Canadian Pacific Railway's 100% Effective Lubrication Initiative

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ABSTRACT

North American railroads have for many years applied lubrication to the wheel/rail interface to control wheel and rail wear, reduce lateral forces in curves and produce substantial savings in train energy (fuel) consumption. The traditional method of applying lubricant to the rail is through wayside lubricators. In recent years substantial improvements in wayside equipment technology has improved equipment reliability, reduced maintenance requirements, increased the track miles treated by each lubricator and minimised lubricant waste. While wayside systems can provide excellent gauge face protection to the high rail of curves, results on Canadian Pacific Railway (CPR) demonstrate that current wayside systems are unable to reliably provide the recommended fiction levels for the top of the rail. Wayside systems must be supported by other technologies, such as on-board systems, hi-rail applicators or innovative wayside systems to provide effective top of rail friction management. CPR's experience in developing and implementing 'best-practice friction management guidelines' are provided in this paper.

1   Introduction

CPR operates a coast to coast, 15,000 mile railway between Vancouver on the west coast of Canada to New York on the east coast of the USA. Some of the toughest railroading in the world is experienced on the western coal route between the mines in southern British Columbia and Vancouver, where unit trains with payloads of 14,500 tons (13,250 metric tonnes), powered by three 4400HP AC traction locomotives, negotiate the steep grades and sharp curves over a 750 mile (1207 km) route. Between Golden and Roberts Bank, the coal traffic joins up with the primary east-west mainline, which carries approximately 80 MGT (73 million gross tonnes) per year.

The route is predominantly single track with 46% of the routing traversing curves tighter than ½ degree (less than 3492 m radius) and 80 miles (129 km) of curves greater than 6 degrees (less than 312 m radius). Maximum curvature is 11 degrees (170 m radius). Temperature extremes in the Thompson River valley range from 110°F (+43°C) to -30°F (−34°C). The rail in curves of 8 degrees and sharper is predominantly 136 lb/yd 350-390BHN head hardened rail. Ties in curves are 9 ft (274 cm) long hardwood ties on 16 in (41 cm) rolled eccentric plates.

CPR spends a great deal of time and money on wayside lubrication. They were very surprised therefore when an October 1999 run of the Portec hi-rail tribometer (§3.3) revealed the effectiveness of their lubrication program to be poor. CPR commissioned the National Research Council of Canada (NRC) to do a study on the benefits of implementing improved lubrication equipment and a more effective lubricant to a 50-mile test site on the Thompson Subdivision near Kamloops, British Columbia. In March 2000, NRC measured the lubrication effectiveness with the existing 18 hydraulic lubricators in place. In October 2000 the test area was upgraded with eight new Portec electronic lubricators, supplemented by two existing Portec hydraulic lubricators – the remaining higher maintenance, hydraulic lubricators were shut-off. A dedicated lubricator maintainer was appointed for the entire subdivision, to better manage the lubrication process. The lubricant selected for the trial (Shell Cadura Plus) was based on: performance characteristics measured in laboratory tests, tests conducted in the Nipigon Subdivision, and a financial analysis by CPR. At the same time, CPR was using LEADER® Systems technology from New York Air Brake on two of their unit coal trains. Leader measures, in real time, the fuel consumption of the locomotives, located via GPS on the coal route. The fuel consumed by the two test trains was monitored from August 2000 to April 2001, before and after the upgrade in lubrication strategy.

2   Friction Management

Friction Management is the process of controlling the frictional properties at the rail/wheel contact to values that are most appropriate for the particular operating conditions [1], [3]. In general terms, the goals are:

- Lubrication of the gauge face of the rail to minimise friction, wear and curving resistance (μ between 0.1 and 0.25).
- Provide an intermediate friction coefficient (μ between 0.30 and 0.35) at the top of the rail under trailing cars, to control lateral forces in curves and rolling resistance in both curved and tangent track. A special class of products is generally required to achieve the intermediate friction conditions [2, 3, 4] - lubricants are generally not suitable since they compromise locomotive traction and safe braking of trains.
- Improve traction under driven locomotive wheels (and possibly under emergency braking situations) through the application of adhesion enhancers. Sand is most commonly used to

improve adhesion but other products including alumina [as used on Japanese high speed] and solid stick products [5] are also used.

3 Wayside Lubrication – Capabilities and Operation

Wayside lubrication systems have the potential to provide substantial savings to railroads through reduced wheel and rail wear, minimised track deterioration and reduced fuel consumption. The performance of lubricant in the track can vary widely depending on the climate, track characteristics, traffic type and operating patterns, the dispensing equipment utilised for the task, the type of lubricant being used, and lubricator maintenance practices. Proper application includes:

- Selection of the most appropriate equipment for dispensing lubricant
- Selection of the optimal type of lubricant for the particular operating environment
- Measurement and management of lubrication effectiveness
- Optimal positioning of lubricators, including the development of a practical lubricator placement model
- Proper maintenance to ensure that lubricators are always filled and working

CPR's implementation of optimum lubrication practices was supported by field and laboratory investigations conducted by engineering staff from NRC.

3.1 Selecting the Most Appropriate Equipment for Dispensing the Lubricant

The selection of the optimal type of lubricant for field trials on CPR was achieved through laboratory simulation to measure the performance of candidate lubricants against the key performance characteristics described in Section 3.2. Field trials were required to determine the suitability of the lubricant and the lubricator hardware for the territory. New equipment technology has greatly improved wayside lubrication effectiveness. Overall the choice of the best lubricator system for CPR was determined using the following criteria:

- Ease of installation and simplicity of operation
- Reliability of performance and ease of maintenance
- Availability of spare parts
- Availability of lubricant to be used

- Financial considerations

NRC undertook a worldwide literature review of the current lubricator technology to determine the best systems for CPR to employ in their track. The majority of wayside equipment in service today utilise a mechanical contact or hydraulic activation system in which wheels impact a plunger that in turn drives a motor. Experience on CPR shows that these systems have a history of high maintenance requirements, and do not activate effectively at low train speeds. The newer technology lubricators 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. Control box settings can be adjusted to regulate the volume of lubricant dispensed based on the number of wheels travelling through the site, minimising lubricant waste "fling-off" from the wheels. The lubricator can also be turned on/off remotely by the section crew to facilitate ultrasonic inspection throughout the territory without the operator having to leave the vehicle. The objective is to minimise lubricant consumption and the number of lubricators necessary to achieve the desired gauge face coefficient of friction through optimal placement of the hardware and to ensure its proper adjustment. NRC determined from tests in the Thompson subdivision that the new electronic lubricators dispense 48% less lubricant to cover the same distance of track per year as compared to the standard hydraulic lubricators. Also, considerably less time is spent maintaining the new lubricators.

