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Annual report – Rail curve lubrication best practice for Australian heavy haul lines
Wayside lubrication method is widely used in rail industry for reducing rail–wheel wear. Several approaches have been attempted in the past to select the correct lubricant, lubricator and placement model. However, research on the Australian heavy haul network is limited. This report captures the current practices of the curve lubrication and assesses their effectiveness, based on lubricators, lubricants and placement for developing a best practice for heavy haul lines.
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Executive summary
Proper management of the rail–wheel interface helps the rail industry to reduce wear and fatigue, which results in enhancement of asset life. It helps industry to grow business and improves reliability of service. Wear has a detrimental effect on rail and wheel life, and adds to maintenance costs. Lubrication is considered one of the most effective maintenance programs to reduce wear, energy consumption and noise.

The wayside lubrication method is widely used in the rail industry. Several attempts have been made in the past to select the correct lubricant, lubricator, and placement model. However, research on the Australian heavy haul network is limited. The performance of lubrication on the track can change significantly, depending on the weather conditions, track characteristics, dispensing equipment, type of lubricant and maintenance activities. There is a need for improved understanding of the effect of lubricator performance, applicator bars (short and long bars), and locations of the bar based on track geometry, direction of traffic, lubricants and other important factors. Proper application of wayside lubricators also includes appropriate equipment selection, suitable lubricant for the particular operating condition, measurement and management of the lubrication effectiveness, positioning of lubricators, and maintenance.

Performance of wayside lubrication is generally indicated by carryover. There is a need to develop an effective lubrication strategy combining lubricators, lubricants and placement.

The objective of the research is to capture the current practices of the curve lubrication and assess their effectiveness, based on lubricators, lubricants and placement for a best practice in heavy haul lines. A detailed literature review has been conducted on the current technology and lubricants. Field trials and lab tests have been conducted for data collection and analysis of performance and development of the lubricator placement model.
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Abbreviations and acronyms

AAR   American Association of Railroads
CQU   Central Queensland University
GF    Gauge face
MGT   Million gross tons
QR    Queensland Rail
RCF   Remote performance monitoring
TOR   Top of rail
Introduction
The Australian rail network carries passengers, freight and heavy haul across the country through all types of terrain, and experiences varied climatic conditions. It is one of the most significant driving forces of the Australian economy and commerce. Rail is one of the high capital intensive industries, with long asset life. Proper maintenance and investment have a significant impact on the reliability, availability, maintainability and safety (RAMS) of rail operations. To increase productivity and achieve safety, it is necessary to ensure that existing rail assets are maintained effectively. Total revenue from rail activities grew to $11.3 billion in 2007–08, and turnover grew by $1.5 billion, or 14.9 per cent, between 2004–05 and 2007–08 (www.ara.net.au). According to a rail productivity review in August 2008, in 2005–06, 992.91 million tonnes of freight was carried by rail, representing a 9.6 per cent increase over the 2002–03 freight load of 906.33 million tonnes. Transport of coal and mineral ores comprised 51 per cent and 27 per cent of the total tonnage respectively. Coal and bulk freight delivered by QR Network (QR) in 2007–08 comprised 185 and 56 million tonnes respectively. The growing needs of the industry and commerce led the railway operators to increase the number of trains, number of wagons per train, or the load per wagon, i.e. heavy axle loads. Increase of axle load in heavy haul lines increases the challenges of maintenance due to track deterioration, wear, change of track geometry and derailments, resulting in loss of assets, lives and revenue due to disruption of service. Wear in general and fatigue are major problems in railway infrastructure. Wear is a result of friction between wheel and rail. Gauge side wear in curve for high rail is a common problem (Turner 2008). Wear affects the life and performance of below rail and above rail (wheel) assets. The influential wear factors are: axle loads, lateral forces, longitudinal force, creepage, curve radius, gradient of the track, cant/super elevation, track gauge, surface condition of the wheel and rail, speed, length, frequency and type of trains, rolling stock performance, and operational, maintenance and environmental issues.
1. Background of research

1.1. Overview
Lubrication enhances wheel–rail life by reducing wear. It also reduces energy consumption, noise and risks of derailment. Excessive lubrication has an impact on operating conditions, and could cause rollover, abnormal truck behaviour, top of rail contamination, and reduction of traction and braking capacity. The American Association of Railroads (AAR) estimated that the wear and friction occurring at the wheel–rail interface of trains due to ineffective lubrication costs American railways more than US$2 billion each year (Sid & Wolf 2002). Daniels (2008) reported that, in 2004, more than US$10 billion was spent on rail transit system maintenance in the USA due to poor lubrication. There is a need for better lubrication practice which covers technology, lubricants and placement.

1.2. Scope of research
Wayside lubrication is widely used for its cost-effectiveness and ease in operation. There are many influential factors which impact on the effectiveness of lubrication, for example, length of curve, curve radius, tangent track, lubricant properties, type of applicator bars (short and long), use of single pair or double pair bars, applicator bar height from top of rail, application rate, train direction (bi-directional or uni-directional), locomotive truck wheelbase, axle load, speed, track alignment factor, train braking, bogie type, sanding, gradient, wheel–rail profile, rail–wheel temperature, contamination and climate.

Of the various types of wayside lubricators available in the industry — mechanical, hydraulic and electric — the electric lubricator has the best performance, with improved application accuracy and less lubricant waste. Electric lubricators are more reliable, are used with large tanks, and are able to use remote sensing technology to better plan maintenance based on when and where it is needed.

The placement of wayside lubricators is dependent on bar type (long or short), bar height below the top of the rail, placement in tangent or curve spirals, track gauge at the lubricator site, grease application rates, RCF present on the rail surface, optimal dispensing rates to minimise splash, and effective grease carry distance (coefficient of friction).

Models for lubricator placement have not considered the following important wheel–rail interaction characteristics: wheel and rail temperature, wheel and rail profile, track gauge in curves being lubricated, and the effect of pressure and temperature on the lubricant properties. These factors need to be investigated in future lubricator placement models based on cost-benefit analysis.

