Advantage

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Contents

Evaluation of forest access road designs for use with CTI-equipped logging trucks I: green access roads

Abstract

A forestry operation in northern Alberta constructs its temporary access roads with native, fine-grained materials and uses these roads during both frozen and unfrozen conditions. The log hauling fleet associated with this operation utilizes central tire inflation systems to reduce road damage and improve mobility. This first of two reports describes an evaluation of the design and construction of temporary access roads trafficked in the same year that they were constructed; quantifies grading maintenance savings resulting from the use of road surface compaction and optimized tire inflation pressures; and discusses the validation of a USDA Forest Service rutting model and its potential for use in other applications.

Keywords

Road transportation, Logging trucks, Tires, Central tire inflation system, Roads, Forest roads, Compaction, Rutting, Performance, Evaluation, Alberta.

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Introduction

Since beginning forest operations in northeastern Alberta, Alberta-Pacific Forest Industries Inc. has had varied success with accessing its harvest blocks during unfrozen periods. Wet weather, scarce gravel sources, and moisture-sensitive, fine-grained soils have resulted in reduced trafficability and increased road maintenance. Alberta-Pacific asked FERIC to review the construction of its summer-use, temporary forest access roads (i.e., those intended to be reclaimed within two years) and suggest opportunities to reduce maintenance costs and improve access (i.e., reduce the need for truck assists and maintain haul speeds). Additionally, the review was to take into account efficiencies possible through the use of central tire inflation (CTI) systems.

FERIC began its investigation by reviewing and summarizing available literature on the effect of variable tire pressures on road design and damage (Bradley 1997). During the summer of 1998, FERIC and Alberta-Pacific constructed two groups of five variations of Alberta-Pacific's usual "V-ditch" temporary access road design and then trafficked them in a freshly built, or green, condition. Alberta-Pacific's CTI-equipped log hauling fleet trafficked the first group of test sections using normal highway tire pressures and the second group using optimized tire pressures. This report documents the results of this field trial. For FERIC members wanting greater technical detail, a more comprehensive version of the report is available upon request.

A second phase of the access road evaluation was conducted by FERIC and Alberta-Pacific in September 1999. This phase of testing evaluated six temporary access road test sections constructed without surface compaction in September 1998 and left to season (i.e., densify) for one year. These test sections were trafficked in September 1999, half with normal highway tire inflation pressures and half with optimized tire inflation pressures. The results of this second "seasoned road" phase will be presented in a subsequent report.

Objectives

The primary objective of this study was to evaluate Alberta-Pacific's temporary access road design and construction technique, and was met through the completion of the following tasks:

- Quantify the cost of construction and maintenance of each road design.
- Determine the effectiveness of surface compaction for improving road performance.
- Quantify the influence of optimizing tire pressure on road performance.
- Suggest refinements to the access road designs.
- Validate the use of a USDA Forest Service rutting model in Canadian forestry applications by comparing its rut depth predictions with those observed during the trial.

Study methods

Road construction

Five variations of Alberta-Pacific's standard temporary access road design were evaluated in this trial: V-ditch (baseline case), Compacted V-ditch, 0.5-m Lift, Compacted 0.5-m Lift, and Lift-over-rootmat. In July 1998, ten test road sections were constructed consecutively to form a 1.1-km-long test road joined at either end to the 78-08 South forest access road (Figure 1). This arrangement allowed traffic to be directed onto either route as necessary. The test road was constructed such that each of the five road designs was replicated twice, one set to be trafficked with normal highway tire pressures and one set with tire pressures optimized by CTI for the trucks' operating conditions. FERIC monitored the construction of the test road and assessed the construction cost of each road design. The finished road sections were surveyed to determine cross-section geometry and pre-trial surface profile.

Trafficking trial

The loaded trucks entered the test road with their tire pressures adjusted to the normal highway (high) pressures programmed into their CTI system controllers. After passing over the first group of five test sections, the trucks were stopped at a check point where their tires were deflated to optimized inflation levels before proceeding over the next five test sections. The optimized pressure settings were based on recommendations by the Tire and Rim Association (1998).

FERIC monitored traffic over the test road during normal 24-hour hauling operations. Each loaded truck was inspected before being

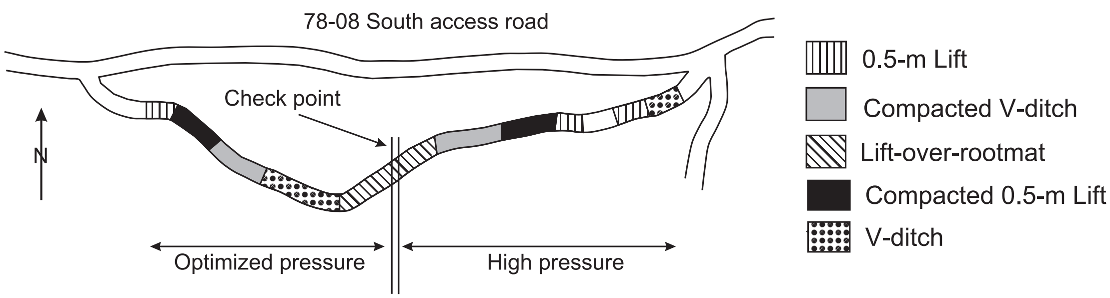

Figure 1. Plan view of green test road showing test sections.

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allowed to proceed onto the test road to ensure that its tire pressures were correctly adjusted.

