Canadian Pacific Railway 100% Effective Friction Management Strategy

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Canadian Pacific Railway (CPR) has spent the past 5 years implementing an optimised "100% effective gauge face lubrication" strategy on 3250 km of their 24,000 km network to control friction at the interface between the wheel flange / rail gauge face. Conclusive test results in 2001 demonstrated substantial savings in rail gauge face wear and in train energy (fuel) consumption. As new equipment technology became available, CPR started testing a top of rail friction management strategy to complement the gauge face systems on their high tonnage coal and mixed freight Thompson Subdivision in British Columbia, Canada. Results to date demonstrate substantial additional savings over and above "100% effective gauge face lubrication" in the following areas: reduced lateral curving forces, reduced rail wear, reduced train energy (fuel) consumed, reduced requirements for wayside gauge face lubrication units and lubricant, and reduced tie and fastener damage. CPR's experience with the implementation of a strategy for "100% effective friction management" in a heavy haul territory is provided in this paper.

Index Terms: lubrication, friction management, top of rail, rail wear, curving forces

1.0 INTRODUCTION

CPR operates across Canada and the USA Northeast and Midwest, over 24,000 km (15,000 miles) of railway between Vancouver on the west coast of Canada to New York on the east coast of the USA. In western Canada, coal is transported over 1207 km (750 miles) on a route consisting of sharp curves and steep grades, in unit trains with payloads of 13,250 metric tonnes (14,500 tons), powered by three 4400HP AC traction locomotives. The route carries approximately 78 million gross tonnes (86 MGT) per year of mixed freight, grain, double stack inter-modal container cars as well as coal.

The route is predominantly single track, running bi-directional traffic, with 46% of the routing traversing curves sharper than 3492 m radius (½ degree), 129 km (80 miles) of curves less than 312 m radius (greater than 6 degrees) and a maximum curvature of 160 m radius (11 degrees). Temperature extremes in the Thompson River valley range from +43°C (110°F) to –34°C (-30°F). The rail in curves of 218 m radius (8 degrees) and sharper is predominantly 68kg/m (136 lb/yd) 350-390BHN head hardened rail. Ties in curves are 274 cm (9 ft) long hardwood ties, spaced at 508 mm (20 inch), on 41 cm (16 in) rolled eccentric plates.

For the past 5 years CPR has been progressively rolling out a "100% effective gauge face lubrication" program [1, 2]. This program was justified on the basis of a business case developed from tests conducted by the National Research Council of Canada's Centre for Surface Transportation Technology (CSTT) on the Thompson Subdivision in British Columbia between the years 2000 and 2001. The program has currently replaced all previous gauge face lubricators and lubricants in 3250 km of CPR main line with the new technology lubricators using high performance lubricant. This lubricant contains a graphite EP additive with a microgel thickener. CSTT uses the lubricator spacing formulae developed specifically for the CPR on each subdivision to plan the placement of all lubricators. CPR is continuing to roll out this gauge face lubrication strategy on all high curvature primary and secondary main lines and plans to complete the process by 2005.

CPR realised that "100% effective gauge face lubrication" was not completely solving their rail wear problems. In the Thompson subdivision for example there was evidence of an increase in the wear from the top of the low rail. CPR has used extensive gauge face grinding to reduce the incidence of deep seated shells with "100% effective gauge face lubrication". As new products and dispensing technology became available to reliably distribute and dispense friction modifying product to the top of the rail,

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CPR commissioned CSTT to study the process and develop a best practice for implementing top of rail friction control in one of their toughest territories, an 80 km (50 mile) section of the 132 km (121 mile) Thompson Subdivision. This is a single track territory consisting of 62% curves with a maximum curvature of 160 m radius (11 degrees).

In February 2004, Kelsan Technologies Corp (Kelsan) tested a winter top of rail product to verify that it could be used in the future winter tests in the Thompson subdivision. In April 2004 Instrumentation Services installed a strain gauge-based lateral/vertical load (L/V) site in a 270 m (6 degree 30 minute) curve. Data was transmitted by cell phone to Kelsan, and CPR identified the types of trains that travelled through the site so that the loaded coal trains could be identified. This site was used in an optimisation process for variations in the number of top of rail friction modifier units to be used, the spacing of the units and the settings for friction modifier product dispensation. The base case for the comparison was "100% effective gauge face lubrication" with a lubrication activation setting of ¼ second every 16 wheels (0.34 litres/1000 axles). The track was preventively ground in July 2004 using a 96 stone rail grinder. Subsequently, eight Portec Protector IV top of rail (TOR) units were installed to dispense KELTRACK friction modifier (TOR) product. The goal at the start of the optimisation process was to achieve at least a 30% reduction in lateral forces at the L/V site, a target that has been achieved on other heavy haul railroads in North America [6]. Current industry thinking is that a 30% reduction in lateral forces would lead to a significant increase in asset life. After an intensive optimisation process, a significant reduction of lateral forces was achieved. Rail vertical wear on the high and low rail was substantially reduced in several test curves. Fuel savings were calculated based on a fuel test on British Columbia Railway.

A total of 17 TOR units have now been located throughout the 80 km (50 mile) test area of the Thompson Subdivision. One gauge face unit was removed from between MP 10 and 19.5 and the quantity of lubricant was halved for all gauge face units. The CPR dedicated lubricator maintainer manages and maintains the electronic gauge face units, between Kamloops and Vancouver, a distance of 406 km (252 miles) as well as the TOR units in the 80 km (50 mile) test area. CPR has implemented a hi-rail based system to fill the gauge face units and the TOR units on the Thompson Subdivision using dedicated equipment to dispense product from 1100 litre (290 US gal) totes.