1.3. Aims and objectives of the research
The goal of this project is to develop the best practices in wayside lubrication. This will be achieved by developing:

- the method for determining the best lubricant for the track and traffic
- the criteria for the selection of the best lubricator equipment to dispense the best lubricant to the wheels
- the optimal positioning of lubricators
- the optimal dispensing rate for lubricators
- the measurement of lubrication effectiveness
- the cost-effectiveness of the lubricator placement compared to existing railway standards.
The objectives of the project are to:

- survey the current lubrication practices and assess their effectiveness in reduction of rail–wheel wear, energy consumption, rail–wheel maintenance cost and noise
- test and evaluate different types of lubricants, lubricators and applicators and their position to evaluate their effectiveness
- evaluate the impact of different track-related factors, human factors, and environmental and weather conditions on the lubrication’s effectiveness
- develop a practical lubricator placement decision model based on the evaluation of the lubrication effectiveness and cost–benefit analysis
- develop the most cost-effective lubrication strategy and incorporate it into a best practice standard.
2. Rail–wheel wear and lubrication

2.1. Overview
Rail lubrication is a well-known track maintenance practice. A low coefficient of friction is needed between the rail gauge face and wheel flange. An optimum level of friction is needed on the rail surface to maintain proper traction and reduce bogie hunting in the tangent tracks, in addition to reduced friction in the gauge face contact area.

2.2. Wear in rail–wheel interface
In sharp curves, wear becomes more dominant. Level of wear depends on temperature, track geometry, applied force, types of material or material layers, operating speeds and other operating conditions. Predicting wear in railroad applications includes traction, angle of attack and load, where angle of attack has the greatest effect on flange wear (Waara 2001). Danks and Clayton (1987) found three types of wear by using Amsler twin-disk machine wear for the top of the rail and gauge face.

Reiff (1985) investigated the effect of different levels of lubrication on wear rate. From field tests, Rippeth et al. (1996) showed that the life of track sections, originally worn out after 18 months, could be extended by up to four or five years through proper lubrication and rail grinding. Elkins et al. (1984) showed that even moderate levels of lubrication on standard carbon rail had an improvement of a factor of 17 compared to dry rail. For a low level of effectiveness of lubrication, relative improvement is close to a factor of 5.

2.2.1 Wear zones on wheel and rail
The area worn away is defined as the area between the two measured profiles, and is calculated from where the profiles intersect on the rail head to the intersection point with the lower inner flange (Waara 2001). Wear zones on wheel and rail can be seen in Figure 2.1.

Figure 2.1: Wear zones of wheel and rail
(a) Wheel wear zones (Esveld 2001)  (b) Worn rail profile (the area worn away is shaded) — W1, rail head wear; W2, horizontal rail flange wear; W3, gauge corner wear (Waara 2001)

The following figures show the condition of unlubricated worn rail in curves which were recorded in field trips.
Danks and Clayton (1987) analysed three types of wear by using Amsler twin-disk machine. Wear is common on the top of the rail and on the gauge face. According to Waara (2001), four methods can be used to evaluate rail wear:

- comparing the difference in worn and new rail profiles
- comparing the vertical wear on the rail head – W1
- comparing the horizontal wear at a vertical distance, h, from the rail head – W2
- comparing the wear measured at some angle, α, on the rail or gauge corner between two profiles – W3.

The nature of the shape change of the rail and wheel is a function of the wear and material flow caused by various contact conditions, which depend on the track curvature, vehicle alignment, axle load, vehicle speed, vehicle type, traction and braking (Tourney & Mulder 1996).

Povilaitiene and Podagelis (2003) report that curve radius, rail steels, and rail track geometrical parameters such as rail rise and gauge width have significant influence on rail side wearing (intensity of rail side wearing is the size of wearing in mm after every million gross tonnes (MGT)). Curve radius has the greatest influence on side wearing intensity. If the radius of the curve increases from 300 m to 600 m, side wear intensity is decreased by 2.1 to 3.2, and if it is increased from 600 m to 900 m, side wear intensity is decreased by 1.6 to 1.9 (Povilaitiene & Podagelis 2003). The quality of rail steel has a significant effect on the rail side wear. When the curve radius is within 400 m to 600 m, the wear intensity of standard carbon rails is 30 per cent more than that of tempered rails; and when the curve radius is within 800 m to 1000 m, it is 20 per cent more than that of the tempered rails. The variation of gauge width from standard has a significant effect on the rail side wear. For curves from 350 m to 400 m radius, the gauge should not be less than 1526 mm (i.e. 1530 mm, with deviations not more than 4 mm to the inner side). A gauge of 1530 mm instead of 1520 mm can reduce wear by two times.

Povilaitiene, Podagelis and Kamaitis (2006) proposed that the effective standards that regulate the gauge should be specified to reduce wear on curves for different curve radii. The results of the experimental research carried out on Lithuanian railway lines show that widening the gauge on the curves with a radius less than 650 m decreases rail head side wear up to 1.72 times. Sadeghi and Akbari (2006) observed that gauge deficiency is the most influential geometrical factor in rail wear in tangent track and switches. Narrowed gauge increases the lateral wear, and widened gauge increases the vertical wear. Regular track inspections were recommended for controlling track geometrical parameter deficiencies. Highly viscous lubricants were recommended to reduce vertical wear, and higher hardness rail was recommended to decrease switch wear. Knothe and Liebelt (1995) suggested that in sliding contact, temperature increases...
and surface damage can have the major influence on contact temperatures. Thermally induced stress can have a strong influence on the tribological behaviour.

Alp, Erdemir and Kumar (1996) simulated tribological conditions of the rail–wheel interface in a curve to analyse lubricants, and ranked them according to the performance of power consumption, coefficient of friction, sliding distance and duration of lubricant breakdown. In the early stages of sliding contacts, an applied load is transmitted through the interface and/or lubricant film, and gross sliding occurs when the tangential stress exceeds the shear strength of the contact surface. The interface shear strength can be reduced by applying lubricant in the interface. The shear strength of the lubricant film plays an important role in the sliding friction coefficient. When a lubricant is applied to the rubbing surfaces, adhesive forces between contacting asperities is reduced substantially, and the tangential stress becomes small, as the shear strength of the lubricant film is smaller than that of the metal. Friction decreases and load carrying capacity increases with lubrication (Alp, Erdemir & Kumar 1996).

2.3. Methods of rail–wheel lubrication

Different methods of rail lubrication have been developed based on suitability of application and performance requirement. Figure 2.3 shows the three current methods of lubrication:

- wayside lubrication
- onboard lubrication
- high-rail lubrication.

Wayside lubrication is a commonly used method. Grease is applied to the track from a lubricator unit through the applicator bars installed beside the track. Reiff (2006) reported that when curves are concentrated in specific locations, wayside applicators are useful.

Onboard lubrication is a method where the lubricator is mounted on the locomotive, and the lubricant is applied to the locomotive wheel flange. When curves are uniformly distributed, locomotive-mounted applications are more useful.

High-rail lubrication means the lubrication of the line by the controlled application of a bead of grease directly to the wear face of the rail from a vehicle travelling on the track. The high-rail vehicle is usually an adapted delivery vehicle, equipped with a special storage and application system (de Koker 2004).