All loaded and empty traffic, except loaded log trucks incapable of adjusting to optimized tire pressures, was allowed on the test road during the trial. Trafficking was continued for approximately 250 loads—the number that experienced local road builders predicted would be sufficient to give a clear indication of design performance.[1]

A sample of 70 axle weight distributions was gathered with the assistance of Alberta-Pacific's scale staff and used to estimate payload distribution for all of the trial truckloads. Each truck's axle weights were then converted to equivalent single axle loads (ESALs)[2] using equivalencies developed by the US Army Corps of Engineers (Barber et al. 1978) (Appendix I).

FERIC measured soil strength, soil densities, and moisture contents during and after the construction process. Measurements of soil shear strength were gathered with a dynamic cone penetrometer (DCP). Surface density profiles and moisture contents were gathered after finish grading, and after compaction. Measurements were made in both wheel paths and along the centreline. Soil samples were gathered and analyzed to identify soil type and to quantify basic soil properties.

Rut depth measurements were taken in both wheel paths of each test section at regular traffic intervals and before and after grading. When the average rut depth on a treatment section reached approximately 15 cm, a grader was summoned and the test road closed while that test section was graded.

Weather data for the test period were gathered from the nearest climate stations and expressed in terms of precipitation and fire weather index (FWI).[3]

For comparison purposes, the basic cost of constructing each test section was estimated by summing the cost (activity time × charge-out rate) of all pieces of construction equipment used. This cost was exclusive of large cuts and fills, operational delays, equipment transport, signs, and culverts. A relative comparison between road designs was made on the basis of total cost (i.e., the section's estimated basic cost of construction plus its grading cost during the trial). Based on this analysis, area-specific and use-specific revisions were suggested to the current road design process used by Alberta-Pacific.

Data on tire pressure, axle loads, number of passes, and road strength were input into the earth-road model of the USDA Forest Service's Aggregate Surfacing Design Guide (Whitcomb et al. 1990) to compare predicted rut depths[4] with those observed in the test sections.

Subgrade strength (measured in the top 30–45 cm of the subgrade) was taken to be the average measurement for each road design type. These strengths were determined from pre-trial DCP measurements converted to California Bearing Ratios (CBR) using an empirical formula from the USDA Forest Service's DCP operator field manual (1993).[5] The strength of the 15-cm-thick surface layer was assumed equal to 1.7 times the subgrade strength (Whitcomb et al. 1990).

Once validated with the test road data, longer-term predictions of rutting were made for the test sections.

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1 Ken Lyle, Frontier Resources Ltd., personal communication, June 1996.

2 ESALs are a concept developed by road design engineers that allows one to quantify the road damage potential of any size and type of vehicle in terms of a standard unit - the ESAL. Working in ESALs allows the design of roads for any type of vehicle or combination of traffic. It also allows one to predict the influence on road life after changing some traffic parameter such as volume, axle loading or tire pressure.

3 FWI gives a good indication of drying conditions and is calculated from a variety of weather indices including daily precipitation, temperature, wind speed and relative humidity, and from the previous day's FWI.

4 The following rut depth prediction equation was used:

$$\text{Rut depth (mm)} = \frac{140.9522 \times (\text{ESALS} \times \text{load repetitions})^{0.2418}}{(\text{CBR of surface layer})^{0.9169} \times (\text{CBR of subgrade})^{0.0365}}$$

5 $CBR = 405.3/(DCP)^{1.259}$ where DCP is the penetration rate in mm/blow.

Results and discussion

Road construction

Soil samples gathered from random locations along the test road were found to be predominantly sandy silts having little plasticity. Further detail on the soil analyses is presented in Appendix II. Sandy silts are considered fair-to-poor material for constructing road subgrade according to AASHTO (1990). Having little or no strength when completely dry, these soils are moderately compressible, and can be susceptible to frost heave. However, when fully compacted and saturated, they develop fair shear strength and become semi-to-fully impervious.

Alberta-Pacific's road builders have adjusted their work procedures to deal with the impervious nature of these silt-based roads. They build new roads in short segments that can be quickly sealed (machine trafficked) in case of impending rain to avoid saturation of the roadbed. If construction is resumed on a roadbed that has been saturated, before it is thoroughly dried, the impervious surface layer developed by machine traffic will trap moisture remaining in the roadbed, reducing its bearing strength and promoting rutting. Use of green access roads by loggers' vehicles (especially skidders) has sometimes created deep surface ruts that collect water and allow it to infiltrate into the roadbed—especially in depressions. If the weather is drier, a bulldozer or grader is used to rework the road surface to dry it and re-establish proper drainage during periods of active use by loggers. If the weather is wet, Alberta-Pacific stops all traffic on its roads until the surface has dried. Hills in this region typically contain dry layers of sand and clay. When making cuts to reduce road grade, road builders sometimes access these materials and use them to fill wet depressions and to clay cap the road surface.[6]

The most detrimental attribute of Alberta-Pacific's silt-based forest access roads may be their loss of surface traction when wet. Because they lack a surface layer of traction gravel, surprisingly little precipitation can bring about a sudden and total loss of vehicle traction.

Careful road planning (e.g., orientation for drying and anticipating drainage), construction technique (e.g., proper cross-section and width, compaction, and working in dry conditions), and maintenance (e.g., ensuring drainage through adequate maintenance) can reduce the traction recovery time after a precipitation event and may improve the reliability of Alberta-Pacific's silt-based access roads.

Figure 2 shows a typical as-built V-ditch test section, the most common type of access road built by Alberta-Pacific. V-ditch road derives its name from the V-shaped ditches created by the bulldozer during construction. This type of road is usually not compacted. The average cost of constructing both V-ditch test sections was about $106/100 m, excluding all large cuts and fills, equipment transport, cross-drains, and signs (Table 1). The average construction cost of the two Compacted V-ditch sections was slightly higher at $134/100 m.