2.0 FRICTION MANAGEMENT OBJECTIVES

Friction Management is the process of controlling the frictional properties on all rail surfaces contacted by wheels to achieve the best balance between wear, lateral forces in curves, and fuel efficiency. In general terms, the goals are:

- Lubrication of the gauge face of the rail to minimise friction, wear and curving resistance (coefficient of friction (μ) not to exceed 0.25).
- Friction control on the top rail surfaces (μ between 0.30 and 0.40) to control wear, lateral forces and rolling resistance in curved track. A special class of products is required to achieve these friction conditions [3, 4, 5 and 6] as lubricants are generally not suitable since they may compromise locomotive traction and safe braking of trains.
- Improve traction under driven locomotive wheels (and possibly under emergency braking situations) through an enhanced and constant coefficient of friction.

Controlled tests [1] on the Thompson Subdivision using electronically activated gauge face lubricators with longer lubricant dispensing bars and a better-engineered lubricant showed a large reduction in high rail gauge face wear, reduced fuel consumption and reduced track maintenance costs. However improved gauge face lubrication increased the vertical wear on the low rail of curves. CPR continued to over-pump the lubricators using a setting of ¼ second every 8 wheels (0.48 litres/1000 axles) to avoid having a dry top of rail which has been associated with spike failures and high lateral loads [2,3]. However CPR realised that top of rail friction targets could not be achieved in a controlled manner using gauge face lubricators.

3.0 WAYSIDE EQUIPMENT AND FRICTION PRODUCT PERFORMANCE

Wayside TOR systems have the potential to provide substantial savings through reduced wheel and rail wear, minimised track deterioration and reduced fuel consumption. The performance of the TOR equipment and the TOR product on the track can vary widely depending on the climate, track characteristics, traffic type and operating patterns, type of TOR equipment, and equipment maintenance and monitoring practices. Best practices in wayside equipment application include:

- Selection of the most appropriate equipment for dispensing the top of rail product
- Selection of the track location that ensures proper distribution of the product and minimised damage to equipment
- Measurement and management of TOR effectiveness and thus optimal equipment placement
- Proper maintenance to ensure that TOR systems are always filled and working

CPR's implementation of a TOR friction management strategy was supported by field investigations conducted by engineering staff from CPR, CSTT, Kelsan and Portec.

3.1 Equipment to Dispense Top of Rail Product

New, proven, TOR equipment technology has recently become available to dispense TOR product using four 610 mm (24 inch), field side-mounted bars (Figure 1). In future these bars will be replaced with four longer, 1400 mm (55 inch) bars for better wheel and rail coverage. These bars use the existing Portec Protector IV electronic equipment as used in the application of gauge face lubrication. These systems employ a non-contact (i.e. low-maintenance) rail-mounted sensor, which detects the passing of wheels and signals the electric motor to dispense lubricant or friction modifier. Control box settings can be adjusted to regulate the volume of product dispensed based on the number of wheels travelling through the site. On CPR this equipment has been proven with gauge face lubrication and the new TOR bars are easily maintained and suitable for dispensing TOR product.

Figure 1: TOR equipment bar showing liquid TOR product being dispensed to the field side of the rail.

Kelsan have two top of rail products that were tested on CPR – KELTRACK Trackside Freight (summer) which is used down to temperatures of -6 degrees C (21degrees F), and KELTRACK Trackside Freight LT (winter) which is used for temperatures down to -15 degrees C (5 degrees F). These products are compatible so units can be topped up in the fall with winter product, in time for the product to be available for the lower temperature range.

TOR equipment applicator output testing has been done at temperatures as low as -14 degrees Celsius (-7 degrees F) with KELTRACK LT. Although the output rate at -14 degrees C was reduced by approximately 30-35% due to increased viscosity (versus temperatures above +4 degrees C), the pumping of the TOR product through the TOR equipment did not present any issues. The friction modifier product remained useable after a freeze-thaw cycle.

3.2 Guidelines for Proper Installation of Top of Rail Units for Proper Distribution

There are guidelines for the proper installation and location of TOR equipment to ensure good TOR product distribution and lower maintenance costs. Usually two bars per rail are installed in the following recommended locations:

- At the appropriate spacing and settings (§3.3).
- In tangent track and at least 30 to 60 m from the nearest gauge face unit to prevent contamination.
- With sufficient sunlight year round for solar powered units to operate.
- Bracketing groups of sharp curves for bi-directional traffic.
- At rail locations where there are no significant rail surface defects.
- At rail locations where the rail profile has a suitable crown radius (CPR uses a 250 mm crown radius) and without field side plastic flow, so that the bars can be fitted and the top seal on the bar is not struck by wheel false flanges
- At rail locations where track gauge is within +/- 3mm ($^{1}/_{8}$th inch) without significant cross level errors.

CPR ensures that the production rail grinder grinds through TOR tangent sites at frequent intervals to maintain the rail to profile and the surface free of defects.

3.3 Measurement and Management

CPR has adopted best-practice targets as part of a strategy to improve and better manage the friction on the rail. The Thompson Subdivision between milepost 0 and 50 consists of 62% curves with maximum curvature up to 160 m (11 degrees). This Subdivision has had a “100% effective gauge face lubrication” program in place since 2001. CPR and CSTT selected this 80 km (50 mile) test area which had 8 Portec Protector IV electronic gauge face lubricators and 2 Portec hydraulic gauge face lubricators using a high performance lubricant (lubricant). In May 2004, the settings for the gauge face lubricators was changed from ¼ second and 8 wheels (0.48 L/1000 axles) to the optimal setting of ¼ second and 16 wheels (0.34 L/1000 axles). CSTT measured the coefficient of friction using a hand operated tribometer and for the gauge face it was on average less than 0.2 and for the top of the rail it was on average between 0.5 and 0.6. The objective of the top of rail friction management strategy was to manage the reduction in lateral forces using an instrumented curve as the coefficient of friction could not be measured using a hand operated tribometer [5] and (§3.3).

