the conditions studied in this trial. The strain that would be imposed by a truck loaded to 75% restriction with normal highway tire pressure is included on the left of the chart for reference. This strain imposed by the load-restricted axle is larger than the strains imposed by the fully-loaded axles using optimized tire pressures.

The road strength when each axle group combination imposes the maximum allowable strain limit was determined (Table 1). Once the road strength recovered to these levels, the respective configuration resumed hauling.

The tridem tractor/tridem pole trailer at optimized tire pressure and 90% load was first to resume hauling on March 13, followed by the tandem configuration at optimized tire pressure and 90% load on March 20. By March 23, the road strength had recovered sufficiently to allow the tridem configuration, at optimized tire pressure and 100% load, to

Important:
These are predicted strains for the test road and they would vary depending on the road structure.

Table 1. Strain-based sequence for haul resumption

Configuration axle group	Tire pressure	Load legal axle weight (%)	Haul resumption modulus [a] (kPa)
Tridem	LP	90	13 800
Tandem	LP	90	14 500
Tridem	LP	100	15 500
Tandem	LP	100	17 200
Tridem	HP	90	41 400
Tandem	HP	90	44 800
Tridem	HP	100	43 100
Tandem	HP	100	50 000

[a] Road strength modulus where maximum allowable strain limit (1.37×10^{-3} mm/mm) is reached.

Note:
The most road-friendly configuration (tridem groups) was able to haul an additional week before the next most road-friendly configuration (tandem groups) resumed hauling. No configurations with single axle groups were available at the time of the trial.

haul. The tandem configuration at optimized tire pressure and 100% load was allowed to haul after March 28. By the end of the trial, the road had not recovered sufficiently to allow the normal highway tire pressure configurations to resume hauling. On March 27, the tridem configurations were shut down as long logs were no longer available, and by April 3 the tandem configurations were shut down because the higher elevation bush roads had started to thaw. Figure 9 shows the corresponding Benkelman beam deflections and haul resumption dates of the configurations.

In total, over 150 loads were hauled across the test road prior to the end of the traditional load restriction period, and an additional 22 haul days were realized through the use of road-friendly technologies. These 22 additional hauling days were based on the number of days between the start of hauling (March 13) and when the forest roads were shut down (April 3). An additional four haul days could have been achieved before the 70% load restriction was lifted to 100% had the forest roads not been shut down.

Economic benefits

The economics for a mill requiring 320 000 m^3 of logs annually with 160 haul days and a fleet of 16 CTI-equipped log trucks were examined; the haul cost would be approximately \$9.20/m^3. Increasing the number of hauling days for the entire fleet by 22 reduces the haul cost by about \$0.60/m^3 or \$192 000 per year. The average cycle time for these scenarios was just over 3.5 hours. This cost saving is based on achieving an average of 22 additional hauling days per year as a result of using this technology. In addition to the economic benefits that may be achieved, the public may benefit from reduced heavy haul traffic density that could result from an extended haul season.

Important:
This is only the haul cost saving and does not include any savings from reduced log yard inventory costs, more flexible harvesting operations or improvements in product quality from using greener wood. Also, the number of days that the haul season can be extended is dependent on how quickly the road recovers and will vary from year to year.

Road temperature and moisture content analysis

The collected temperatures and road strength data from the test road were plotted as functions of date (Figure 10). The road strength data were derived from the Benkelman beam test data using ELSYM-5. The slope of the temperature index[6] curve changes from negative to horizontal near the date when the load restrictions were applied (February 25), and then the slope turns positive with the road strength recovery. Also,

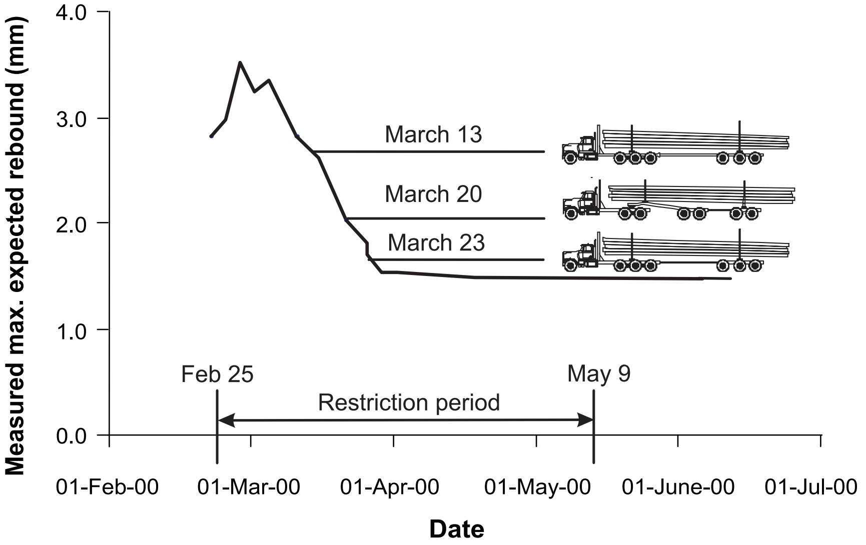

Figure 9. Benkelman beam results.