The second construction design evaluated was a 0.5-m Lift (Figure 3). This type of design would commonly be used in depressions and other wet areas where the roadway needs to be raised above the water table.[7] Lifted road sections also are usually not compacted. The average cost for constructing the two Lift sections was $373/100 m. Surprisingly,

6 Emery Gorman, Green Country Resource Managers, personal communication, July 1998.

7 Alberta-Pacific's experience with local soils is that 0.5 m of lift is adequate to ensure drainage. However, lifts need to be as high as 1 m in a part of its FMA having predominantly clay soils.

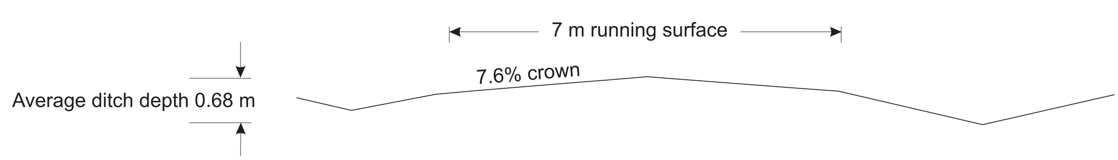

Figure 2. Schematic of a typical as-built V-ditch prism.

Table 1. Construction costs of the test sections

	Construction equipment used [a] D7H	D7G	E	C	G	Total cost of construction ($)	Constructed length (km)	Unit cost of construction ($/100 m)	Average cost of construction ($/100 m)
V-ditch (HP) [b]	X			X		172	0.096	179	106
V-ditch (OP) [b]		X	X		X	133	0.192	69	
Compacted V-ditch (HP)	X		X	X	X	276	0.163	169	134
Compacted V-ditch (OP)		X	X	X	X	138	0.145	95	
Lift (HP)	X	X	X		X	572	0.118	485	373
Lift (OP)		X	X		X	92	0.060	153	
Compacted Lift (HP)	X		X	X	X	604	0.138	438	319
Compacted Lift (OP)		X	X	X	X	170	0.105	162	
Lift-over-rootmat (HP)	X		X		X	446	0.106	421	419
Lift-over-rootmat (OP)	X		X		X	694	0.166	418	

[a] D7H = Caterpillar D7H bulldozer, D7G = Caterpillar D7G bulldozer, E = Hitachi EX270LC excavator C = Hamm tamping foot, vibratory compactor, G = Caterpillar 14G grader.
[b] HP = normal (high) tire pressures; OP = optimized (lowered) tire pressures.

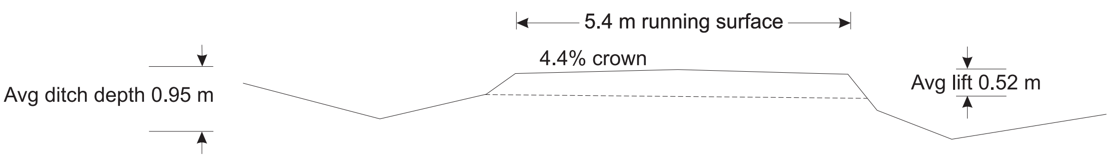

Figure 3. Schematic of a typical as-built Lift prism.

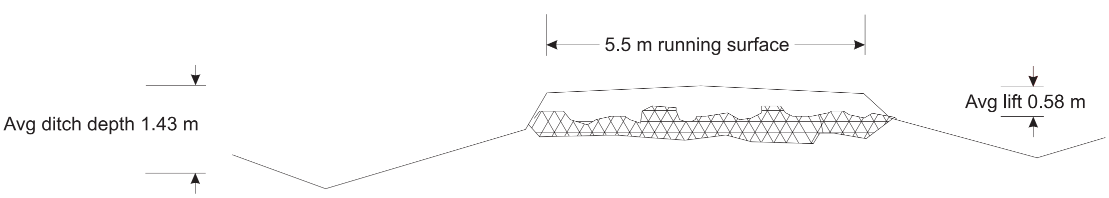

Figure 4. Schematic of a typical as-built Lift-over-rootmat prism.

this construction cost was actually slightly higher than the average cost of the Compacted Lift sections ($319/100 m). Although the sample is small, differences can be explained by productivity differences between the techniques used to build the road sections.

The third road design, Lift-over-rootmat, is a technique used successfully in Ontario in situations where subgrade soils are very wet or are absent (i.e., the root mat lies over bedrock) (Figure 4). Roots provide reinforcement and drainage to the lift material. The tree harvester should cut the stumps as low as possible, as tall stumps require more lift material to cover and may protrude through the running surface as trafficking progresses.

The average amount of lift on the two test sections built was 0.58 m, which was slightly more than for the Lift test sections. At an average construction cost of $419/100 m, these two sections were the most expensive to build. However, this construction method may be economic when compared with Alberta-Pacific's technique of bridging problematic wet areas with a corduroy (log) mat covered by fill.

Table 1 presents a summary of the cost of constructing the test sections, and a detailed account of Alberta-Pacific's road construction process is given in Appendix III. There was a large variation in the unit cost of construction of the test sections, e.g., the Lift (HP) section cost was three times that of the Lift (OP) section. Productivity varied substantially with the types of machines used and how they interacted.

Comments by experienced machine operators indicated that, for the fine grained soils encountered in this trial, a lower-powered, lighter bulldozer and grader would have been adequate and possibly more productive than the heavier models actually used.[8]

The excavator was equipped with a wrist-mounted shaping blade (Figure 5) which improved the machine's dexterity and allowed it to construct ditches faster, and with smoother, more stable backslopes than the bulldozer.[9] One year after the trial, the author observed more backslope slumping and ditch blockages in sections ditched by the bulldozer than in sections ditched by the excavator using its shaping blade.