The wayside lubricator wiping bars vary in length from 24 in (61 cm) with eighteen lubricant ports to 55 in (140 cm) with forty-eight lubricant ports. The longer bars can dispense lubricant over the entire circumference of the wheel. Usually two bars per rail are installed in a tangent location, preferably adjacent to low and medium curvatures (less than 3 degrees curvature), allowing the lubricant to carry for greater distances. NRC tests on CPR determined that the longer bars dispensed 36% less lubricant than the short bars to achieve the same effective distance of gauge face coverage. Reiff [3] reports that Norfolk Southern Railway introduced longer and improved lubricator bars and found a 107% improvement in lubricant carrying distance for gauge face protection, a 67% reduction in lubricant consumption, and a 57% reduction in lubricant wastage. Improvements in lubricator efficiency reduced the number of lubricators from forty-nine to twenty in an 80-mile mountainous territory. Train stalls were also completely eliminated.

CPR has found that the use of long bars and Shell Cadura Plus lubricant must be diligently managed. Any lubricator shutdown may cause the ports to plug. The shorter bars, however, are easier to manage as they have less tendency to plug.

New state-of-the-art electronic lubricators were purchased from Portec Rail Products (Canada) for trial in the Thompson Subdivision. Eight units were installed to replace sixteen existing (non-Portec) hydraulic units. Two Portec hydraulic lubricators were retained in the test area. Of the eight electronic units installed, seven were solar powered and the last was connected to the local power supply available at a signal location.

Initial operational problems occurred with the solar powered equipment due to short days, poor solar incidence angle between December to February and the siting of the lubricators in the narrow cuttings along the Thompson River. The power requirements for the units exceeded the power generated by the solar panels. CPR used replacement batteries as a temporary solution.

CPR has successfully used a dedicated lubricator maintainer in northern Ontario for many years. CPR now employs a full-time lubricator maintainer in the 120 mile Thompson Subdivision and finds this greatly improves the reliability and efficiency of the lubrication program. This practice ensures that lubricant is on the rail all the time to reduce rail/wheel wear and locomotive fuel consumption.

3.2 Selecting the Optimal Type of Lubricant for the Particular Operating Environment

The rail/wheel contact occurs over a dime-sized patch and is macroscopic when compared with the thickness of the lubricant film. At the wheel/rail interface, the lubricating constituents (e.g. graphite or moly) are taken into the interface along with the carrier (e.g. soaps) to provide the final performance. Laboratory wheel/rail simulations, using full-sized and smaller scale test rigs, have proven effective in evaluating the comparative performance of various lubricants at the wheel/rail interface. CPR commissioned NRC to test various commercially available lubricants from several manufacturers, with the objective of determining the optimal lubricant for CPR conditions [13}. These tests eliminated the necessity for expensive field testing of different lubricants.

The three key characteristics of lubricants that impact performance in wayside systems are:

1. **Lubricity** refers to the lubricant's capacity to reduce friction, with poor lubricity corresponding to higher wear rates. As most lubricants available can provide a friction value of less than 0.25, lubricity is rarely a deciding factor. Since the rates of wear under "dry" conditions are orders of magnitude greater than those under lubricated conditions, the key to effective lubrication is ensuring that there is lubricant where needed at the wheel flange/rail gauge face.

2. **Retentivity** is a measure of the time (or number of wheel passes, or MGT) that the lubricant is able to retain its lubricity. Laboratory tests show that retentivity decreases with increasing load and increasing lateral creepage (angle of attack). The practical implication of this is that loaded trains consume ("burn") lubricant at a much higher rate than empties, and that lubricant is consumed much faster in sharp curves than in mild curves. Also the CPR frame braced trucks on the coal fleet burn less lubricant in curves up to five degrees.

3. **Pumpability** is the continuous delivery of lubricant to the wheel/rail interface. The importance of maintaining a build-up of lubricant cannot be over-emphasised. Ensuring that lubricators are not allowed to go dry or to be shut down for extended periods of time is a key factor. Additionally, preventing gauge face wear in curves depends greatly on their ability to be pumped at all temperatures experienced on the railway system. For example: on the Canadian Pacific, the operating temperature range is –34° to +43° Celsius. Testing of the lubricant in a cold chamber at a temperature of –40°C showed that the lubricant became stiff, while at a hotter temperature of about +60°C, the lubricant tended to separate and slump from the rail.

CPR selected Shell Cadura Plus [13], which exhibited high retentivity, good gauge-face lubricity, suitability for summer and winter operation in their northern climates, and was available in Canada at a reasonable cost. CPR tested this lubricant in the Nipigon Subdivision with the existing hydraulic lubricators, and found savings by reducing the number of lubricators in the subdivision.

3.3 Measurement and Management of Lubrication Effectiveness

In October 1999, the Portec Hi-Rail tribometer (Figure 1A) was run over the CPR System. Covering

Figure 1: A) Portec hi-rail mounted tribometer used on CPR

Figure 1: B) Hand operated tribometer used on CPR. The Portec solar-powered, electronic lubricator is shown in the background

large sections of track at speeds of up to 30 mph, data were collected simultaneously from the top and gauge corner of both rails. Figure 2 shows the measured coefficient of friction over a 50-mile section of the Thompson Subdivision. At that time eighteen hydraulic lubricators were used in this section of track. Even though the section crews spent considerable time maintaining these lubricators, the lubrication practice was clearly not effective.