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[6] Temperature index is the sum of the average daily temperatures.

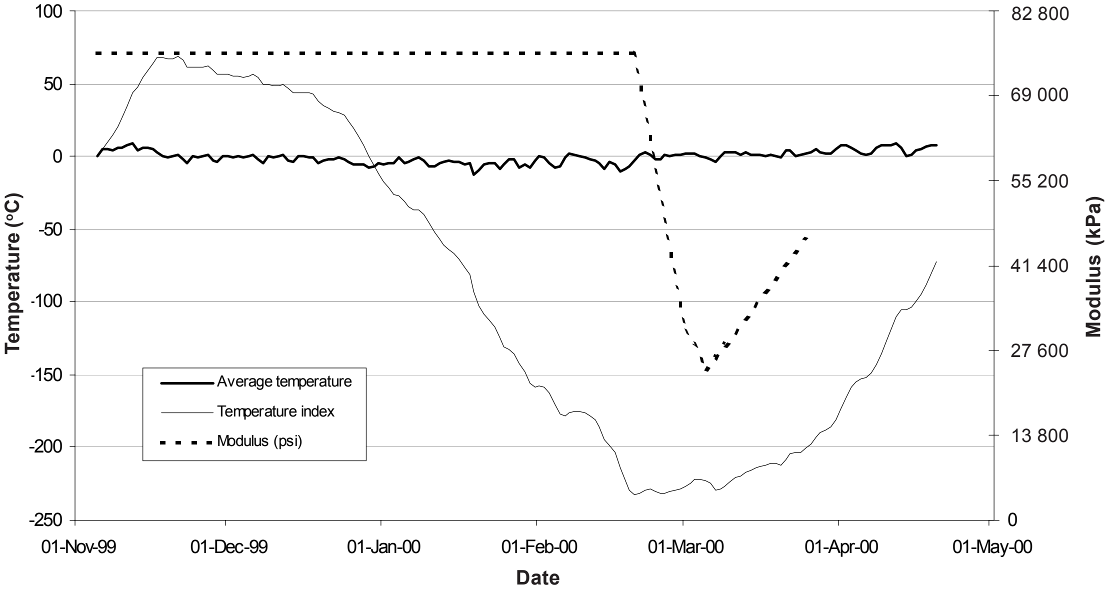

Figure 10. Average ambient temperature, degree-day temperature index and road strength as functions of date.

the road strength recovery parallels the temperature index.

In the recovery portion of the curve, the plot of road strength as a function of the temperature index (Figure 11) results in a relationship with an R^2 value of 0.86.[7] This suggests that it may be possible to predict the road strength by using the average daily ambient temperatures. These results pertain to the field trial in Kelowna and are based on a limited dataset, but similar trends have been noted by other researchers (e.g., Kestler et al. 1999, 2000; Ovik et al. 2000). Determining a relationship between road strength and ambient temperature would permit regulators to conveniently monitor the strength of individual roads and customize load restriction periods. It might eventually lead to regulatory changes whereby trucks resume hauling based on their road-friendliness ranking.

Soil moisture content has also been used to predict frost depths in roadbeds and implement load restrictions (Roberson and Siekmeier 1999). As shown by other organizations, the moisture content data from this trial indicated a significant increase in moisture content coinciding with the start of the load restriction period. No meaningful correlation was found between the recovery of the road strength and the moisture content data.

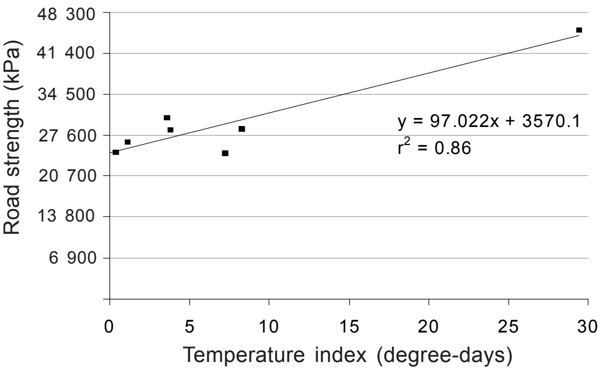

Figure 11. Road strength recovery as a function of temperature index.

Conclusions

For this road section and the weather conditions encountered, the use of road-friendly technologies, particularly CTI, extended the log haul season by 22 days, allowing the resumption of hauling before the traditional end of the spring load restriction period. This log haul season extension was achieved without causing increased damage to the road. The potential haul cost saving for extending the haul season by 22 days was shown to be about $0.60/m^3 or $192 000 annually.

Modelling the log trucks and the road in ELSYM-5 to rank the road-friendliness of

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[7] R^2 is a measure of the strength of a relationship between two variables. The closer the R^2 value is to 1, the better the relationship.

log truck configurations was an acceptable method for determining the return to hauling because the road was not substantially damaged by hauling sooner after the spring break-up.

The two methods (surface distress surveys and rutting rate measurements) used to monitor the surface condition of the road showed no significant increase in damage. Although there were two small, localized failures of the road, local regulators claimed that the road was in as good a condition as in years when hauling had been suspended.