Figure 5. Ditching with excavator using shaping blade.

Figure 6 shows a Hamm tamping-foot vibratory compactor preparing one of the test sections. This is a standard type of compactor used for highway construction and is considered effective to a 20-cm depth over most soil conditions. Following a compactor manufacturer's recommendations (Hyster Company 1972), the compactor made eight overlapping passes, using vibration, over the entire running surface of each of the compacted test sections.

Figure 6. Tamping foot vibratory compactor used on test road.

Compacting silt-based forestry roads strengthens the road surface and increases its ability to shed precipitation. This, in turn, reduces grading requirements and allows trafficking to resume sooner after rain. More information about the soil density measurements is included in Appendix II. Although the in-situ density increases were relatively small, they were sufficient to noticeably reduce the grading requirements of the Compacted Lift sections (Figure 7), but had no measurable benefit on the Compacted V-ditch sections during the trial period (Table 2).

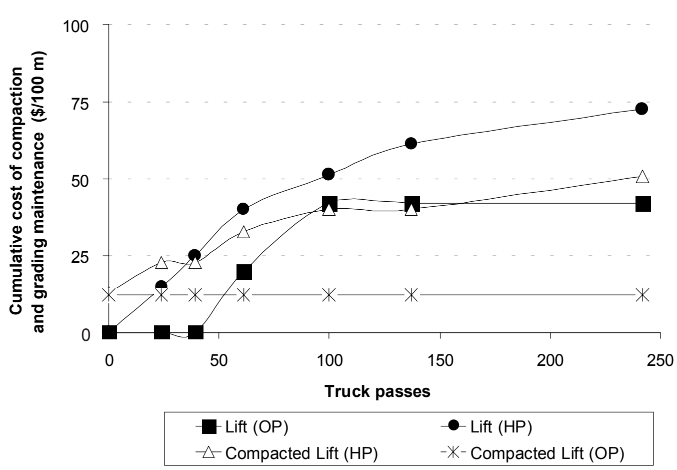

Figure 7. Effectiveness of compacting Lift sections.

8 Allen Burnett, bulldozer operator, and Guy Loftstrand, grader operator, personal communication, July 1998.

9 Ray Vincent, excavator operator, personal communication, July 1998.

Table 2. Effect of optimizing tire pressure on grading maintenance costs

Road design	(HP) Section maintenance cost ($/100 m)	(OP) Section maintenance cost ($/100 m)	Savings from use of optimized tire pressures ($/100 m)	(%)
V-ditch	0	0	0	0
Compacted V-ditch	0	0	0	0
Lift	48.7	39.6	9.1	19
Compacted lift	37.9	0	37.9	100
Lift-over-rootmat	39.0	40.2	(1.2)	(3)

The natural water content of the compacted test sections was no more than 3% wetter than optimum. Had the road surface been allowed to dry longer before compacting, higher field densities would have been achieved. Compacting between placements of successive 15-cm-deep layers of material added to the Lift road sections would likely have created a firmer structure which, in turn, would have supported a higher degree of surface compaction. This would be especially effective if, after compacting the base, a protective surface cap of clay was placed and compacted.[10] Compaction of incremental lifts was not attempted during the construction of the Lift sections for reasons of cost and equipment availability; however, tow-behind compactor attachments are available and should be considered for future work.

Trafficking trial

Weather conditions during the trial period were mixed, with cloud, sun and warm temperatures during the day and temperatures as low as 2ºC during the night. A small amount of rain fell shortly before and during the trial, but was not enough to interrupt the log haul. FWI reflected the mixed weather conditions observed during the trial, varying between 11 and 26, and followed short wetting and drying trends.

The average gross combination weight (GCW) of the log hauling trucks during the trial was a highway legal 60.2 tonnes (t), which was slightly under the legal allowable GCW of 62.5 t, and their average payload was 40.4 t (Appendix I). The normal highway tire pressures (HP) and optimized tire pressures (OP) used by the loaded trucks in the trial are shown in Appendix I. Only 39% of the CTI systems were capable of optimizing their steering tire pressures, so the average optimized steering tire pressure was only reduced by 15 kPa to 640 kPa.

The improvement resulting from optimized tire pressures varied considerably with road design as indicated in Table 2. The reason for the variation between the Lift and Compacted Lift sections is believed to be that the uncompacted lift surface material was too weak to support the loaded trucks, even with optimized tire pressures, whereas compacted lift material was strong enough to support these trucks if they used optimized tire pressures. Grading frequency of these lifted sections reduced as the trial progressed because the trafficking and grading strengthened the road surface, although the grading interval increased more slowly in the sections trafficked with high tire pressures.

The four V-ditch sections showed no difference in grading maintenance cost because none required grading during the trial period. However, both uncompacted V-ditch sections had deteriorated by the end of the trial and would have required grading if the trial had been much longer. The Lift-over-rootmat sections were both graded five times and always at the same time. Although the high-pressure section appeared to rut a bit faster overall, a

[10] Emery Gorman, Green Country Resource Managers, personal communication, July 1998.

soft depression in the Lift-over-rootmat (OP) section required just as frequent maintenance.

Figure 7 illustrates the effectiveness of compacting the Lift test sections. Cumulative road cost in this figure includes only the cost of maintenance grading and the cost of compacting the road. Other construction costs were assumed equivalent for all Lift roads and were not included. The cost of compacting the test sections was approximately $125/km. The cumulative road cost of the high tire pressure (HP) sections became equal after 40 passes (i.e., the extra cost of compaction was paid for after only 40 passes). From that point onwards, the cumulative road cost was less for the Compacted Lift (HP) section than for the Lift (HP) section. The optimized pressure (OP) sections showed a similar trend with a break-even point occurring at about 60 passes. It is expected that compacted silty Lift roads would shed water better and recover faster after being wetted.