CPR has adopted best-practice targets as part of a strategy to improve and better manage the lubrication process. The coefficient of friction guidelines adopted by CPR for lubrication management [3] are as follows:

- Maintain top of rail friction coefficient differential, left to right $< 0.1\mu$
- Top of Rail friction $0.3 \leq (\mu) \leq 0.35$
- Gauge face of high rail coefficient $(\mu) \leq 0.25$

The Thompson Subdivision between milepost 10 and 14.5 consists of a series of back-to-back sharp curves of up to 11 degrees in curvature. In March 2000, NRC measured the lubrication effectiveness using a hand-operated tribometer (Figure 1B) with the original mechanical and hydraulic lubricators in place. The results, summarised in Figure 3, show that in most places, the gauge-face friction coefficient is greater than 0.3.

In October 2000, CPR installed eight new Portec electronic lubricators with two existing hydraulic lubricators and a new lubricant, Shell Cadura Plus, in this 50 miles of track. A dedicated lubricator maintainer was appointed for the entire subdivision. Initial settings for all lubricators was ½ second of pumping of lubricant every four wheels. The objective was to ensure a thick coating for the high rail gauge corner and to contaminate the top of the rail to achieve the specified friction levels. That same month, the Portec hi-rail tribometer was run over the test section to verify the improvement in gauge face lubrication (Figure 4). In December 2000, NRC measured the lubrication effectiveness (Figure 5) using the hand-operated tribometer. Note that when the conversion factor is applied to compare the hirail mounted system to the hand held system, the results for the gauge face coefficient of friction is within the desired range. This demonstrates the improved gauge-face lubrication achieved between milepost 10 and 14.5 and is representative of the 50 mile section. The coefficient of friction on the gauge corner is less than 0.2. Previously three hydraulic lubricators were used in this section of track and now there are two. Note that although the target top-of-rail friction coefficient was achieved at the left side of the graph (west end of the test site) by using the high contamination setting, i.e., over-pumping lubricant, the top of rail is dried down by directional traffic moving west to east. Considerable wastage of lubricant was present at each lubricator site and therefore the lubricator tanks had to be filled each week with 400-lb of lubricant. The new systems were doing an excellent job of controlling the gauge face friction however, the wayside system was unable to control the top-of-rail friction. Even so, rail wear measurements determined that significant savings were being achieved over the past practice (§ 4.1).

NRC then determined the lubricator settings that would result in minimal wastage of lubricant at the site. This setting was found to be ¼ second every
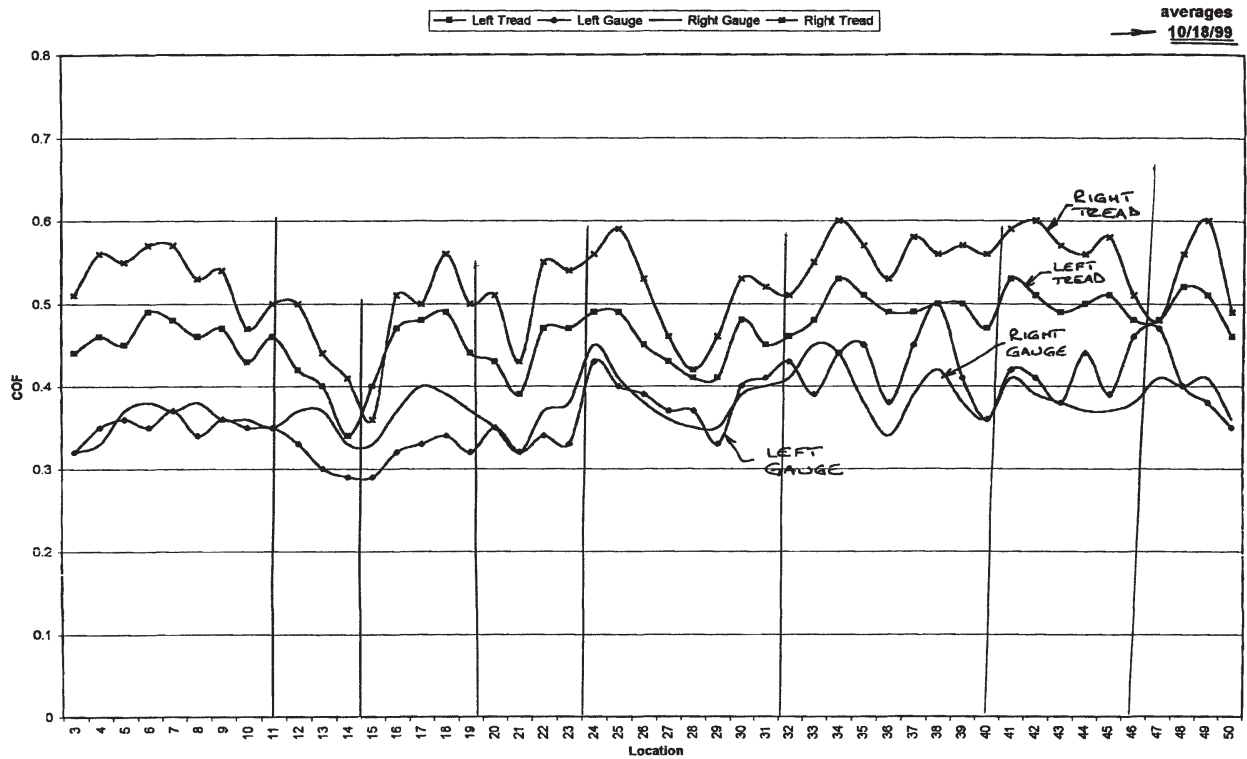
Figure 2: Friction data from the hi-rail tribometer on Canadian Pacific Thompson Subdivision between milepost 0 and 50 October 1999
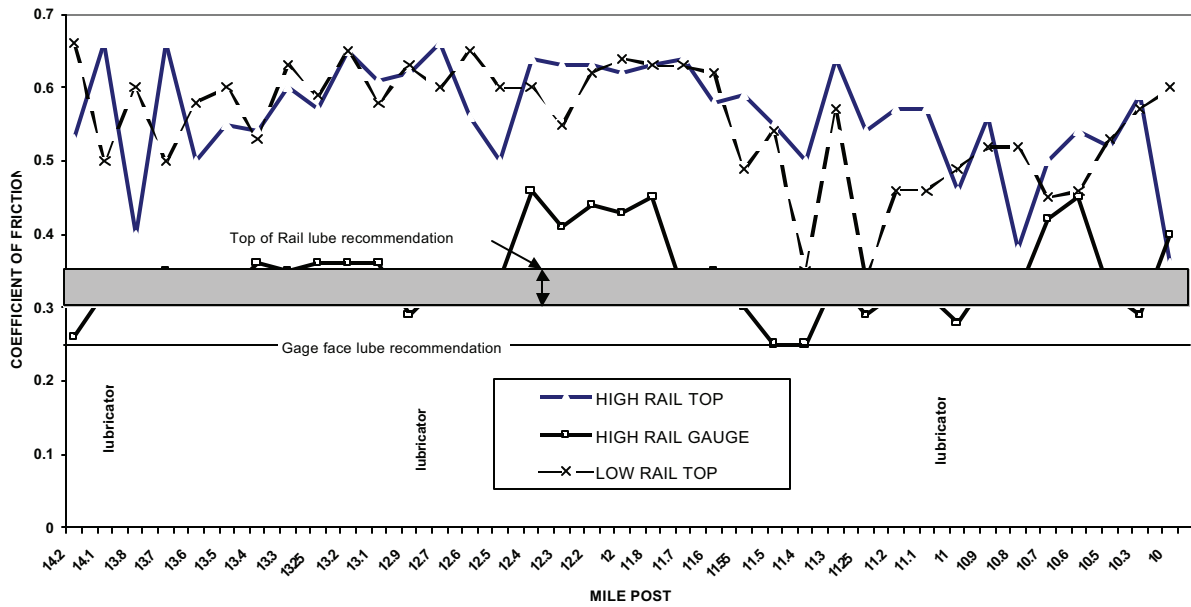