A strain gauge-based lateral/vertical load site (L/V site) was installed and calibrated in April 2004 by Instrumentation Services Inc (ISI). The two instrumented cribs for the measurement of L/V (Figure 2) were placed in the body of a 268 m (6 degree 30 minute) curve at MP 11.95, between units TOR2 and TOR4 (Figure 3). Wiring from the instrumented cribs was run into a signal bungalow at MP 11.8 where AC power was provided to the data processing unit for the L/V site.

Also provided at the signal bungalow was access to an active cellular phone signal. After each 24 hour period of data collection, the data processing unit transmitted processed L/V (per-axle peak) data to Kelsan by email. Baseline data was collected from May-July, 2004. CPR ground through the test site in July 2004. While some baseline data was lost due to a lightning strike in May and a

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corrupted solid-state hard drive in June/July, this did not compromise the integrity of the baseline data and the site operated reliably for the remainder of the trial.

TOR equipment implementation in the Thompson Subdivision was to be done in two phases: an optimisation phase in a 19 km (12 mile) sub-zone (July-September, 2004), followed by a roll-out phase in the overall 80 km (50 mile) test zone based on the optimisation results (October-November, 2004).

Figure 2 shows the instrumented cribs in 6 degree 30 minute curve at MP 11.95.

For the optimisation portion of the trial, TOR units were distributed between MP 7.8 and 18.9 (Figure 3). Application rates during the optimisation process ranged from 0.3 to 0.5 L/1000 axles (0.08 to 0.13 USgal/1000 axles), while average inter-unit distances of 2.7 km (1.7 miles) and 4 km (2.5 miles) were achieved by activating or shutting down units TOR1 and TOR 5 as appropriate. Note that in all cases, the span across the L/V site (between TOR2 and TOR4) was 5.6 km (3.5 mile).

The distribution of units shown in Figure 3 was chosen, in part, to determine whether the clustering of TOR units would generate successful product carry across this 5.6 km (3.5 mile) span with a lower total application rate than a more typical uniform spacing configuration.

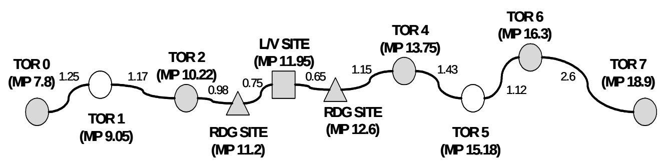

Figure 3: TOR applicator distribution in the CPR sub-zone between MP 7 and 19 for the optimisation trial. Note: L/V and Rail Deflection Gauge (RDG) sites are also shown.

Selection of the optimisation conditions was guided by a decision tree, with a target minimum lateral force reduction of 30%. The final sequence of conditions used in the optimisation process is listed in the table 1.

After receiving the L/V site data by email, Kelsan post-processed the per-axle peak force data to produce per-train average lateral loads for trains meeting a set of filtering criteria. The filtering criteria were designed to enhance the comparability of data sets between trial conditions, as well as focus on the highest (most damaging) lateral forces.

Table 1. The final sequence of TOR equipment distribution for the optimisation process.

Condition	1	2	2b	3	4	4b
TOR0 (MP 7.8)	½ ON*	½ ON*	ON	ON	ON	ON
TOR1 (MP 9.05)	off	off	off	ON	ON	off
TOR2 (MP 10.2)	ON	ON	ON	ON	ON	ON
TOR3 (MP 11.95)	L/V site	L/V site	L/V site	L/V site	L/V site	L/V site
TOR4 (MP 13.75)	ON	ON	ON	ON	ON	ON
TOR5 (MP 15.2)	off	off	off	ON	ON	off
TOR6 (MP 16.3)	ON	ON	ON	ON	ON	ON
TOR7 (MP 18.9)	ON	ON	ON	ON	ON	ON
Pump Setting **(sec x axles)** **(L/1000 axles)** **(USG/1000 axles)**	 0.25x20 0.35 0.09	 0.25x16 0.40 0.11	 0.25x16 0.40 0.11	 0.25x16 0.40 0.11	 0.25x12 0.50 0.13	 0.25x12 0.50 0.13
Total Application Rate (L/1000 axles)	1.6	1.8	2.0	2.8	3.6	2.5

Table 1. *TOR0 is located in a dual-track location. In conditions 1 and 2, only one TOR unit was installed (north track has ~60% of traffic). For conditions 2b to 4b an additional unit was installed in the south track.

The filtering criteria used were:

- **Cars/Locomotives:** The use of self-steering bogies on locomotives tends to produce significantly lower lateral forces than are produced by cars. As such, locomotive axles were removed from the data.
- **Axle Loads:** Vertical wheel loads were sorted into 0-12, 12-25 and 25+ kips ranges. As lateral loads tend to increase with vertical loads, only wheels with loads greater than 25 kips were included (in addition, only trains with more than 20 wheels with greater than 25 kip vertical loads were considered).
- **Train speed:** Trains deviating significantly from balance speed in this curve of 40 kph (25 mph) have a low incidence of high lateral loads and tend to produce outlying lateral forces. As such, only speeds between 35 kph (22 mph) and 47 kph (29 mph) were included.
- **Train Direction:** Loaded coal trains travel West through the Thompson Subdivision, while empty coal trains travel East. With this in mind, data for trains in each direction were reported separately.
- **Leading/Trailing Axles:** Leading axles tend to produce higher lateral loads than trailing axles, particularly in less than 350 m (5 degrees) radius where saturation occurs with the CPR frame braced bogies. The data analysis reported leading axles separately (Figure 4).