Appendix I quantifies the change in potential access road damage of a typical, loaded 8-axle B-train with a reduction in tire inflation pressure. Theoretically, optimizing tire pressures causes a reduction of 5.76 ESALs per round trip. This corresponds to 61% slower rutting (and 61% less frequent grading) caused by this configuration when its tire pressures are optimized.

To estimate how much less road damage is done when a truck's ESALs are reduced, the USDA Forest Service developed the Surfacing Thickness Program (STP) rutting model (Whitcomb et al. 1990), an empirical model that was validated in subsequent field trials (Truebe and Evans 1994). FERIC used this model to predict rut development for the test sections that were not graded during the trial: all V-ditch sections and the Compacted Lift (OP) section. The predictions were graphed and compared with actual rut measurements (Figures 8 and 9). Predictions were not attempted for the Lift-over-rootmat sections because the root layer imparts an unknown strength to the overlying material.

STP predicted rut development in the V-ditched test sections with an average error of 6% (i.e., the average combined error for the four V-ditched sections was an underestimate of 6% for the break-in period (247 trips). STP predictions for part way through the break-in period were less accurate, averaging a 22% overestimate when compared to actual rut depth measurements. For the purpose of evaluating comparable truck configurations, road treatments, or grading intervals, this degree of accuracy may be acceptable.

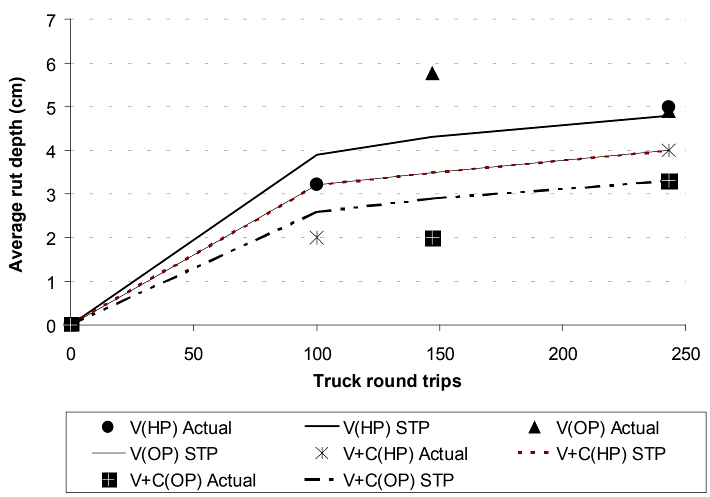

Figure 8. Actual vs. predicted rutting depths for the V-ditched test sections.

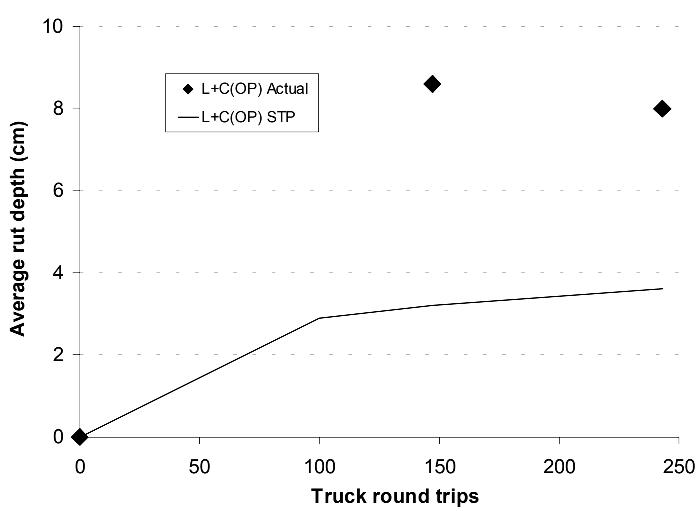

Figure 9. Actual vs. predicted rutting depths for the Compacted Lift (OP) test section.

Rut depths for the Compacted Lift (OP) section were underestimated by 63% and 55% at 150 and 250 truck passes, respectively (Figure 9). The reason for this is unclear, however, it may be partly due to the fact that compaction was only applied to the top surface, after all the lift material was in place. It may also relate to the difficulty drivers experienced in varying their wheel paths to ride down the raised edges of ruts, due to the reduced running surface width on these sections. In this case, the as-built running surfaces of the lifted sections (i.e., Lift, Compacted Lift, and Lift-over-rootmat) averaged 5.5 m wide, which is about 0.5 m less than Alberta-Pacific's design specification and 1.1 m less than for the V-ditched sections. Varying wheel paths is a vital aspect of reducing rut development using optimized tire pressures (Bradley 1996).

When a road is soft and ruts are deep, the chief opportunity for varying wheel paths is when trucks are unloaded.[11] Typically, drivers are apprehensive about driving onto the softer, raised shoulders of deep ruts when heavily loaded.

During trafficking, deep rutting progressed along the road from all three cross-drain locations. This rutting is believed to have initiated when the trucks sank into relatively uncompacted fill around the culverts. This suggests that current culvert installation practice should be adjusted to increase the compaction of the fill around each cross drain. Adequate compaction can be achieved by following recommended culvert installation practices (Wilson 1996).

The rutting model was used to make long-term rut development predictions for the V-ditched sections of the test road (Figure 10). For the purpose of making predictions, a grading trigger depth of 7.6 cm was specified (that is, grading is assumed to occur after rut depths reach 7.6 cm). The predictions assumed road strengths were similar to those measured during the trial and, based on measured CBR values, that the compacted road was 1.5 times stronger than the uncompacted road.