One or a combination of the above systems is used by rail operators to achieve 100 per cent effective lubrication and significant savings in fuel and wheel–rail maintenance.

Figure 2.3: Three methods of rail–wheel lubrication
2.4 Wayside lubrication

The wayside lubrication method is used for both gauge face application and top of rail application. The whole unit consists of a reservoir tank, grease pump unit, controller, connecting hoses, power supply unit, applicator bars, wheel–axle sensor unit or plunger, and sometimes a telemetry or remote condition monitoring system such as RPM (remote performance monitoring).

2.4.1 Wayside lubricators

There are three types of wayside lubricators available.

Hydraulic lubricators

Hydraulic lubricators are predominantly used in Australian rail networks (Portec RTE-2S lubricators, Australian made, and Portec PW 37.5 lubricators). Figure 2.4 shows the hydraulic lubricator in a wayside application. The main features of hydraulic lubricators are a grease reservoir, grease pump, hydraulic plunger or actuator assembly clamped to the field side of the rail, with a single hydraulic line connected grease pump externally mounted on the grease reservoir, and grease distribution units (applicator bars) and hose system. Hydraulic lubricators are very simple in construction. The grease pump is activated with the hydraulic actuator, and delivers grease to the applicator bars when the wheel strikes the plunger. No power supply is needed from an external source, e.g. electricity or solar power. Grease is delivered by the action of the wheels passing over and depressing a mechanical plunger at the field side of the rail head.

This system has little control over grease delivery rates, and results in substantial amounts of grease delivered by the unit to the bars. This results in grease waste to the track, and contamination of the top of the rail. These units are installed on the high rail side at the transitions to left- and right-hand curves, and therefore have to be removed before each grinding cycle to prevent damage to the units.

Figure 2.4: Hydraulic lubricator (inset – hydraulic plunger)
Mechanical lubricators

Mechanical lubricators (Figure 2.5) are of simple design, and rely on the same principle of operation as the hydraulic units.

Figure 2.5: Mechanical lubricator

It consists of a grease tank, grease delivery pump and grease distribution unit. With the passage of each wheel over the plunger, the ramp lever rotates, and this lever is connected to the pump through the drive shaft. The drive shaft uses the pressure from the wheel impact to pump lubricant to the applicators.

The entire pumping mechanism is housed in the reservoir, and can be removed for servicing. The grease tank can be of different capacities, and applicator bars are also of different sizes. There is no need for an external power supply. No precise control of grease application rate is possible. Due to excessive grease delivery, there is top of the rail contamination and waste to the ballast in the track. RCF can be the result of non-grinding, due to units being left in track each grinding cycle. No remote sensing feature is available.

Electric lubricators

Electric lubricators are the latest generation lubricators, with precise electronic control, based on axle or wheel count via the sensors mounted beside the rail. It consists of a grease reservoir, electronic controller unit, delivery pump, battery or A/C controller, and distribution bars. These are high pressure, positive displacement and positive distribution systems, which are designed to dispense grease on the gauge face or friction modifier to the top of the rail. Lubricators can be used for gauge face and top of rail application. They are available in different specifications of power supply, reservoir size, applicator units and telemetry. Figures 2.6 and 2.7 show electric lubricators with different applicator bars.
Figure 2.6: Electric lubricator in the spiral of a curve on a heavy haul network

Figure 2.7: Lubricators and applicator bars (www.portecrail.com)

The most significant features of the electric lubricator are:

- highly reliable and efficient operation
- application of grease based on the axle-wheel count
- precise control of grease application rate to reduce lubricant wastage
- ability to survive for longer periods in harsh weather
- less total cost of ownership
- flexibility in grease application due to change of conditions
- continuous performance in all weather and seasons
- less maintenance cost and time
- ability of maintenance personnel to plan daily work based on remote condition monitoring of the units
- intelligent condition monitoring unit, able to transfer data to remote authority
- continuous power generation from solar energy or power grid, and rechargeable battery for emergency back-up
- higher capacity tank in most cases.

Electric lubricators rely on solar or electric power.
2.4.2 Lubricant applicator bars

There are two types of applicator bars — short bars and long bars. Lubricant applicator bars are mounted on the gauge face of the rail to deliver lubricant in the gauge corner. Figure 2.8 shows different types of applicator bars installed on the gauge face of the rail. Short bars are generally placed on the high rail in the spiral of a curve. Long bars are suitable to be placed in the tangent track before a curve. Generally, two short bars are installed on the gauge side of high-rail, whereas one or two long bars are installed on each rail. The ideal application should be evaluated based on the effective lubrication carry distance and coverage in the gauge face.

Figure 2.8: Long bars (in tangent) and short bars (in spiral) application

Long bars have advantages over short bars in that they are installed on the tangent track and don’t need to be removed during a curve grinding cycle. Because of placement on the tangent track, they deliver grease on both the high and low rail; and left- and right-hand curve. Long bars apply grease on the greater length of the track, therefore wheels have a better chance to pick up grease. Short bars have to be removed in every grinding cycle and placed back again. During this period, the track remains unlubricated, which can cause severe wear. Severe RCF was seen in the field trip around short bars due to the bars not being removed during the grinding cycle, requiring the grinder to skip that location. Rail not ground for long periods develops severe RCF in heavy haul track.

Short bars apply grease to smaller lengths of track. Generally, two units are needed to cover left- and right-hand curves.

Figure 2.9 shows the gauge side of the high-rail with severe RCF and abrasive wear caused by lubricant contamination on the top of the rail.

Figure 2.9: Severe RCF and abrasive wear on the gauge side in short bar grease application area
Proper placement of applicator bars and their comparative study are essential for effective lubrication. Research needs to be conducted on the design and application of applicator bars. Lubricator and applicator bars are significant elements in lubrication effectiveness. Therefore, improvements in lubricator technology, good lubricants and dedicated maintenance of lubricators are necessary for effective lubrication.

2.4.3 Lubrication transport mechanism
Wheel flange and its contact with rail are used as the lubricant transport mechanism. The success of a lubrication strategy depends on the transport mechanism. According to Thelen and Lovette (1996), lubrication can be successful only if the transport mechanism is handled in an effective manner. Human factors have some impact on the transport mechanism, as with any technical issue.

2.4.4 Factors influencing effective lubrication
Lubrication in the rail–wheel interface is influenced by many factors, including:

- location and placement, including positioning of applicator bar
- lubricator unit, and the ability to adjust the precise application of the lubricant
- properties and composition of lubricants
- rail–wheel temperature
- axle loads, lateral and longitudinal forces, creepage, curve radius and gradient
- speed, frequency and length of trains
- rail–wheel interaction, which may cause grease to be squeezed off the rail at the transition or in sharp curves, and impact on carry distance
- surface roughness
- rail–wheel profile conformity
- track surface irregularities
- management dedication and technical expertise of workforce
- environmental factors.