Lateral force reductions (Figure 4) of between 16% and 22% were achieved for a 5.6 km (3.5 mile) TOR unit spacing for each of the optimization conditions however the 30% goal was not achieved.

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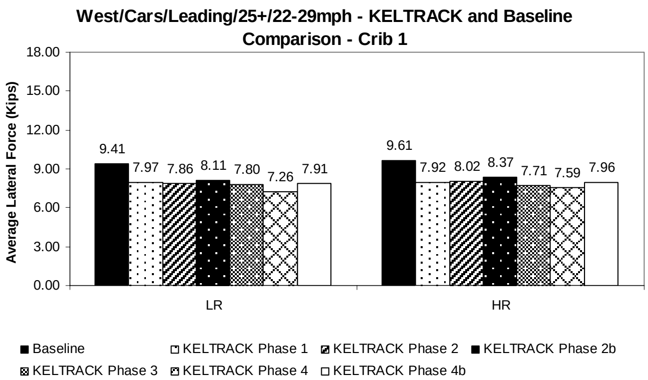

Figure 4. Average lateral forces recorded by the L/V site for the leading axles of westbound trains meeting the filtering criteria.

In addition to calculating average lateral forces, lateral load distributions were calculated on a per-train basis for the leading wheel of leading axles of loaded westbound coal trains. These trains were selected for use in generating the lateral force distributions shown in Figures 5 and 6 based on the filtering criteria.

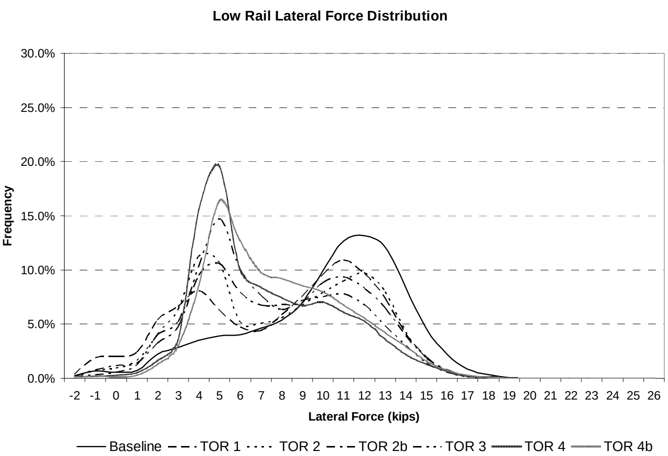

Figure 5. Low rail lateral force distribution for westbound coal trains meeting the filtering criteria.

The lateral force distributions show that the peak lateral force and the incidence of high lateral forces on the rail have been significantly reduced. The low rail and high rail peak lateral forces have reduced from 12 kips to 4 kips and 13 kips to 6 kips respectively. The stress state of high lateral forces on the track has also been reduced with the shift of the distribution curve to the left.

In addition to lateral force measurements, rail deflection and top of rail friction levels were monitored for each optimisation condition. Rail deflection was measured at MP 11.2 and MP 12.6 using LVDT-based Rail Deflection Gauges (RDG's and Figure 7) top of rail friction was measured in the instrumented curve at MP 11.95 using a push tribometer.

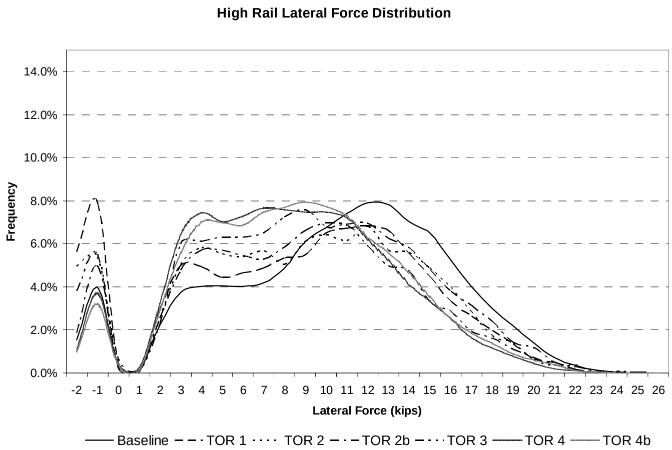

Figure 6. High rail lateral force distributions for westbound coal trains meeting the filtering criteria.

Figure 7. An LVDT based Rail Deflection Gauge (RDG) used to measure lateral rail deflections.

Equipment problems during baseline RDG measurements rendered the data from MP 12.6 unusable (follow-up measurements at this location during the re-established baseline conditions are planned in January 2005). Deflection data from MP 11.2, however, was successfully collected and analysed for baseline, as well as conditions 1, 3 and 4 (condition selection was governed by equipment availability). Figure 8 shows the average values of peak lateral deflection from corresponding leading axles of loaded coal trains.

Typical rail friction values as measured by the tribometer from MP 11.95 are shown in Figures 9 and 10. As shown, the TOR coefficient of friction for the high and low rail is greater than the 0.3 to 0.4 range, which was typical of readings throughout the optimisation process. From other testing [5] the measurement of the top of rail friction is not as important as the measurement of lateral force reduction to verify the success of friction modification. Kelsan proposed that the wheels may be carrying the TOR product through the L/V site.