There was a trend between the road strength and the temperature index. The slope of the temperature index curve changed with both the start of spring thaw (initiation of road restrictions) and the strength recovery. As well, the road strength recovery had a linear relationship with the temperature index. These relationships may make it possible to better predict the start of spring thaw and the road strength recovery without having to use Benkelman beam measurements.

Using the relationships between road strength and temperature, coupled with the computer modelling of the truck's road-friendliness may provide a cost effective method for indicating when hauling can be permitted on thaw weakened roads.

Further work is needed to verify the relationship between the road strength and both the ambient temperature and soil moisture content. This research is recommended because such relationships could provide a simplified, cost-effective method for predicting when the road has regained sufficient strength to allow the resumption of hauling.

Implementation

Using road-friendly technologies to extend the haul season into the traditional load restriction period showed good potential to reduce log haul costs and should therefore be pursued by the forest industry. Forest operators should work closely with their respective highway regulators to implement these findings. Each road will need to be individually reviewed to optimize the haul season extension and then considered in combination with the road-friendliness of the log trucks in the haul fleet. A method for monitoring compliance with tire pressures and vehicle speeds to travel on load-restricted roads will be necessary. On-board truck monitoring systems equipped with global positioning systems may provide such an opportunity.

Forest companies can use the following process to capture extended hauling opportunities on thawing roads:

- Determine the haul route and obtain a road use agreement with the regulating agency to haul during the load restriction period. A method for verifying compliance with the correct loads and tire pressures would be necessary. As part of the agreement, a methodology for monitoring the road surface condition should be established.
- In consultation with the regulating agency, determine a full-load reference strength for the haul route.
- Determine the road-friendliness rankings based on optimized loads, speeds, axle arrangements and tire pressures for the available log truck configurations and the haul resumption strength for each configuration.
- Monitor the recovering road strength with a Benkelman beam or other acceptable method of pavement testing, and resume hauling once the haul resumption strength for a log truck configuration has been reached.
- Provide compliance and road surface conditions to the regulatory agency as per the road use agreement.

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Appendix I: ELSYM-5 as a modelling tool

ELSYM-5 is a computer program developed for the U.S. Department of Transportation and the Federal Highways Administration. It uses linear elastic layered theory to compute the stresses, strains and displacements in a road structure for an imposed wheel load.

Before Philpott Road could be modelled with ELSYM-5, FERIC verified the accuracy of the model for use with optimized tire pressures by comparing the predicted values to Benkelman beam data gathered by Weichel in 1995 (Table I-A). Weichel took readings for a standard truck as well as beam readings for a tandem drive group of a loaded log truck at varying tire pressures.

The absolute difference between the predicted and measured values increased inversely with tire pressure, probably due to the ELSYM-5 method of modelling the tire footprints as circles. A normal highway tire pressure footprint is circular in shape, whereas an optimized tire pressure footprint is more rectangular; this will lead to some variation between predicted and measured deflections. The largest variation between the rebounds measured with the Benkelman beam and those predicted by ELSYM-5 was slightly greater than 6%. The variations between the predicted and measured values were small and ELSYM-5 was considered to be an acceptable modelling tool for this trial.

Table I-A. Measured and predicted road surface rebounds

Test vehicle	Axle load (kg)	Tire pressure (kPa)	Measured deflection (mm)	Predicted deflection (mm)	Difference (%)
Benkelman beam truck	8 120	690	1.73	1.73	0.0
Tandem axle, dual tire	8 480	690	1.81	1.80	0.6
Tandem axle, dual tire	8 480	414	1.85	1.81	2.2
Tandem axle, dual tire	8 480	276	1.56	1.66	6.4

Appendix II: Methodologies to determine spring thaw

The majority of research performed by other organizations has focused on developing methodologies for determining the start date of spring thaw (i.e., when to impose load restrictions), primarily to reduce the repair and maintenance costs of road networks. One of the more progressive jurisdictions is the Minnesota Department of Transportation, which is now using a thaw index calculated using degree-days (Ovik et al. 2000). This method adds three average daily temperatures plus three-day forecasted temperatures to determine a degree-day value to predict the start of spring thaw. Once this degree-day value reaches a reference value (25 degree-days in Fahrenheit), Minnesota imposes spring load restrictions. The thaw index appears to work well for determining when to impose load restrictions and preventing increased damage from heavy haul traffic when roads are at their weakest. According to work performed by the U.S. Army Corps of Engineers, Engineer Research and Development Center, Cold Regions Research Engineering Laboratory, almost 24% of the states that impose spring load restrictions now use a quantitative method (e.g., frost probes, thaw index) to determine when to impose load restrictions (Kestler et al. 2000).

Some work has examined when to remove load restrictions using roadbed moisture content and temperatures (Kestler et al. 1999). Both measures have shown promise, but defined time periods and visual inspection/observation are still the predominant methods used for establishing dates for load restriction removal (Kestler et al. 2000). Most of this research has examined the road strength, temperature and moisture content, and has not explored the potential benefits of improved truck road-friendliness.