Figure 3: Friction data obtained from the hand operated tribometer on Canadian Pacific Thompson Subdivision in March 2000, between milepost 10 and 14.5
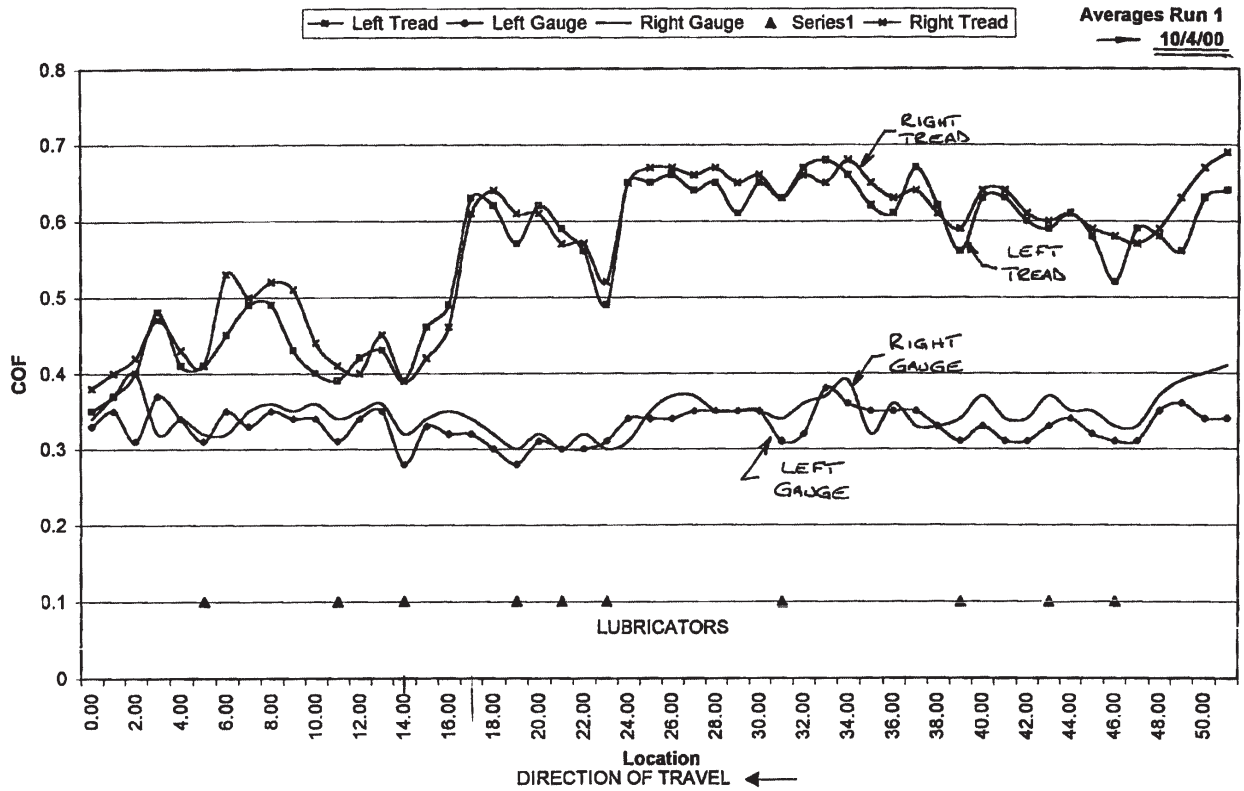
Figure 4: Friction data from the hi-rail tribometer on Canadian Pacific Thompson Subdivision between milepost 0 and 50 in October 2000
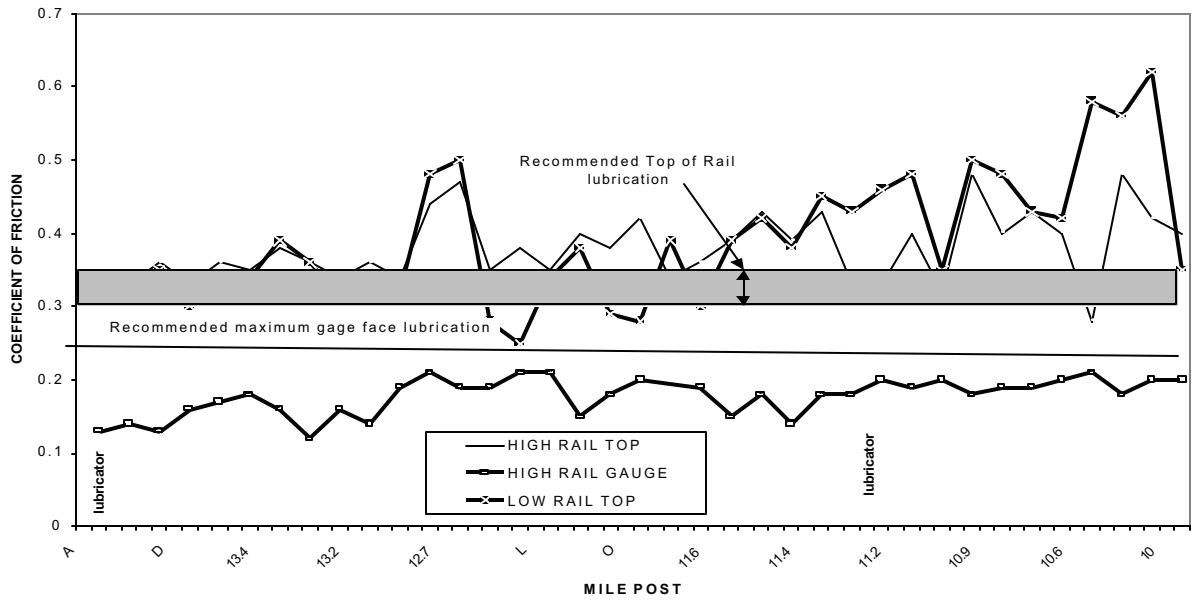