From the information (data and graphs) presented above, the following observations were made:

- CPR was not seeing the 30% reduction in lateral forces at the L/V site, which was 2.8 km (1.75 miles) from nearest TOR unit, with the reductions in unit spacing and increases in application rate (Figure 3 and Table 1).
- RDG data shows that TOR condition 3 and 4 provides a significant reduction in deflection at MP 11.2 at 1.6 km (1.0 miles) from nearest TOR.
- From the histogram distributions (Figure 4), conditions 3 and 4b appear to provide very similar reductions in lateral forces. In addition, statistical testing reveals no significant difference between the mean values of these conditions (i.e. it can be expected that condition 4b achieved maximum product benefit at a distance of 1.6 km (1.0 miles) from the nearest TOR unit).

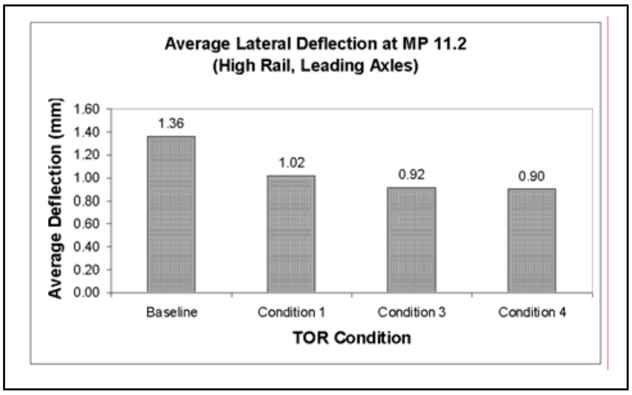

Figure 8. RDG measurements at MP 11.2 shows the average lateral deflections for leading axles of loaded coal trains. This site was 1.6 km (1.0 miles) from the nearest TOR unit.

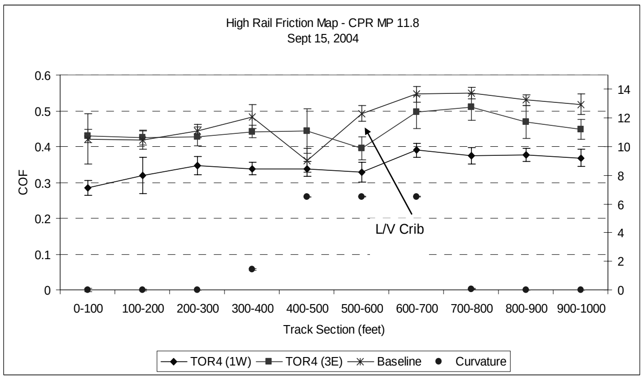

Figure 9. High rail TOR coefficient of friction levels and the track curvature at the MP 11.95 L/V curve.

From this conclusion in the sub-zone a new distribution of units was implemented throughout the 80 km (50 mile) test area in the rollout phase. Note that this distribution focused on clusters of curves with sharper radius than 290 m (6 degree), with a total distance of approximately 30 kms (18.5 miles) of untreated track (i.e. 37% of the zone). Approximately 14 of these miles, however, contain no curves sharper than 436 m (4 degrees). Results from this distribution are shown in §4.2.

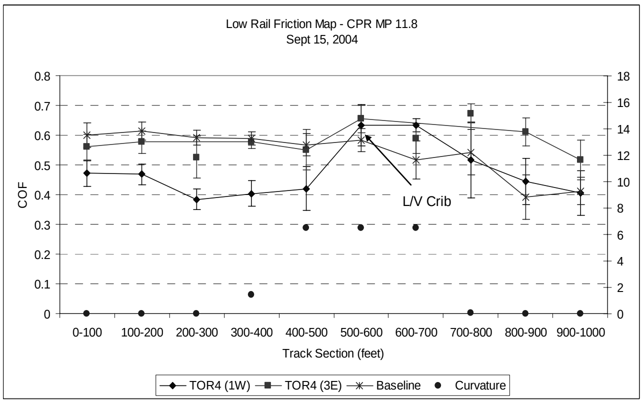

Figure 10. Low rail TOR coefficient of friction levels and track curvature at the MP 11.95 L/V curve.

3.4 Proper Maintenance

CPR has successfully used a dedicated lubricator maintainer to manage the maintenance of the lubricators between Kamloops and Vancouver, a 406 km (252 mile) territory. This has greatly improved the reliability and efficiency of the gauge face lubrication strategy. The maintainer is supported by one section person who spends 3 days each 3 weeks filling the gauge face units and the TOR units. He uses a highway/rail (hi-rail) maintenance truck fitted with 2 bulk distribution systems, one for each product. TOR product is supplied in 1100 litre (290 US gal) totes and is changed to a winter product in the fall of each year in anticipation of temperatures that are likely to be below -6 degrees C. The summer and winter product can be mixed, allowing for an easy change of operation between summer and winter.

The CPR lubricator maintainer checks the lubrication and TOR units to ensure that the equipment is working effectively. His checks at each location include:

- Ensuring that at least 90% of the total ports on the gauge face bars are working.
- Minimal wastage of product on the track.
- The control box is counting the wheels accurately. Wheel counts that are significantly different from adjacent units may imply that the unit has failed since the last visit.
- The magnetic sensor is working and located properly (at the right height below passing wheel flanges).
- The battery voltage for the solar powered system is sufficient for proper operation.
- The top seal of the bar is not damaged by contact with wheel false flanges.
- The level of product in the tank is sufficient until the next filling cycle.