By the end of the trial, the V-ditch (HP) and (OP) sections displayed deeper rutting than the Compacted V-ditch (HP) and (OP) sections. The model predicts that the V-ditch (HP) section would have required grading well after the end of the trial (i.e., after 1125 truck passes or about 45 750 t of payload) and relatively frequent grading thereafter. Because of the road friendliness of trucks using optimized tire pressures, the V-ditch (OP) section is predicted to require grading after 2875 passes or 116 918 t of payload. Much longer grading intervals are predicted for the compacted V-ditch sections, indicating that heavily trafficked V-ditch access roads should be compacted. However, caution should be used in making predictions over a

[11] John Ellison, Alberta-Pacific Woodlands staff, personal communication, June 1998.

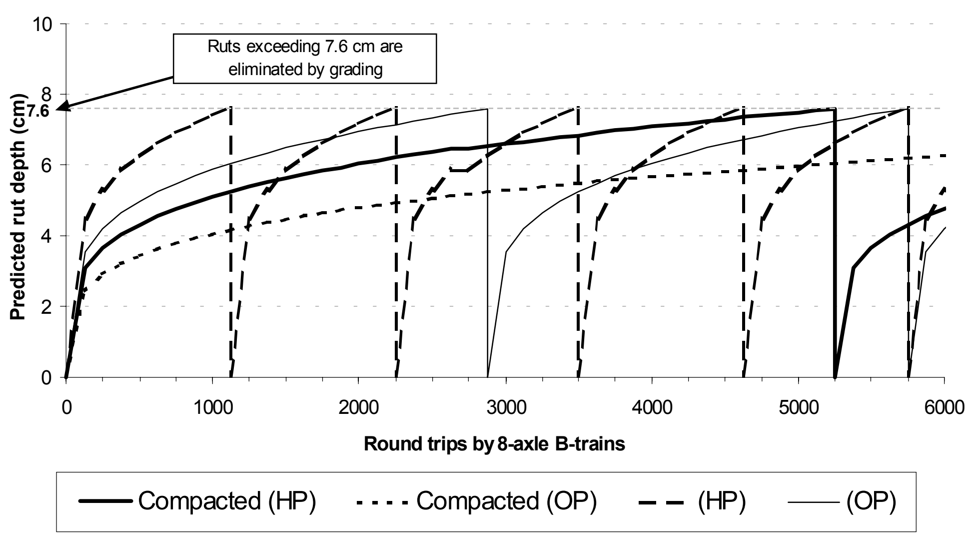

Figure 10. Predicted rutting for V-ditched road using STP.

long time frame because weather changes may cause road strength to vary significantly from that specified for the predictions.

The rutting model appears to be a useful tool for modelling the effect of changes in traffic variables on rut development in the V-ditched test roads. Further testing is advisable to confirm its application for the wide variety of soil types and weather conditions found in Canadian log hauling operations. Once confidence in the model is established, however, many potential applications for its use exist.

Overall Performance

Table 3 rates the performance of the green road test sections that were subjected to optimized tire pressure traffic (i.e., subjected to conventional Alberta-Pacific haul conditions). The minimum construction cost is the lowest-cost construction technique for that design—assuming the most efficient construction technique would be used in its construction. Rut depth after 250 loads was included to illustrate the condition of the road at the end of the trial and the likelihood of additional maintenance cost in the near future. The performance rating for the five designs was based upon combined road cost and requirements for the situation, given the relatively dry weather and soil conditions during the trial.

The V-ditch section was rated as the best design based on its good performance and lowest combined cost. The performance of the V-ditch design is predicted to have dramatically improved with compaction. However, this improvement is not considered necessary given the expected volume of traffic over the test access road. Therefore, the Compacted V-ditch design is considered over-built and rated as the next best design. The added lift in the 0.5-m Compacted Lift design was not required given the well-drained soil conditions of the test road, so this design was also considered over-built given the trial conditions. However, its higher combined cost and imminent grading (if the trial had continued) resulted in it being not rated as highly as the Compacted V-ditch design. The 0.5 m of loose material in the Lift design presented a rutting problem and would have greatly benefited from being compacted. Therefore, it was rated as unsuitable. The Lift-over-rootmat was rated the least suitable design because of its high cost and frequent maintenance. This design may benefit from compacting, but builders of this design in wet sites in Ontario have found that excessive vibration during compaction may draw water up through the root mat.[12]

The performance of the test designs and, hence, the performance ratings would likely have been different given different soil and/or drainage conditions. Had the sites been located in wet depressions, elevating the grade would have been more necessary and the Compacted Lift design might have been the best design. However, for the purposes of this comparison, a test road location having consistent alignment, soil type, drainage

[12] John Ellison, Alberta-Pacific Woodlands staff, personal communication, June 1999.

Table 3. Rating the performance of the optimized tire pressure road sections

Road design	Minimum construction cost ($/km)	Grading maintenance cost ($/km)	Combined road cost ($/km)	Rut depth after 250 loads (cm)	Performance rating
V-ditch	693	0	693	6.5	best
Compacted V-ditch	952	0	952	4.2	next best
Compacted 0.5 m lift	1 619	0	1 619	9.0	over built
0.5 m lift	1 533	396	1 929	graded 2x	unsuitable
Lift-over-rootmat	4 180	402	4 582	graded 5x	least suitable

conditions, weather and traffic volume was selected to hold these influences constant and permit a comparison of compaction and tire pressures.

Conclusions

The cost of constructing sections of the same design varied greatly, with the differences strongly influenced by the combinations of equipment used and how the machines interacted. The wrist-mounted shaping blade on the excavator improved this machine's dexterity and allowed it to construct ditches faster and with smoother and more stable backslopes.