2.4.5 Issues and recommendations for friction management guidelines
The following issues need to be considered in proper application of wayside lubrication systems:

- selection of most appropriate equipment for dispensing lubricant
- selection of the optimal type of lubricant for the particular operating conditions
- regular measurement and management of the lubrication effectiveness
- evaluation of wear data per certain MGT intervals, and reporting of lubricator performance
- optimal positioning of lubricators for grease pick-up and longer carry distance
- dedicated maintenance and servicing program with effective training
- regular evaluation of program policy, performance of lubricators and lubricants
- regular communication with vendors about product performance and problems.

Severe wear was seen in some curves having a lubricator on site because the lubricator was out of order, the grease tank was empty, or there was poor grease carry in the curve. An investigation of the rail showed it was fairly dry within few metres of lubricator site. Special attention is required for lubricating switches and curves with turnouts. Lubricators should be placed in a suitable location so that the grease can be picked up effectively by the wheel flange. According to Sroba et al. (2001), some selection criteria for appropriate lubricator unit include:

- ease of installation and simplicity of operation
- reliability of performance and easy to maintain
- availability of spare parts
- availability of lubricant to be used
- economic viability
- availability of remote monitoring system.

**Friction management guidelines**

AREMA recommends (Reiff 2006):

- gauge face friction values should be < 0.20
- gauge corner friction value should be < 0.20 which was under review
- top of rail friction value should be 0.35 +/-0.05
- left to right rail friction value differential should be < 0.1.

Canadian Pacific Railway (CPR) suggested (Sroba et al. 2001):

- top of rail friction coefficient differential should be left to right < 0.1
- top of Rail friction coefficient should be 0.3 ≤ μ ≤ 0.35
- gauge face of high rail coefficient of friction should be μ ≤ 0.25.

Tools to measure lubrication effectiveness are:

- tribometer
- lubrication level (Goop) gauge
- instrumented wheel set
- temperature measuring instrumentation.

### 2.4.6 Benefits of lubrication

Train resistance around the curve can be reduced dramatically by lubrication of the rail–wheel flange interface. Successful lubrication can produce enormous benefits for the rail industry by managing friction in the desired level, reducing wear of rail and wheel, improving rail–wheel life, saving energy, reducing noise and reducing maintenance costs. Figure 2.10 shows the benefits of lubrication and friction control in the rail–wheel interface.

![Figure 2.10: Lubrication, friction control and benefits](image)

Reduction in the wheel–rail coefficient of friction reduces the train resistance, leading to significant fuel savings. Effective lubrication must be ensured on both tangents and curves to obtain the highest fuel savings. If only curves are lubricated, the flanging effect of tracks will rapidly dry off wheels on long tangents, and it’s impossible to maintain adequate lubrication between widely separated curves. The study
at FAST produced Table 2.1, which shows the fuel savings when lubrication was used (Sims, Miller and Schepmann 1996).

Reduction in rolling resistance due to rail and wheel flange lubrication of up to 50 per cent around the curves, and up to 30 per cent on straight or tangent track, was measured against unlubricated track in the USA, leading to energy savings of between 20 per cent and 30 per cent under service conditions (de Koker 2004). A good correlation exists between energy saving and rail lubrication. Spoornet conducted a test on a 200 m radius curve in unlubricated and lubricated condition, and calculated the energy consumption. It showed that for an unlubricated curve, the wagons required 54 Newton/ton to traverse the curve, but when lubricated, only 28 Newton/ton, requiring 48 per cent less energy (de Koker 2004). Rail lubrication results in increased tonnage ratings where curves control train composition. In practice, 10 to 20 per cent more wagons can be added to a train if the line is consistently and well lubricated (de Koker 2004). Table 2.1 shows considerable improvement on energy savings with application of different lubricating systems.

Table 2.1: Energy savings comparison of different lubrication applicators (Sims, Miller & Schepmann 1996)

<table>
<thead>
<tr>
<th>Lubricating system</th>
<th>Efficiency (gal/MGT)</th>
<th>Savings over dry rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry rail</td>
<td>6000</td>
<td>n/a</td>
</tr>
<tr>
<td>Wayside lubricator-active</td>
<td>4100</td>
<td>32%</td>
</tr>
<tr>
<td>1-in-4 Lub. Car Graphite</td>
<td>4100</td>
<td>20%</td>
</tr>
<tr>
<td>Low graphite</td>
<td>5300</td>
<td>11%</td>
</tr>
<tr>
<td>Hi-rail vehicle (1-in-35 trains)</td>
<td>5500</td>
<td>8%</td>
</tr>
<tr>
<td>Onboard</td>
<td>5140</td>
<td>14%</td>
</tr>
</tbody>
</table>

Another study on energy consumption performed by AAR found that lubrication can reduce fuel consumption by as much as 5 per cent. This report also suggested that the reduction could be higher if favourable conditions are maintained (Sims, Miller & Schepmann 1996).

Wheel–rail life improvement and cost of lubrication implementation

Lubrication at the wheel–rail interface dramatically reduces the wheel and rail degradation. Rail life has increased by a factor of two and wheel life by a factor of five (Queensland Rail) using appropriate lubrication. Spoornet (South Africa) reported that rail life was increased from 27 MGT to up to 350 MGT, depending on curve radius. HKMTRC (Hong Kong) reported a cost saving of £783,000 per year on wheel and rail maintenance on the solid lubricant lines. Eurostar conservatively estimates savings of £1,000,000 per year on maintenance and wheel replacement costs with effective lubrication (Reddy et al. 2006). Table 2.2 shows the ERL/Malaysia recorded data on improvement of wheel life and of annual wheel cost with lubrication compared to no lubrication.

Table 2.2: Reduction of wheel maintenance due to lubrication (Larke 2003 and Reddy et al. 2006)

<table>
<thead>
<tr>
<th>Track/vehicle condition</th>
<th>Wheel life in (km)</th>
<th>Wheel life in (week)</th>
<th>Annual wheel cost in (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No lubrication</td>
<td>170,000</td>
<td>20</td>
<td>1.6 million</td>
</tr>
<tr>
<td>Rail lubrication</td>
<td>300,000</td>
<td>35</td>
<td>825,000</td>
</tr>
<tr>
<td>Vehicle lubrication</td>
<td>1,000,000</td>
<td>118</td>
<td>250,000</td>
</tr>
<tr>
<td>Target</td>
<td>1,500,000</td>
<td>177</td>
<td>170,000</td>
</tr>
</tbody>
</table>
Compared to rail–wheel life improvement, energy savings and other benefits, the lubrication cost is significantly low. Table 2.3 shows the cost of lubrication in different railway operators around the world.