This practice ensures that lubricant and top of rail product is on the rail all the time to reduce rail/wheel wear, lateral track forces and locomotive fuel consumption.

4.0 BENEFITS OF "100% EFFECTIVE FRICTION MANAGEMENT"

CPR selected one of the toughest operating environments on their System, the Thompson Subdivision, to test top of rail friction management and assess the benefits. The results show substantial rail wear reductions, reduced lateral forces, reduced number of lubricators and lubricant usage. Fuel savings have been estimated from tests on a similar Canadian freight railway.

4.1 Rail Life Benefits

Between May 2004 and December 2004, CSTT monitored rail wear using a MiniProf® profilometer on fourteen curves between mile posts 10 and 16, with curvatures varying from 436 m (4 degrees) and 160 m (11 degrees). Readings were taken before and after each grinding cycle. The gauge face lubricators were set at ¼ second for every 16 wheels (0.34 L/1000 axles).

Figures 11, 12 and 13 show the changes in vertical rail head wear projected over 73 mgt (80 MGT) for the base case with gauge face lubrication only and for gauge face and top of rail friction-managed rail on three curve classes - less than 5 degrees, 5 to 8 degrees, and greater than 8 degrees.

On average, "100% effective friction management" has significantly reduced high rail vertical wear by 50% and low rail vertical wear by 57%. Gauge face wear has been eliminated as expected with "100% effective friction management".

The rail surface condition has been clean and surface defect free in the test area even after 36 mgt (40 MGT) between grinding cycles. CPR has not yet determined whether there has been a reduction in the incidence of deep seated shells with "100% effective friction management" however there has not been a problem in the Thompson Subdivision since the introduction of TOR friction management. Also, there have not been any reports of traction or braking issues in the Thompson Subdivision since the start of the test which is consistent with other reports [5].

4.2 Reduction in Lateral Forces

Resulting lateral force levels measured at the L/V site at MP 11.95 after the optimisation, redistribution and installation of TOR equipment in the 80km (50 mile) test area are shown in Figures 14, 15 and 16.

This redistribution resulted in a TOR unit being installed at MP 11.75 very close to the L/V site. Lateral force measurements show an average reduction in lateral forces of 42%. RDG measurements from the optimisation process in the 80 km (50 mile) test area support these lateral force reductions.

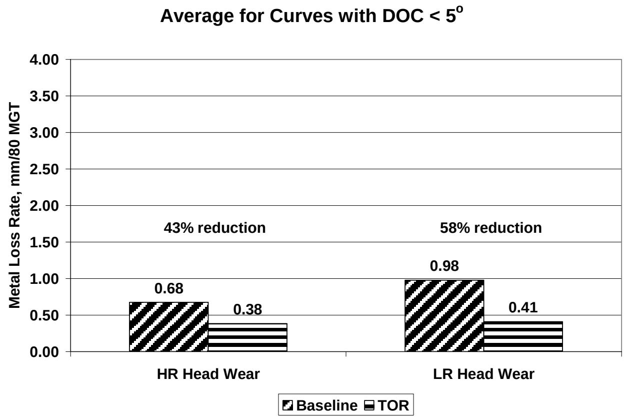

Figure 11. Mild curve average vertical rail head wear rates, for baseline and top-of-rail friction modified conditions. Gauge face wear has been eliminated.

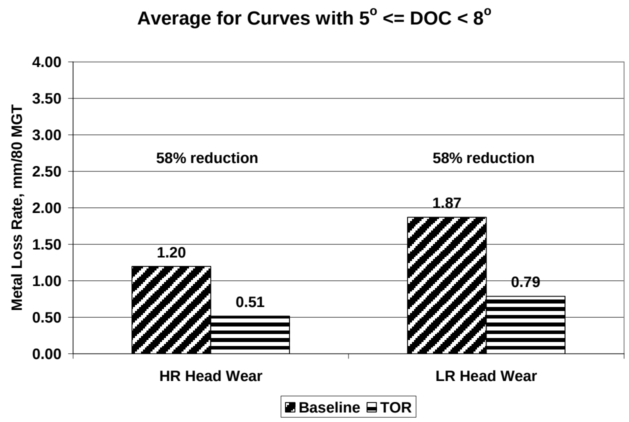

Figure 12. Moderate curve average vertical rail head wear rates, for baseline and top-of-rail friction modified conditions. Gauge face wear has been eliminated.

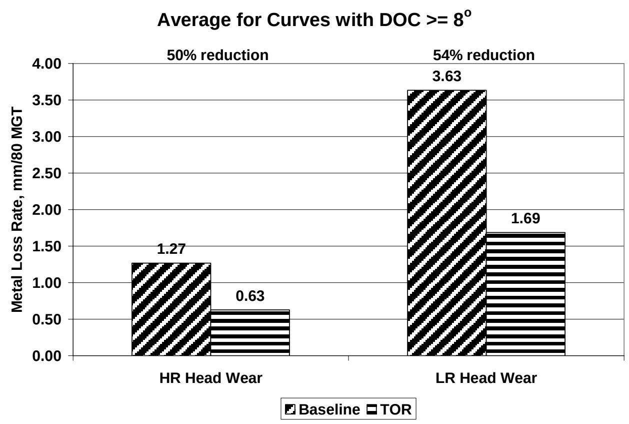

Figure 13. Sharp curve average vertical rail head wear rates, for baseline and top-of-rail friction modified conditions. Gauge face wear has been eliminated.

The reduction in lateral loads on both the high and low rail can produce a substantial reduction in the stress state of the wheel and rail system. Lateral forces are significantly higher with gauge face lubrication as compared to TOR and gauge face friction control, as shown in Figures 15 and 16. Reduced lateral forces will increase sleeper and rail fastening life.