Figure 5: Friction data obtained from the hand operated tribometer on Canadian Pacific Thompson Subdivision, between milepost 10 and 14.5 in December 2000

sixteen wheels. This setting achieved the target gauge face friction coefficient (μ<0.25), however the top of rail coefficient of friction increased to between 0.5 and 0.6. The top of rail wear increased significantly. The lubricators have been temporarily reset to ¼ second every eight wheels to increase the top-of-rail contamination and reduce the lateral forces until a better solution is found. At this setting, the lubricant bead is splashed onto the rail surface by the passing wheels.

Although the top-of-rail friction targets are not being achieved today, CPR is continuing to investigate strategies in the near future (§6). Lubricators are being continuously evaluated, adjusted and fine-tuned to provide the optimal placement and optimal settings.

4   Benefits of Effective Rail Lubrication

Benefits from effective wheel and rail lubrication have been reported in many recent studies with wayside lubricators and top of rail friction modifiers. Some of the benefits of effective lubrication have been reported as follows:

- J.deKoker [6] reports on tests on Spoornet in South Africa which have demonstrated 51% reduced energy required to traverse a 8.7 degree (200 metre radius) curve, 28% less energy used by trains on the Richards Bay Coal Line, and a 6 fold increase in wheel life.

- J.deKoker [6] reports lubrication studies by Sante Fe, Conrail and ICG Railroads where energy savings of 25% to 30%, 24% and 17.5% respectively were achieved.

- Reiff [7] documents the reductions in fuel consumption at FAST of 30% with generous lubrication compared to dry conditions. Numerous lubrication tests in the field on Class 1 railroads with long tangents, sharp curves and grades have demonstrated fuel savings of 5% to 15%. A lubricated top of low rail and generous high rail gauge face lubrication also significantly reduces curve lateral forces.

- TTCI [9] NUCARS analysis demonstrated energy savings of: 15% with wayside lubricators, 39% with Top of Rail friction modifiers alone and 65.5% with top of rail and good wheel flange (gauge face) lubrication.

- J.Rucinski [8] Queensland Rail reports energy savings on their narrow gauge coal lines of 4.3% for loaded trains and 1.4% for empty trains.

4.1   Improvements in Rail Life on CPR

CPR selected one of the toughest operating environments in their System, the Thompson Subdivision, to test lubrication management and assess the benefits. Between March 2000 and May 2001, NRC monitored rail wear using a Miniprof® profilometer on twelve curves between mile posts 12 and 14.2, with curvatures varying from 4.5 to 11 degrees. Readings were taken before and after each 25 MGT grinding cycle. The lubricators were set at ½ second on every four wheels. There was substantial waste of lubricant at each site.

Figure 6 shows the changes in rail wear over 80 MGT (73 mgt) for three different lubrication strategies and the influence of various lubrication strategies on three curve classes - less than 5 degrees, 5 to 8 degrees, and greater than 8 degrees. All are in the Thompson Subdivision between milepost 12 and 14.2 and represent base case, top-of-rail contamination and gauge face only lubricated.

In Figures 6 the first three bars of each graph show the base case of the old hydraulic systems. The next three bars show the new electronic lubrication results with top of rail contamination. The next (last) three bars show the new electronic lubricators turned down to provide optimal gauge face lubrication and no top of rail contamination.

Improved wayside lubrication along with some top-of-rail contamination reduced gauge face wear by 87% on all sharp curves. Not achieving 100% reduction may be attributed to the time required for the lubricant to spread through the system at the start-up of the new lubricators. The top of high-rail wear has been reduced by 41%. The top of low rail wear has increased by 6%.

NRC evaluated the optimal settings of the electronic lubricators in February 2001 and found there was minimal wastage at the setting of ¼ second every sixteen wheels. Monitoring of the top-of-high and top-of-low rail wear rate between February 2001 and May 2001 with this new setting for the lubricators resulted in a significant increase in wear. Compared to the base case, gauge face wear reduced by 100%, top of the high rail wear reduced by 23% and top of low rail wear increased by 39%.