Table 2.3: Lubrication cost to rail players (adapted from Larke 2003 and Reddy et al. 2006)

<table>
<thead>
<tr>
<th>Railway</th>
<th>Quantity (tonnes/yr)</th>
<th>Lubricator (£/yr)</th>
<th>Lubricant (£/yr)</th>
<th>Cost (£/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoornet</td>
<td>200</td>
<td>125,000</td>
<td>134,000</td>
<td>259,000</td>
</tr>
<tr>
<td>IBCV</td>
<td>Not known</td>
<td>325,000</td>
<td>279,000</td>
<td>604,000</td>
</tr>
<tr>
<td>HKMTR</td>
<td>0.3 (depots)</td>
<td>5.600</td>
<td>550</td>
<td>6,150</td>
</tr>
<tr>
<td>Eurostar</td>
<td>1.1</td>
<td>Not known</td>
<td>Not known</td>
<td>70,000</td>
</tr>
<tr>
<td>Banverket</td>
<td>20</td>
<td>Not known</td>
<td>31,000-62,000</td>
<td>Not known</td>
</tr>
</tbody>
</table>

2.5 Wayside lubricator placement model

Wayside lubricator placement guidelines were developed in different rail networks in recent decades. Most of them depend on arbitrary assumptions, and no specific model was developed. The first placement model of wayside lubrication placement was developed by de Koker (1994), which was extended by Sroba et al. (2001). SAR&H circular 10128 (1957-11-05) reports on bi-directional line trackside lubricators being spaced about 6 km on high rail, or between 300° and 360° of deflection angle of the curve. These values came from the addition of the length of curve or the accumulated deflection angle between the tangents. Marich, Kerr and Fogarty (2001) recommendations about lubricator position on track are as follows:

- The ideal position within the transition of curves of 400–600 m radius is where the wheel flanging just starts.
- It is within the body of the curve for curves with a radius from 600–1000 m.
- Lubricator should not be placed on the tangent track or curves greater than 1000 m radius, as no flanging occurs.
- If possible, lubricator should not be placed at curves with a radius less than 300 m.
- In the transition, it should be placed at the beginning of the curve or end of the curve, depending on traffic direction.

Modelling of wayside lubricator placement needs to consider factors related to location and position of lubricator, lubricator type, applicator bar, lubricant, traffic and track, environment and human. In de Koker’s (1994) and Sroba et al.’s (2001) models, the placement interval is decided based on the length of track being considered for lubrication, adjusted by a number of track- and traffic-related factors.

For a complete placement model a hierarchical approach needs to be considered using cost–benefit analysis. Data can be used to calculate the distance between lubricators, and consequently the position. Field and lab tests are needed to estimate parameters.

Properties of curved and tangent track, locomotive axle loads and wheel configurations, train speed and length, rail–wheel profile, rail–wheel temperature, weather conditions, and lubricator’s reliability have a significant effect on the carry distance of grease. Carry distance determines the distance between consequent trackside applicators. Carry distance is measured based on the coefficient of friction in the gauge face. Sroba et al. (2001) suggests that the coefficient of friction is considered to be 0.25, and measurement is taken by hand-pushed tribometer.
For more effective spacing of lubricators, it is considered that more investigation is necessary to determine the effect of other factors related to lubricators, lubricants, track, traffic, and environmental and human factors.

The effect of rail–wheel temperature on rail lubrication
Rail–wheel temperature has a significant effect on rail–wheel lubrication. Frohling, de Koker and Amade (2009) reported that the joint investigation of Companhia Vale do Doce (CVRD), Estrada de Ferro Vitoria Minas (EFVM), the Transport Technology Centre Inc. (TTCI) and others recommends the improvement of rail lubrication using high durability/retentivity grease. Over a 10-day period, monitoring of the coefficient of friction and rail temperatures shows that a typical 15,800 tonne 160-wagon ore train in a 160 m curve increased the temperature of a dry rail by 31.6 °C, whereas the temperature of a lubricated rail increased it by only 7.9 °C, and the coefficient of friction μ on the gauge face exceeded the target value of 0.35 between five to ten trains. Transnet Freight Rail (SA) conducted an investigation to establish any possible relationships between temperature rise in the gauge corner and the coefficient of friction (μ), mass, speed, wagon number, or the bogie type of train. Strong correlation was found between the increases in temperature rise and the length of the trains; between the temperature rise and the accumulating flange forces. Rail–wheel temperature could have a significant role on grease durability and lubrication effectiveness.

According to Ertz and Knothe (2003), thermal stress caused by rail–wheel temperature plays a significant role on elastic limit, and the shakedown limit as it is superimposed on the mechanical contact stresses. They reduce the elastic limit of the wheel and rail, and yielding begins at lower mechanical loads. The shakedown limit of rail and wheel can be seen in figure-2 (Appendix 1: Track and traffic factors). There is a need for research on rail–wheel temperature and its effect on lubrication effectiveness.

Effects of rail–wheel profile on lubrication carry distance
Rail–wheel profile plays an important role in lubrication effectiveness. According to Thelen and Lovette (1996), the success of a lubrication strategy depends on the transport mechanism; and the wheel flange and its contact with the rail. Conformal flange contact is an optimum condition for a non-steering vehicle and supports lubrication (IHHA 2001). Contact in the rail–wheel interface needs to be considered in detail for the evaluation of lubrication effectiveness.

2.6. Summary
A brief overview of wear, rail lubrication practice and placement modelling has been presented in this chapter. Wear and rail lubrication best practice are crucial to the rail industry. A thorough study has been conducted here to acquire the depth of knowledge and understanding of rail–wheel wear, and types of lubricators, measurement of effectiveness, lubricants and placement practices.
3. Methodology in lubricator placement model

3.1 Overview
Lubrication of the wheel–rail interface is necessary to prolong the life of both the rail and wheels. It is desirable to apply lubricant to the interface between the rail gauge face and the wheel flange to minimise the wear of both. The application of lubricants to the wheel–rail interface is an accepted practice across the rail industry. Lubricant is applied to the wheel flange which, in turn, distributes it along the rail. For heavy haul railways, wayside applicators are commonly used in Australia and North America.