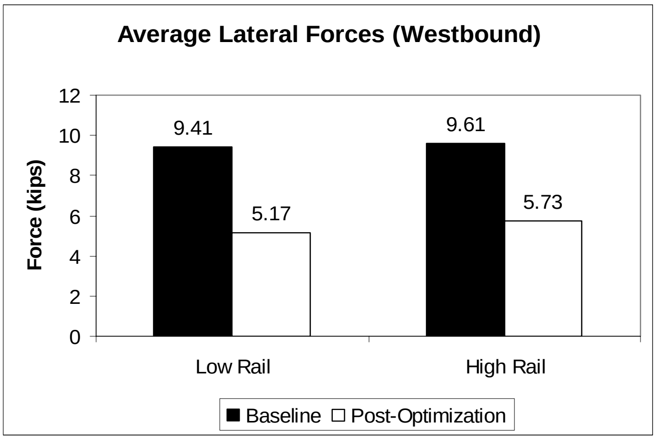

Figure 14. Lateral force reductions at L/V site (MP 11.95) after optimisation rollout to the 80 km (50 mile) test area.

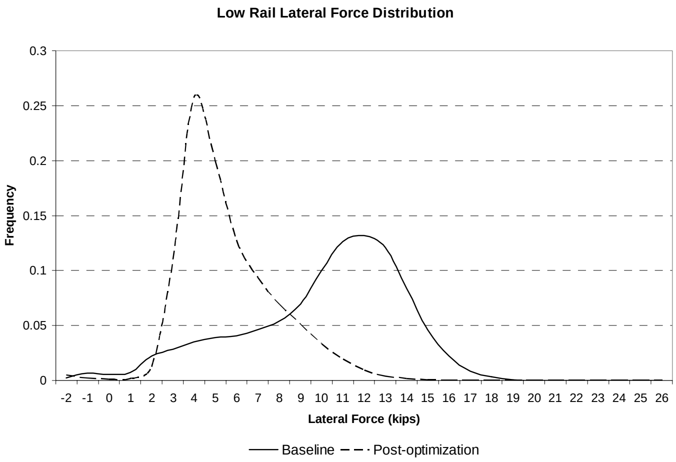

Figure 15. Lateral force distribution at L/V site (MP 11.95) after optimisation rollout to the 80 km (50 mile) test area shows the low rail lateral force distribution has been shifted to the left.

An analysis of all trains in the data base for L/V ratios was carried out for the various friction management strategies tested in the Thompson Subdivision. The results are shown in Figure 17.

The highest incidence of L/V ratios exceeding 0.5 was experienced with the baseline case using gauge face lubricators only. When the gauge face lubricators were turned off and the post optimization rollout condition (TOR5) left on, the L/V distribution showed the lowest peaks in L/V ratios. Lower L/V ratios with "100% effective friction management" will improve the safety of track with less risk of wheel climb derailments. Also CPR found that with TOR friction management the gauge face lubricators could now use the lower optimised lubricator settings and therefore do not need to be turned off during ultrasonic inspections.

4.3 Fuel Savings

Kelsan's recommended practice for estimating fuel savings resulting from top of rail friction control is based on extensive experimental work that was conducted to evaluate the reduction of Greenhouse Gas (GHG) emissions at

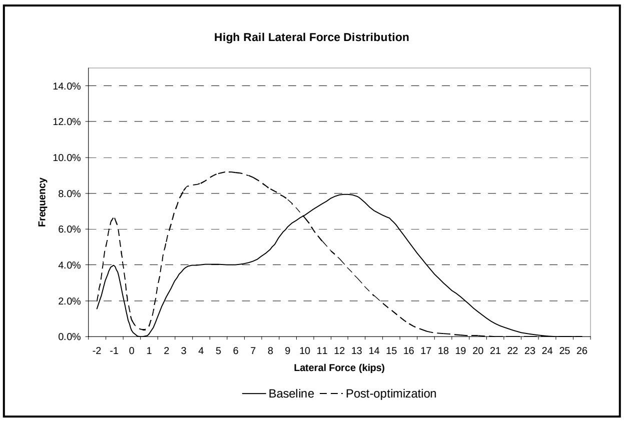

Figure 16. Lateral force distribution at L/V site (MP 11.95) after optimisation rollout to the 80 km (50 mile) test area shows the high rail lateral force distribution has been shifted to the left.

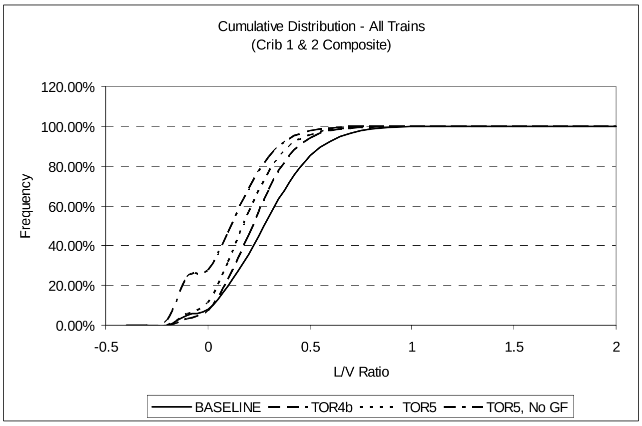

Figure 17. Cumulative distribution for L/V for all trains in the analysis for gauge face lubrication, pre- and post-optimisation of TOR units and no gauge face lubrication.