Rail savings with the lubricator set to provide some top of rail contamination for the 50 miles of the Thompson subdivision were $US600,000 ($943,000) in the first year. Over a 4-year period savings are estimated to be $US1.6 million ($2.4 million) in the Thompson subdivision alone. The savings for the CPR System are predicted to be substantial.
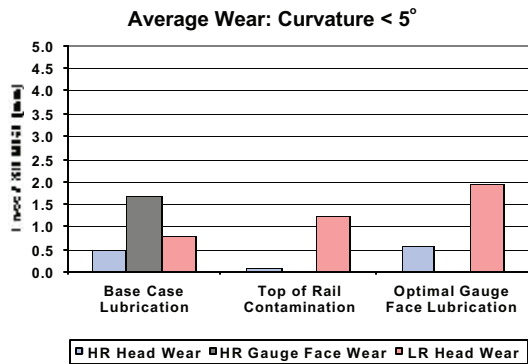
Average Wear: Curvature < 5°

Figure 6: A) wear rates for curves less than 5 degrees

Average Wear: 5° < Curvature < 8°
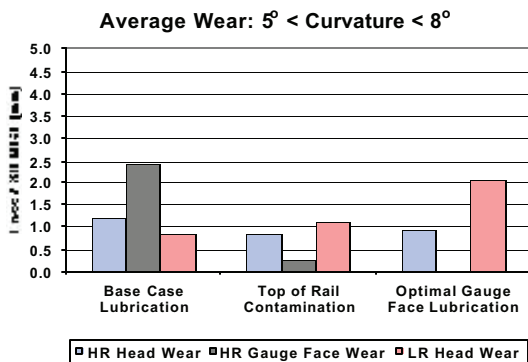

Figure 6: B) wear rates for curves 5 to 8 degrees
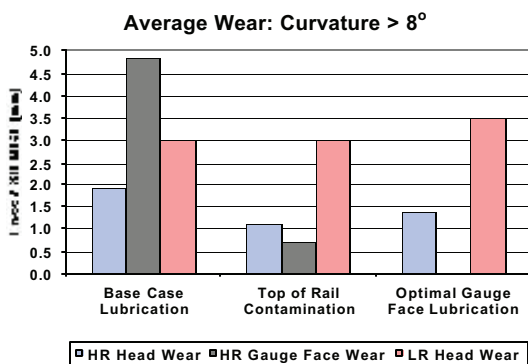
Average Wear: Curvature > 8°

Figure 6: C) wear rates for curves greater than 8 degrees

For the track between Calgary and Vancouver plus the coal line from Golden to the mines in southern BC, the savings attributable to 100% effective gauge face lubrication are estimated to be an impressive $US34 million ($53 million), over a four year period.

Tie savings attributable to reduced lateral forces incurred on spiked track are estimated to be considerable. CPR projects an average increase in tie life of 3 years for every deferred year of rail replacement.

4.2 Reasoning Behind the Increased Top of Rail Wear Due to 100% Effective Gauge Face Lubrication

A positive rolling radius differential is present whenever a wheel flanges against the gauge face of a high rail in a curve. This differential manifests itself as a longitudinal force (in the forward direction) that acts to reduce the angle of attack (AOA) that the wheelset develops in a curve. The magnitude of this force is related to the coefficient of friction on the gauge face of the rail. If the coefficient of friction on the gauge face is very high ($\mu = 0.6$), this longitudinal force will be large and will significantly reduce the AOA of the leading wheelset. If the coefficient of friction is low ($\mu = 0.15$), the magnitude of the force will be small, and it will have a lesser effect on AOA reduction (i.e., it will manifest itself as an AOA "increase").

An increased angle of attack causes the slip vector at the top of rail to increase in magnitude. The effect of this is to increase the amount of "rubbing" that takes place in the wheel-rail contact patch. Two phenomena occur as a result of the enhanced rubbing (caused by the increase in AOA):

1. Contaminants on the top of rail are displaced out of the contact patch, at a rate proportional to the AOA.

2. More iron oxides are generated on the top of rail, at a rate proportional to the AOA.

Contaminants can be any type of carbon-based material, such as excess lubricant, diesel oil, coal dust, leaves or pine needles. They serve to reduce the coefficient of friction on the top of rail, which reduces the rate of wear. If they are displaced from the contact patch, the top of rail wear rate increases. Iron oxides have high coefficients of friction ($0.6 < \mu < 0.7$), and their presence leads to increased top of rail wear rates.

Therefore, if the AOA is not large (i.e., poor gauge face lubrication), the contaminants on the top of rail last longer and the generation of iron oxides is reduced. The net result is that the average peak of the adhesion curve is located between a μ of 0.3 and 0.4. If the angle of attack is large (i.e., good gauge face lubrication), the contaminants are removed more quickly and the rate of iron oxide generation increases. The outcome of this situation is that the average peak of the adhesion curve is elevated to a μ of approximately 0.6. The increase in the peak of the adhesion curve is responsible for the increased top of rail wear.

4.3 Savings Due to Improved Fuel Efficiency

New York Air Brake deployed two coal trains equipped with LEADER® Systems to measure and capture operational data in the CPR Coal route. Included in the analysis of this data is a partitioning of energy use into categories including curve resistance and rolling resistance. Curve resistance (Table 1) in the Thompson Subdivision was reduced by 44% on the 50-mile section with the upgraded lubrication systems. There was a slight increase in tangent resistance due to more precise lubrication with the new systems. Extrapolation of these improvements to the 750-mile coal route gives an overall saving of 5.7%. The annual fuel saving for Vancouver to Calgary plus the coal line south of Golden to southern BC is estimated to be $US 2.2 million ($3.5 million) per year. Further savings in fuel are envisaged with improved top of rail friction management

Table 1 : Fuel saving as measured by Leader for the period August 2000 to February 2001.

(In Imperial Gallons)	Curve Resistance Fuel	Rolling Resistance Fuel
Pre-Lubrication Period	70	107
Post Lubrication Period	39	119
Difference	-31	11
% Difference	-44%	11%

4.4 Savings Due to Improved Lubricator Efficiency

The replacement of eighteen old style hydraulic lubricators using an ineffective lubricant, with the new Portec electronic lubricators with a higher performance lubricant, has produced savings of $US64,000 ($100,000) in the first year. This includes the annual cost of purchasing, installing, lubricant use, and maintaining the new systems. The operational savings each year, after the first year, is estimated to be $US105,000 ($165,000). The installation of these lubricators on the CPR System is economically justified.

Further savings can be achieved by improving top of rail friction management. Lateral forces can be reduced by controlling the top of rail friction coefficient to the recommended range of 0.3 to 0.35. With good gauge-face and top-of-rail friction management, benefits have been quantified as follows:

- Further increase in energy savings over wayside lubrication alone
- Reduced lateral loads over wayside lubrication
- Reduced vertical wear on the top of the rail
- Reduced track damage through reduced lateral loads
- Improved train handling/throttle changes

At present CPR is dispensing more lubricant than necessary to provide some contamination to the top-of-the-rail. However, new hi-rail, wayside and on-board locomotive systems with advanced friction control products are being considered as a means to control "top of rail" friction.