Australia and North America practices differ in the type and location of the applicator bars. The Australian practice is to place one or two short bars (approximately 600 mm long) on one rail in the transition of a curve. The North American practice is to use one or two long bars (approximately 1500 mm long) on each rail on a tangent track. Both methods are the focus of this study. The CRC for Rail Innovation includes project R3-110 – Placement of Lubricators on Curves. Project R3-110 is undertaking research work to improve practices of wheel–rail friction modification. The project is also seeking to contribute to performance-based standards, considering costs and risks for lubrication decisions, and undertaking lubricator and lubricant trials. The first trial was to compare the effectiveness of the lubricant application between the Australian short bar on curve method with the North American long bar on tangent method. The test had to be expanded to include a test of the current lubricants available to the rail industry, both locally and overseas. A study of current practices in curve lubrication has been carried out, including a practical visit to railway organisations, and collation and analysis of current practices and data, along with survey data from practitioners.

3.2 Test plan for the proposed model
Lubricator field tests have been conducted on the QR North Coast Line and Blackwater System. The test plan has been designed to develop lubrication best practice for Australian heavy haul lines.

3.2.1 Scope of work
100% effective friction management targets on the high rail showing coefficients of friction on a wheel template. Friction levels greater than 0.25 on the gauge area are considered poor lubrication. Good lubrication area on rail can be seen in figure-1 (Appendix 2: Lubricator trial plan).

3.2.2 Test objectives
1. To determine best practice in wayside gauge face lubrication for Australian heavy haul lines by:
   • determining the best lubricant for use on heavy haul lines
   • determining the most efficient lubricator system and placement
   • determining the most efficient lubricant application rates
   • determining the most appropriate system
2. To do a comparative test on the effectiveness of various lubricants using long bar lubricator technology in tangent track
3. To do a comparative test between the effectiveness of short lubricator bar technology used in the spiral of curves and the long bar technology in tangent track, using the best grease from item 2 in above
4. To develop and document a scientific model and methodology for the placement of lubricators on the QR coal lines
5. To investigate the benefits of remote condition monitoring technology on the lubricator units
6. To perform an economic analysis on the two systems — short bar technology and long bar technology — compared to the current lubricators on the coal lines. This analysis will include:
• the number of lubricators in place and required
• the volume of grease dispensed by the total number of units required
• the requirement of removal and re-installation for the grinding program
• the maintenance requirements
• the labour required to maintain the units
• the benefits of remote monitoring of unit’s health and call for help on failure

It is intended to undertake some follow-up trials based on the findings of this test.

3.2.3 Test location
The test location is on the QR North Coast Line (NCL) between Gladstone and Rockhampton. This section of the NCL is shared with the Blackwater Coal System, and gets both the NCL mixed traffic and the Blackwater Coal System coal trains. The proposed test location is between the 553 km and the 555.5 km points on the up-track of the Yarwun Bank, between Callemondah Yard and Mt Larcom, as can be seen in figure-2 (Appendix 2: Lubricator trial plan). This section of track has two narrow gauge (1067 mm) bidirectional tracks. Both tracks have 60 kg rail on concrete sleepers with resilient fastenings. The maximum permissible axle load is 26.5 tonnes and the traffic includes:

• Blackwater coal trains — distributed power [10 000 tonnes gross
• NCL freight trains (intermodal, and unit trains — grain, livestock, molasses)
• loco-hauled passenger trains
• electric tilt trains
• diesel tilt trains.

There are four operators on this section of track — QR National, ARG, Pacific National and QR Passenger, and train control is via direct traffic control from Rockhampton.

There are three test sites — two on curves and one on tangent track:

A. 553.440 km — this site is on the leading transition (mine end of the curve) of a 595.7m radius left-hand curve
B. 553.908 km — this site is on the leading transition (mine end of the curve) of a 595.7m radius right-hand curve
C. 554.00 km — this site is in a long section of tangent track.

3.2.4 Equipment to be trialled

Lubricator units
The trial will compare short bar and long bar systems of two suppliers to the Australian market. Three units will be supplied by each manufacturer:

• 2 x standard short bar units for installation on the curve transitions
• 1 x standard long bar unit for installation at the tangent test location
• 2 x standard long bar unit for installation at the tangent test location.

One supplier has made available units fitted with modern remote condition monitoring and telemetry equipment.

Lubricant
The lubricant used for the test will be Rail Curve Grease S, currently in use. This grease is to be used in the trial because it is the grease used by the lubricator attendant in this area.
3.2.5 Test procedure

Each test will be run in 11 stages, and the test will be run for each supplier.

Pre-test measurements

- Mark out measurement sections through downstream curves that will be at least 50 m in length on both rails in each curve.
- Mark spot sample sites and photograph the gauge corner lubrication at these points.
- Perform dye penetrant tests on the rail in the tangent and body of the test curves.
- Measure the rail profile of both rails at the three installation sites with a MiniProf, which can be seen in figure-10 (Appendix 2: Lubricator trial plan).
- Measure track gauge at the three installation sites.

Test stages

1. Shut off existing lubricators – 3 days
   - The existing gauge face lubricators will be shut down, both upstream and downstream.
   - Note must be taken of any crossovers that may permit a train into, or out of, the test section within the measurement area.
   - Let traffic run the rail dry.
   - Run tribometer over measurement sections, as can be seen in figure-9 (Appendix 2: Lubricator trial plan)
   - If tribometer readings are less than 0.45 on the high rail gauge corner of the two test curves, then there is another source of lubrication, and this must be determined and turned off.

2. Install units – 2 days
   - Install all three units, and test to ensure they are working correctly. Units must be installed in accordance with the manufacturer’s instructions. The applicator bars on the tangent track should be installed using a typical ‘worn flange’ wheel profile template to set the height of the bars (figure 3 Appendix 1).
   - Each supplier is to be invited to give technical assistance in the installation and testing of their units.
   - Splash tests are to be undertaken to determine the optimum lubricant pump rate for each location, as can be seen in figure 6 (Appendix 1: Lubricator trial plan).
   - When the correct height has been measured for the tangent units, these bars can be removed from the track until they are to be tested.
   - This work needs to be undertaken under traffic (unless a suitable shutdown is available).

3. Turn on curve units – 3 days
   - Turn on the two trial units set up with short bars in the curves at the 553.179 km and the 553.710 km points.

4. Measurement – 2 days
   - Run tribometer over measurement sections.
   - Photograph spot test sites.

5. Turn off curve units
   - Turn off the two trial units at the 553.179 km and the 553.710 km points.
   - Collect data from units.

6. Run the rail dry – 3 days
   - Let traffic run the rail dry.
7. Measurement – 2 days
   - Run tribometer over measurement sections.
   - Photograph spot test sites.