Compacting the test sections increased their dry densities by up to 5%. However, in-situ densities were still far less than the maximum dry densities. All but one of the compacted test sections had natural water contents greater than their optimum water contents, which may have reduced the effectiveness of the compaction equipment. Nevertheless, the relatively small increase in density with compaction resulted in road savings for the Lift sections after the first 40 to 60 truck passes. No similar cost benefits were shown for the compacted V-ditch sections since no grading maintenance was required on either the compacted or uncompacted V-ditch sections during the trial period. However, when the trial concluded, the depth of rutting was greater on the uncompacted V-ditch sections, indicating that grading would have been required sooner than on the compacted sections.

Optimizing tire pressures theoretically reduced the damage potential of the loaded test trucks by 61%. Over the length of the trial (250 loaded truck passes), the use of optimized tire pressures resulted in 19% and 100% less grading maintenance for the Lift and Compacted Lift sections, respectively, compared to the equivalent sections trafficked with high tire pressures. This variation is believed to have resulted from the inability of the uncompacted Lift sections' surface material to support the trucks, even at optimized tire pressures, without rutting, whereas compaction strengthened the Compacted Lift sections' surface material sufficiently to support the trucks using optimized tire pressures. The grading interval for these lifted sections increased as the trial progressed because the trafficking and grading strengthened the road surface. The grading interval increased more slowly in the sections trafficked with high tire pressures indicating that optimized tire pressures may be more effective at controlling rutting in these road designs and soil types than using high tire pressures and grading.

Narrow running surfaces, such as those observed on sections with high lifts and/or uncompacted soils, reduce the opportunity for trucks to vary their wheel paths and heal rutting. This resulted in increased rutting and more frequent grading on these sections. Faster rutting also results if cross-drains are inadequately compacted, leading to extra grading, culvert damage, slower travel speeds and extra vehicle assists.

The rutting model predicted rut depths developed by 250 truck loads with reasonable accuracy for the four V-ditch test sections. However, predictions at 100–150 truck loads were moderately underestimated. Rut depths of the Compacted Lift (OP) test section were considerably underestimated—an error possibly resulting from having compacted only the top layer of lift material, and possibly as a result of the narrowness of the Lift section's running surface which limited the trucks' ability to vary wheel paths, thereby accelerating rut development.

Rating the performance of the road designs based on cost and suitability found that the V-ditch section was the most suitable road design given the test conditions. The performance of the test designs and, hence, the performance ratings would likely have been different given different soil and/or drainage conditions.

Implementation

To achieve optimal equipment productivity, the size, mass and power of the equipment should be well matched to the requirements of the task. Constructing green access roads in predominantly fine-grained soils requires less power and would benefit from having smaller, lighter equipment. Use of an excavator-mounted shaping blade is preferred when ditching in highly erodible silty soils.

Local trials with Compacted Lift sections and Lift-over-rootmat test sections should be conducted to determine if, and under what circumstances, these designs are economic. This test procedure should be repeated to evaluate designs for sand and till soils.

Field compaction levels achieved during the trial were sub-optimal and could have been improved through more careful control of soil moisture and compaction technique. Field compaction can be improved by developing simple field tests to estimate the moisture content of local soils, and determining the most cost-effective compaction device and techniques for local soils and construction methods.

Lifted material should be compacted in layers no deeper than the effective compaction depth of the compactor. Consideration should also be given to the cost effectiveness of using stabilization chemicals such as quick lime/flyash, in combination with compaction, when attempting to strengthen and dry problematic sections of wet, silty, access road.

During the trial, excessive rutting was observed to initiate at cross-drain locations having inadequate compaction. To prevent localized failures and related hauling delays, recommended culvert installation practices should be followed. Similarly, excessive rutting was also observed where running surface width had been narrowed during construction. A minimum running surface width of 6.0 m should be maintained to ensure that the trucks have adequate room to vary their wheel paths and heal existing ruts. A running width of 7.0 m, as found on the V-ditch sections, would be preferred.

Forest companies utilizing CTI systems should establish and enforce a tire pressure policy based on a set of manufacturer-approved tire pressure settings to ensure that the full benefit of the CTI systems is realized. This may best be done through education programs and driver self-monitoring. Local trials to document tire, fuel, and/or traction-related cost savings accruing from the correct use of the CTI systems also may be persuasive. CTI driver training programs should instruct drivers to ride down the raised edges of ruts with their unloaded trucks.

Dropping vehicle speeds to around 40 kph and optimizing tire pressures may help CTI-equipped log trucks to begin hauling one-half to one day sooner after a rain because the trucks re-compact and dry the surface without cutting deep ruts.[13] This could be a substantial advantage for CTI log-hauling operations, provided no other factors impede haul start up.

The rutting model appears to be a useful tool for modelling the effect of changes in traffic variables on rut development in the V-ditched test roads. Further testing is recommended to confirm its application for a wider variety of soil types and weather conditions. Once confidence in the model is established, many potential applications for its use exist. For example, STP could be useful for predicting incremental road maintenance due to overloads, for apportioning road maintenance costs in shared road use agreements, and as part of an economic evaluation of road stabilization treatments.

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[13] Dennis Young, Weyerhaeuser, personal communication, June 1999.

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APPENDIX I

Tire inflation and axle loads of the test road traffic

Axle grouping	Loaded trucks: Average tire inflation pressure (HP/OP) (kPa)	(psi)	Loaded trucks: Average axle group load (t)	Unloaded trucks average axle group load (t)
Steer axle (1)	655/640	95/93	5.42	5.42
Drive axles (2)	655/365	95/53	16.67	6.37
Lead trailer axles (3)	655/358	95/52	22.05	7.97
Rear trailer axles (2)	655/358	95/52	16.00	0.00
Total			60.14 [a]	19.76 [b]

[a] GCW.
[b] Tare weight.