British Columbia Railway [7]. This work established a correlation between percentage curve density and specific fuel savings measured in litres/MTM (MTM = Million Ton-Miles) when top of rail friction modifier was used on the rail, as shown in Figure 18.

The effects of grades are also included in the work through the filtering of data based on Dynamic Braking (DB) conditions.

Basic steps in estimating fuel savings are as follows:

1. Determine the percentage curve density in the treated area.
2. Identify sections where DB is used and filter these from the data.
3. Determine the specific fuel savings based on the correlation shown in Figure 18.
4. Calculate the traffic level (measured in MTM/year) in the DB-filtered area and the corresponding fuel savings (in L/year).
5. A significant number of frame-braced bogies are used in the Thompson Subdivision. These bogies are outfitted with rubberized bearing adaptors and

are capable of successfully steering through sharper curves than the conventional 3 piece bogies. This self-steering action dramatically reduces the curving resistance and must therefore be accounted for in estimates of fuel savings. In order to do this, the curve density was conservatively recalculated for self-steering bogies, with all curves of curvature shallower than 350 m (5 degrees) being treated as tangents.

Using the methodology described above, estimates indicate that fuel savings generated through TOR implementation in the 80 km (50 mile) test zone correspond to between 1% and 3% of the total fuel consumed in the subdivision (based on sample data from the CPR proprietary ERRAP fuel efficiency program). It can be expected that TOR application throughout the subdivision would result in further savings.

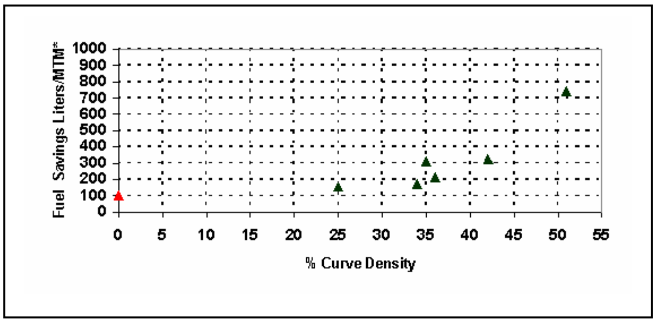

Figure 18. Correlation between % Curve Density and Specific Fuel Savings established in GHG reduction study [7]

4.4 Reduced Use of Petroleum Based Lubricants

Friction modifiers are typically more expensive than conventional curve grease however their use allows a reduction in the quantity of curve grease used. CPR has deliberately used settings of ¼ second every 8 wheels (0.48 L/1000 axles) on their gauge face lubricators to assist with the contamination of the top of the rail and therefore reduce lateral forces. With the introduction of TOR equipment CPR has turned down the lubricators to ¼ second every 16 wheels (0.34 L/1000 axles). Preliminary results show that one gauge face lubricator could be turned off in the intensive sub-zone between MP 7.8 and MP 18.9 due to better lubricant carry with top of rail friction management. In 2005 CSTT will review the 80 km (50 mile) test area to see if fewer lubricators are needed with this strategy.

5. CONCLUSIONS

In controlled tests on CPR's high curvature Thompson Subdivision, CPR, CSTT, Kelsan and Portec implemented an optimised "100% effective friction management" strategy. The addition of a top of rail friction management program to the previously optimised "100% effective gauge face lubrication" strategy resulted in a large reduction in vertical wear from the high and low rail in curves in all curvature ranges, as well as substantial reductions in lateral forces, L/V values, and petroleum based lubricant consumption from existing gauge face lubricators. Savings in locomotive fuel consumption are also expected, based on extensive testing on another similar railroad.

CPR believes the reduction in lateral forces will contribute to significant savings in the prevention of rail fastener failures as well as tie replacement costs.

It is concluded that proper implementation of "100% effective friction management" systems can reap substantial benefits in high curvature territories. This involves optimising the spacing of lubricators and top of rail friction units to maintain a coefficient of friction of less than 0.25 on the rail gauge face and to have measured reductions in lateral forces. The use of a dedicated maintainer was found to provide the best maintenance solution to sustain the benefits. The use of TOR friction modifiers supplementing conventional but optimised gauge face lubrication processes reduces the "stress state" of the System, and can substitute for more expensive capital upgrades that would be required to support CPR increasing tonnage levels.

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References

(1) Sroba, P. et al., "**Canadian Pacific Railway's 100% Effective Lubrication Initiative"** AREMA, Chicago, ILL, September 9, 2001.
(2) Roney, M., "**CPR boosts ADHESION with 100% Effective Friction Control"**, Railway Gazette International, March, 2004.
(3) Bowman, R. Blank, R. Drake, T., **"Adapting track maintenance practices for heavy haul on Norfolk Southern"**, Proceedings IHHA Specialist Technical Session on Implementation of Heavy Haul Technology for Network Efficiency, pp 19-4.25, Dallas, 2003.
(4) Reiff, R. and Gage, S., **"Evaluation of Three Top of Rail Lubrication Systems"**, TTCI report No. R-936, December 1999
(5) Reiff, R. Robeda, J. Gage, S., **"Controlling Friction with Wayside Top of Rail Applicators"**, TTCI Report O-02-001, May 2002.
(6) Eadie, T. Vidler, B Hooper, N., **"Top of rail Friction Control: Lateral Force and Rail Wear in a Freight Application"** Proceedings IHHA Conference, Dallas, 2003.
(7) Cotter, J. et al., **"Utilization of Top of Rail Friction Modifiers to Reduce Greenhouse Gas Emissions for the Freight Railroad Industry"**, Final Report Prepared for Transport Canada, 2004.