5 Considerations for Lubricator Positioning

There is a great diversity in railway operations worldwide. Some of the differences include curve radii, tangent lengths, track gradients, traffic type and wear state, train speed and braking requirements, axle loads, rail types, rail grinding strategies, climate, etc. All these factors influence the migration and retentivity of the lubricant on the rail. NRC researched the latest knowledge of optimal placement of lubricators for CPR to help optimise their lubrication management strategy.

Controlled in-field testing by NRC is being undertaken on CP to establish the reliability and efficiency of wayside lubricators. Many factors are being considered, including:

- The wastage associated with fling-off and build-up on the top-of-rail
- The rate of lubricant burn-off with the passage of trains
- The length of track treated effectively by each lubricator
- The pumpability of the lubricant at all temperature ranges
- The vulnerability to lubricator port plugging
- The rate of lubricant wash from the rail by rain and snow
- The ability to maintain a gauge-corner film with approximately $^1/_{20}$th of the contamination to the top-of-rail
- The tendency of lubricants to slump from the gauge-corner at high ambient temperatures
- Other factors, not directly related to the lubricant or the lubricator, such as:
  - rail grinding surface-finish at the gauge corner of the high rail - *deep grinding facets*

should be avoided as they prevent the transfer and spread of lubricant

- variations in track gauge - *should be within* $\pm^1/_{16}$ *inch at the lubricator site*
- the lubricator location - *should be in tangent track and not adjacent to curves sharper than 3 degrees, away from in-track obstructions such as crossings , switches and detectors*
- the tendency for truck hunting at the lubricator site - *must be avoided*
- availability of sunlight throughout the year - *if needed to power solar panels of electronic lubricators*

Tests were conducted on CPR using the electric lubricator at milepost 23.5 and 15.2 in the Thompson Subdivision to determine the optimal setting for reduced lubricant wastage for long and short bars. Lubricators either side of one electric lubricator were turned off for 3 days with average traffic levels of 30 trains per day to eliminate the influence of surrounding lubricators. The lubricator maintainer, trained by the equipment supplier in the operation and maintenance of the new technology electronic lubricators, was made available to assist with the testing program.

In the past the CPR formulae for lubricator placement was based on adding the product of curve body length in feet, times the curvature (including half the transition length) not to exceed 600 feet-degrees. The spacing between lubricators was approximately 2.8 miles (4.5 km) in the Thompson Subdivision.

Spoornet has developed criteria and an equation for positioning wayside lubricators [10]. This approach has been applied to CPR-specific traffic conditions.

5.1 Lubricator Placement Model

The optimal placement of lubricators must consider the influence of numerous factors. In general the length of track being considered for lubrication is adjusted by a number of track related factors. The adjusted length is then divided by a number of traffic related factors to determine the placement increment. The factors known to influence the carry distance of the lubricant will be discussed.

The final formula, as applied to the Thompson Subdivision, is shown below:

$$\frac{(C+S)\times G \times R \times P}{T \times L \times A \times V \times M \times B_R \times B_G}$$

CPR employs lubricators that treat left and right rails simultaneously. It is unlikely that the dual-lubricators could ever be positioned such that the left and right rails both received the proper amount of lubricant to last until the next dual-lubricator was reached on the track. One rail will be over-lubricated, and the other will be under-lubricated.

The terms in this formula have been based on de Koker's [10] descriptions and on field tribometer data, and are explained below. Note the first five terms (in the numerator) relate to the track only. The remaining terms (in the denominator) relate to the traffic on the track.

- C is the length of the curve, including spirals. The longer the curve, the more that wheel flanges are in contact with the gauge face of the high rail, implying the need for more lubricant to be present.

- S is a fraction of the length of tangent sections. Spoornet used 5% of the length of the tangents, to account for flange – gauge face contact due to mild hunting (body sway). On CPR, tangent track in the Thompson Subdivision had an obvious film of lubricant, implying some lateral movement of trains on tangent track. Thus, CPR used a factor of 1.05 to account for this. This length is then equally split between the two curves at either end of the tangent, which has the effect of extending the length of those curves.

- G is a factor which is required if different lubricants are used at various locations on the track. Field-testing would be required in order to rank the lubricants against one another in terms of their effectiveness. CPR was using one lubricant throughout the Thompson test site, so its factor was taken as unity.

- R is a term to include the effect of curve radius. It has been taken as the average degree of curvature of the curve, including the spirals.

- P is a factor to account for different wayside applicator bars. Short bars and long bars are both available, and can be installed with one or two bars per rail. Note: in the NS testing performed by TTCI, the longer bars with more ports were more efficient. During field-testing at CPR, both lengths of bars were found to provide equally effective lubrication, although the shorter bar used more lubricant than the other (possibly due to fling-off of excess lubricant). Consequently, the factor used was unity. If

testing of other applicator bars is performed, their effectiveness could be ranked against the current bars to yield a factor for the equation.

- T is the factor to describe the direction of traffic. If the track has bi-directional traffic the factor is unity. The factor is 2 for uni-directional traffic. CPR frequently will run five or six trains in the same direction before allowing traffic to move in the opposite direction. After three or four loaded freight trains, the coefficient of friction on the gauge face of the rail can rise to unacceptable levels. This factor was set to 2 for the Thompson Subdivision to ensure proper lubrication whenever several trains were run in one direction.

- L describes the effect of the wheelbases of different locomotives. Longer wheelbase units will tend to flange more than those with shorter wheelbases. de Koker recommends using the most common locomotive on the territory as the baseline, and scaling all other units against it in terms of wheelbase and axle load. The most common units that run through the Thompson Subdivision were the 4400 horsepower AC units. Therefore, this factor was left as unity.

- A is the axle load factor. Heavier freight cars will experience higher lateral flange forces, and this axle load term accounts for this. This factor is only for freight cars, not for locomotives.

$$A = 1 + \frac{A_s \times n}{A_M}$$

where A_s is the standard axle load, n is the fraction of vehicles having an axle load that is less than or equal to the standard axle load, and A_M is the maximum axle loading. The axle load factor used for the Thompson Subdivision.was 1.25.