Axle load equivalencies of Alberta-Pacific's 8-axle B-Trains

	Steer axle	Drive tan/axles	Lead trailer tri/axles	Rear trailer tan/axles	Total ESALs	ESALs per round trip	Change in ESALs per round trip (%)
Mode 1 — normal, highway tire pressures (HP)							
Loaded							
Pressure (kPa)	655	655	655	655			
Load (t)	5.4	16.7	22.1	16.0			
Equiv. factor	0.91	2.29	2.53	2.11	7.84		
Empty							
Pressure (kPa)	655	655	655	655			
Load (t)	5.4	6.4	8.0	0.0			
Equiv. factor	0.91	0.31	0.31	0.00	1.53	9.37	
Mode 2 — optimized tire pressures (OP)							
Loaded							
Pressure (kPa)	640	365	358	358			
Load (t)	5.4	16.7	22.1	16.0			
Equiv. factor	0.86	0.59	0.62	0.52	2.59		
Empty							
Pressure (kPa)	640	365	358	358			
Load (t)	5.4	6.4	8.0	0.0			
Equiv. factor	0.86	0.08	0.08	0.00	1.02	3.61	(61)

APPENDIX II

Summary of soil properties and classification

Sample location	Atterberg limits: Liquid limit (%)	Atterberg limits: Plasticity index (%)	Composition: Sand (%)	Composition: Silt (%)	Composition: Clay (%)	Unified soil classification	Classification as highway subgrade material [a]
V-ditch (HP)	21.3	4.0	30	55	15	Sandy silt of low plasticity	Subgroup A-4 Fair to poor
Lift (HP)	21.4	4.7	26	74 [b]	-	Silt of low plasticity	Subgroup A-4 Fair to poor
Compacted lift (HP)	24.9	9.1	22	51	27	Sandy clay of low plasticity	Subgroup A-4 Fair to poor
Lift-over-Rootmat (HP)	18.7	2.4	20	67	13	Sandy silt of low plasticity	Subgroup A-4 Fair to poor
V-ditch (OP)	18.2	1.5	20	66	14	Sandy silt of low plasticity	Subgroup A-4 Fair to poor
Compacted lift (OP)	20	2.9	18	68	14	Sandy silt of low plasticity	Subgroup A-4 Fair to poor

[a] Based on AASHTO (1990).
[b] Silt and clay content.

Dry density and water contents for the compacted test sections

Sample location	Dry density: Before compaction (g/cc)	Dry density: After compaction (g/cc)	Dry density: Change (%)	Dry density: Maximum (g/cc)	Water content of soil: Optimum (%)	Water content of soil: Natural (%)	Water content of soil: Excess over optimum (%)
Compacted							
Lift (HP)	1.55	1.63	5	1.94	10.8	13.1	2
Lift (OP)	1.52	1.56	3	1.87	11.1	13.9	3
V-ditch (HP)	1.53	1.59	4	1.85	11.3	11.0	(0.3)
V-ditch (OP)	1.57	1.61	3	1.92	10.9	12.0	1

APPENDIX III

Summary of Alberta-Pacific's class IV temporary road construction process

1. Right-of-way timber is felled to a maximum 20-m width with landings spaced approximately 300 m apart. The felled timber is skidded to the landings and piled in log decks. Right-of-ways are narrowed in the vicinity of water crossings to minimize sediment deposition into the stream. Processing of the piled stems is done when convenient to the road construction process.
2. A 14–18-m-wide strip in the right-of-way is grubbed of logging debris, stumps, and overburden with a bulldozer (typically D7-size). The overburden is piled just outside of the ditch line to facilitate subsequent road reclamation.
3. The bulldozer establishes a grade centreline —maintaining as straight an alignment as possible. If the centreline's gradient exceeds specified limits, then it is reduced by cutting down the hill or using fill material recovered from the ditches or nearby. Alberta-Pacific's ground rules specify the following maximum gradients: 8% sustained adverse, 10% adverse pitch, 10% sustained favourable, and 12% favourable pitch.
4. Wet or otherwise unacceptable grade material is stripped by the bulldozer and pushed to the outside of the ditch line. Often just the top 8–10 cm of subgrade is too wet and needs to be stripped.
5. V-shaped ditches are cut on either side of the stripped grade line. The ditch material is piled onto the grade to create a crown and/or lift with wetter materials placed under drier or more acceptable material. The width of the road surface after ditching is typically 7.0 m. V-ditch roads can be created with a bulldozer alone or in combination with one or more excavators. Excavators are utilized when extra lift and/or deeper ditches are required to facilitate drainage (e.g., in swamps).
6. The road surface is smoothed and finished by a grader. The finished V-ditch road design has a 6.0-m-wide running surface, a 5% crown, shoulders sloped to 2:1, and 0.5-m-deep ditches.
7. The road is left unsurfaced (i.e., earth-surfaced) because gravel is usually unavailable. Surface compaction is typically light and accomplished with the constructing equipment and grader. Compaction equipment is not normally employed in access road construction.
8. Finally, drainage structures (for cross-drains and water crossings) are installed to maintain naturally occurring drainage patterns. Culverts on temporary roads are typically made from thick-walled, 40 or 60 cm (inside diameter) used pipe.
9. Once constructed, Alberta-Pacific typically starts hauling on the road immediately so that the road can be reclaimed within the two years required by Alberta-Pacific's ground rules. Alberta-Pacific endeavours to leave some roads untrafficked over winter to season them—a process by which the subgrade dries out and rainfall and wetting-drying cycles compact and strengthen the running surface.