8. Turn on tangent unit – 3 days
   - Install the tangent long bars at 555.5 km.
   - Turn on the trial unit.

9. Measurement – 2 days
   - Run tribometer over measurement sections.
   - Photograph spot test sites.

10. Turn off tangent unit
    - Turn off the trial unit at the 555.500 km.
    - Collect data from units.

11. End of trial – 2 days
    - Turn on existing lubricators.
    - Remove trial units.
    - Tribometer runs.

Using QR’s hand push tribometer, coefficient of friction measurements are to be made along the track in the up direction (decreasing kilometres, or towards Gladstone). The measurements are made at 34 degrees (subsequently modified to 60 degrees) to the gauge corner of the curve high rail and the top of high and top of low rail. Special attention is needed for grinding facets left on the rail at this angle, as grease can be trapped in a facet and produce false readings.

3.3 Results
Carry distance is to be documented up to the point where the coefficient of friction exceeds a value of 0.25µ from the wayside lubricator. The de Koker number for the test lubricator units is to be calculated at the end of each seven-day test period. This number is based on a number of parameters, including lubricant carry distance, lubricant type, track geometry and traffic. This number needs to be used to do a preliminary lubrication design for the Blackwater System.

A brief report is to be produced containing:

- results of the tribometer measurements
- results of the de Koker calculation
- proposed locations for setting out new lubricators for the Blackwater System
- data from the condition monitoring telemetry system, and documentation of all benefits of such a system. Match the telemetry data with events such as trains passing the site
- advantages and disadvantages of each system
- costs and benefits of implementing each lubrication technology
- proposed extended trial and top of rail friction modification testing.

Research and model development
The proposed wayside lubricator placement model and cost–benefit analysis is to be developed based on the simulation tool. In the proposed model, the de Koker number needs to be developed, considering new factors based on track, traffic and lubricator technology, such as lubricator performance, rail–wheel temperature, rail–wheel profile and gauge width. There is a need to reconsider existing factors such as applicator bar, traffic type, bogie type, braking condition and grease performance.
3.4 Expected outcomes
Expected outcomes of the project are:

- extensive literature review
- proposed lubrication best practice for heavy haul lines
- measurement of lubrication effectiveness in Australian heavy haul network
- development of a framework for a standard on rail curve lubrication for heavy haul lines
- development of a decision support tool for cost–benefit analysis of lubrication methods
- development of a lubrication decision chart based on lubricators, long and short applicator bars and lubricants.

3.5 Summary
Based on current practices and their limitations, a systematic way of evaluation for lubrication has been presented. There is a need for best practice to be developed for Australian heavy haul lines. A placement model has been proposed based on the significant influential factors.
4. Rail–wheel lubrication in the Australian rail industry

4.1 Introduction
Rail–wheel lubrication practice in Australia does not have any recommended standard guidelines. Different rail operators implement lubrication strategies based on their own concept and understanding. Responses about current practice show that wayside gauge face lubrication is predominantly used in Australia. Hi‐rail lubrication is also applied on some networks. Lubrication needs to be effective, irrespective of the method of application. Current practice and site investigations show that, although lubricators are regularly filled with lubricant and lubricators are being regularly maintained, there is little ‘effective’ lubricant coverage on the gauge corner and gauge face. Site investigations have verified that there was significantly less lubricant within a very short distance of each lubricator. Therefore, it can be confirmed that the current practice in Australian rail lubrication is not effective.

4.2 Response to current practice
A comprehensive questionnaire has been developed by Central Queensland University (CQU) for the purpose of ‘establishing recommended best practices for rail–wheel friction management and lubrication’. It has been circulated to different rail operators for response, based on current lubrication practice in the network. Responses were received from QR, RailCorp and WestNet. ARTC did not respond, as it believes that its current practices have not yet been standardised.

The responses in Table 4.1 provided by rail operators don’t present a view of standard practice throughout the Australian rail industry. A brief discussion on current practice follows.

Studies show that the current lubrication practices on Australian railways can be substantially improved with improved lubricator technology, lubricator placement guidelines, better training of lubricator maintainers and improved lubricant specifications. With these improvements, below rail and above rail assets will be better protected, and substantial savings to the industry will be achieved.

4.3 Issues in current practice
Field investigation discovered that there are many problems with poor lubrication practice in heavy haul lines. Therefore, the gauge corner of high rail and wheel flange remain unprotected from severe wear. A few examples of common problems in wayside lubrication sites identified in the field study include:

clogging in pump assembly, hose joints and distribution blades
- most of the grease volume ending up on the ballast at the lubricator bar site, with very little picked up by wheels
- hydraulic and mechanical units having most of the applicator ports clogged so that pressurised grease leaks through joints and connections
- the curves to be protected being poorly lubricated, with the gauge corner and gauge face measured to be dry (>0.25 COF)
- lubricator unit’s location and positioning of applicator bars with respect to top of rail not being standardised
- lubricator bars in the spiral of curves having to be removed each grinding cycle, which results in non-removal or late reinstallation, causing rail surface fatigue of gauge face
- plunger head on the actuator of hydraulic lubricators being broken, mushroomed or flattened
- incorrect plunger height in many places
- pumps being out of order or leaking grease from pump assembly
- lubricator units being out of order for long periods of time until the lubricator maintainer returns to the site
- grease separation being common in the tank from poor grease distribution (clogging)
- excessive grease loss, over lubrication, RCF and rail surface contamination, due to lack of precise control of application rate.