- V is a speed factor, to account for traffic of varying speeds. This factor is difficult to apply unless data for each train's speed through all the segments in the subdivision are available. This factor was set to unity for the Thompson Subdivision.

- M is a factor to account for misaligned bogies (trucks). de Koker cites numbers from various North American railways which indicate that lubricating tangent track results in a significant decrease in rolling resistance. This implies that

misaligned trucks are flanging on tangent track. Therefore, a factor is required to account for this. de Koker recommends a value of up to 1.25. We used 1.23 for the Thompson Subdivision, to account for a small percentage of trucks that could be prone to hunting. This implies that up to a 23% improvement in lubrication effectiveness (i.e., a low μ further away from a lubricator) could be attained by eliminating misaligned trucks.

- B_R is a factor that can account for the effect of train braking in the equation. If a loaded freight train descends a long grade with a moderate to severe brake application, the wheels can become hot enough to burn off the lubricant, or cause it to flow down to the bottom of the gauge face. Increasing this factor above unity implies that the lubricators must be placed closer together, because of severe downgrades. This factor was left at unity for the Thompson Subdivision since no severe braking is required.

- B_G is a bogie factor that was not part of de Koker's equation. It has been included to account for the use of self-steered trucks through the Thompson Subdivision. CPR runs coal traffic as well as other trains through this subdivision, and a large portion of the coal fleet is outfitted with frame bracing and rubberized bearing adapters. This equipment permits the axles to align themselves radially to curves (up to roughly 5°), assuming that the wheel and rail profiles can provide adequate rolling radius difference. Therefore, this factor is set to unity on tangent track and for curves less than 2°, to 1.5 for curves between 2° and 5°, and to 2 for curves greater than 5°. This factor should be modified to include the fraction of cars that have self-steering axles out of all the cars on the subdivision, but that information was not available at the time this paper was written.

These factors are used to calculate the value of the formula (referred to here as the "de Koker number") for each track segment (tangents and curves). The "de Koker number" has units of length times degree of curvature, but it does not represent a "distance" along the track as measured from the lubricator. The μ of the gauge face of each high rail was measured, starting at the first curve from the lubricator, until the μ rose above 0.25. The "de Koker number" was calculated for each curve and tangent between the lubricator and the curve where μ rose to 0.25. These numbers were then summed to yield the total "de

Koker number" between lubricators (the total "de Koker number" for the Thompson Subdivision was 10800). The next lubricator would be positioned in the tangent following the curve where the μ was 0.25, and all subsequent lubricators would be positioned in tangent segments such that the total "de Koker number" between lubricators was 10800.

For the high curvature Thompson Subdivision, this results in an average of 4.5 miles (7.2 km) between lubricators for 100% effective gauge face lubrication. Previously, the lubricators were spaced at 2.8 miles (4.5 km).

The location of the lubricator is a balance between several factors:

- not going over the total "de Koker number"
- locating it on a tangent of suitable length
- locating it between curves of opposite direction
- locating it between curves having mild or shallow curvature
- locating it away from switches, crossings and other areas where alignment irregularities may exist

6 Opportunities for Improvement

CPR is investigating top-of-rail friction management due to recent reports [3, 4, 15] of top-of-rail lubrication's ability to dramatically reduce fuel consumption, lateral track forces and wheel/rail wear. They can also reduce the incidence of skid flats, corrugation, crack initiation and growth, rolling contact fatigue and, in some circumstances, truck hunting. The operating and maintenance challenges associated with lubricating the running surfaces of the rails have not yet been fully overcome and trials are ongoing.

A water-based, HPF liquid friction modifier can be applied to the top of rail behind the last driving wheel of the trailing locomotive, or by high rail or wayside systems. The coefficient of friction is reduced to 0.35 and is maintained throughout the length of the train. The down side of hi-rail application is that limited track time may put greater demand on the retentivity of the friction modifier in order to maintain the benefits between applications. In some cases, top-of-rail friction modifiers can also be applied by wayside applicators. A wayside, top-of-rail approach is currently being utilized to control wheel/rail squeal noise at a number of North American and Japanese transit systems. For example, the Port Authority of Allegheny County in Pittsburgh has reported significant success with this

approach [16]. Trials of wayside systems for heavy haul are ongoing.

There are other operating and track-related benefits associated with the use of top-of-rail friction modifiers, as well. On the operating side, top-of-rail friction modifiers have been shown under test conditions to further reduce fuel consumption by 13% to 28% [3].

Also, these tests show that these friction modifiers significantly reduce lateral forces. These lower lateral forces can be translated into reductions in gauge-widening forces and rail wear. Reduced lateral forces in curves presents opportunities to increase wayside gauge face lubricator spacing and further improving the savings outlined above.

The use of top-of-rail friction modifiers also can mitigate wheel and rail surface damage caused by rolling contact fatigue. While both lubricants and friction modifiers behave similarly in their ability to inhibit crack initiation associated with rolling contact fatigue (the potential for which is lowest when the coefficient of friction is 0.3 or less), friction modifiers provide the added ability to minimize crack growth. Once initiated, cracks propagate (unless removed by grinding or wear). Lubricants, being liquid, tend to pressurize these cracks, causing them to propagate – even at friction levels of 0.3 or less – while friction modifiers, consisting of solids, do not. As a result, friction modifiers help to minimize crack propagation and thereby, control fatigue-initiated wheel shelling, rail gauge-corner cracking and related low and high rail surface damage.

7 Conclusions

In controlled tests in a high curvature territory, CPR identified that older lubricators positioned historically and progressively added over the years were not providing the gauge face friction regime necessary to protect the rail. The application of newer electronically activated lubricators with longer lubricant dispensing bars and a better-engineered lubricant showed a large reduction in rail wear, reduced fuel consumption and reduced maintenance costs.

It is concluded that proper management of gauge face friction can reap substantial benefits for a high curvature territory. This involves spacing lubricators to maintain a constant coefficient of friction of less than 0.25 on the rail gauge face. Elimination of ineffective lubricators and use of dedicated maintainers were found to provide the best maintenance solution to sustain the benefits.

Attempts to control top of rail friction with conventional lubricators were not successful, however top of rail friction has been identified as the next big payoff in cost reduction through 100% effective lubrication.

Acknowledgements

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