**Table 4.1: Summary of responses to lubrication survey by Australian rail operators**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>QR</th>
<th>RailCorp</th>
<th>WestNet Railway (EGR, Avon Vally, South WestMain)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of operator</strong></td>
<td>Narrow gauge coal lines, freight and high speed passenger, switching/ terminals, metro/transits</td>
<td>Heavy haul, freight, transit/passenger services</td>
<td>Regional/shortline</td>
</tr>
<tr>
<td><strong>Lubrication method</strong></td>
<td>Wayside specific — gauge face and top of rail, hybrid top of rail units to test products, hand application at specific location</td>
<td>Wayside</td>
<td>Wayside specific — gauge face and top of rail and hi-rail lubrication. Hi-rail systems apply grease on the high rail. There are cameras on back of the hi-rail system to monitor application on a left or right curve. Lubricate the whole curve and do not use.</td>
</tr>
<tr>
<td><strong>Applied formula or rules of installation</strong></td>
<td>No specific formula, but has some rules of installation, such as considering loaded/empty trains, direction of trains, accessibility of curves, curves radius (&lt;(= ) 500 m &gt; 1MGT traffic), i.e. in spiral of shallow curve</td>
<td>Positioning should be in the transition of curves 400 to 600 m radius or in the body of the curves 600 to 1000 m radius. Best strategy is to use moderate radius curves to set up lubricators. Lubricators at sharp curves tend to be ineffective. Carry distance varies with sleeper type</td>
<td>Not been specified for wayside application. Run hi-rail lube system on five lines every day. On the 14 and 20 MGT lines, the hi-rail units run three times per week. Application time per week based on trial and error basis to ensure grease on the rail at all times.</td>
</tr>
<tr>
<td><strong>Type of lubricator</strong></td>
<td>Gauge face — mechanical (PW37, P&amp;Ns, RTE), hydraulic (Portec &amp; other), electric (Portec &amp; Lincoln); TOR — Portec hydraulic and Lincoln electric, manual application in problem areas</td>
<td>Mechanical lubricators for flange lubrication</td>
<td>For wayside application, Portec hydraulic units with 40 kg tank. Also used hi-rail lube system</td>
</tr>
<tr>
<td><strong>Type of applicator bars</strong></td>
<td>600 mm short bars in pairs or single, do not use brush on Lincoln bars, electronic lubricator set to 0.25 sec for 16 axles</td>
<td>RTE clamp-on type lubricators are used due to being easy to remove and replace when required</td>
<td>Familiar with short bars only</td>
</tr>
<tr>
<td><strong>Placement location</strong></td>
<td>Not specified</td>
<td>Positioning should be in the transition of curves 400 to 600 m radius or in the body of the curves 600 to 1000 m radius. Best strategy is to use moderate radius curves to set up lubricators. Lubricators at sharp curves tend to be ineffective. Carry distance varies with sleeper type</td>
<td>Two bars on high rail only</td>
</tr>
<tr>
<td><strong>Positioning of bars</strong></td>
<td>Not specified</td>
<td>Not specified</td>
<td>Not specified</td>
</tr>
<tr>
<td><strong>Common problems</strong></td>
<td>Clogged ports, empty tank, leaking fittings, blown hoses, grease clogging lines due to lumps in grease</td>
<td>Not specified</td>
<td>Break down, need for spare parts, clogging, leaking etc. Too much maintenance. Difficult to keep working and need to remove prior to grinding</td>
</tr>
</tbody>
</table>

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Problems observed during the field study include:

- possible environmental hazard and probable groundwater contamination due to grease loss into the ballast and grease splash from the wheel
- cavitations in the pump unit due to air block or excessively viscous grease
- broken or smashed blades due to wheel flange contact
- poor lubrication within a short distance of a working lubricator
- poor servicing and maintenance due to lack of training
- high labour cost in filling and maintenance with no or little benefit in reducing rail wear.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>QR</th>
<th>RailCorp</th>
<th>WestNet Railway (EGR, Avon Vally, South WestMain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection, servicing and maintenance</td>
<td>Dedicated lubricator maintainer and offside inspect the unit, time-based cycle for filling, use bulk filling or 20 kg pots, lots of maintenance. In general, six to 12 units not working every two weeks</td>
<td>Track maintenance staff fill and service lubricators. Filled by pumping from drum approx. 5 litres every three weeks. Various scheduled track inspections find out problems, like lubricator servicing, track control, annual inspection of rail condition</td>
<td>Filled up and maintained every three weeks by high rail lube operators or gang. Tried to increase the reliability of wayside lubricators. Spot check by track inspectors and hi-rail lube operators</td>
</tr>
<tr>
<td>Parameters of effectiveness evaluation</td>
<td>Rail-wheel wear rates, field inspection of dry wear, no tonnage data for consumption rates</td>
<td>Head to head assessment of competing lubrication products, gauge face friction value, carry distance, level of TOR contamination, grease pumpability and thermal stability</td>
<td>Rail wear particles on the sleeper. Collected rail wear data every six months using Railmate</td>
</tr>
<tr>
<td>Method of overall lubrication effectiveness measurement</td>
<td>Coefficient of friction measurement with tribometer, observation of rail head contamination, rail wear, black line on gauge face</td>
<td>Monitor wear of passenger wheels and instance of flanging or lubricator failure</td>
<td>Wear measurement in curves every six months using Railmate, observe flakes on ties off the rail</td>
</tr>
<tr>
<td>Type of lubricant use</td>
<td>Different sections use different greases, seasonal change of grease type. Currently use Rocol #1 and Rocol #2</td>
<td>Rocol rail curve grease, same product used for winter and summer based on pump adjustment</td>
<td>Rocol #1 (thinner) for wayside lubricators and Rocol #2 (thicker) for hi-rail lubrication</td>
</tr>
<tr>
<td>Standard policy</td>
<td>Has a CETS standard. No overruling of standards</td>
<td>Lubrication strategy provides guidelines for initial installations, but monitoring and adjustment for better performance is done by track staff</td>
<td>Lubrication is decided by superintendent. Grease and components are purchased by them. Engineering team can suggest for better practice</td>
</tr>
<tr>
<td>Other concerns</td>
<td>Lubricators are not turned off for ultrasonic inspection, removed for grinding cycles and put back soon after grinding, removed for ballast cleaning, do not remove for tamping, Cost–benefit may have been done. Electric lubricators are preferred, which may reduce huge amount of maintenance and improve reliability</td>
<td>Noticed differential wear on curves. The further into the curve, the greater the wear in unidirectional track</td>
<td>Not happy with mechanical and hydraulic wayside systems because of too much maintenance. Difficult to keep working and need to remove prior to grinding. Thus prepared to trial electronic gauge face Units, which need less maintenance and are more reliable</td>
</tr>
</tbody>
</table>
Figure 4.1 shows the severe grease waste and ineffective lubrication on site.

**Figure 4.1: Waste of grease and dry gauge**

Figure 4.2 shows cavitation has occurred due to an airlock problem when lubricator is unattended for long time.

**Figure 4.2: Cavitation at the pump inlet**

**Examples of visits to lubricator sites and current problems**
Solar power-operated electric unit with two short bars and positive displacement piston pump on hi-rail was operating at Mt Larcom, Aldoga Section. Problems included ports clogged, grease waste to ballast, measured short carry distance, uneven grease bead size, and airlock in the pump. Track time and labour was required to maintain the unit. Due to the airlock, the units had to be primed before grease was pumped to the tank. The tank capacity of the unit was 37 kg and operating voltage was 24 volts.

**Figure 4.3: Electric lubricator unit at Mt Larcom, Aldoga section – grease waste, clogging and leaking**
RTE25 mechanical units with single short bar (eight ports) on hi-rail were operating at 551.062 km, Mt Larcom, Aldoga section. Investigation shows that there was no grease in the gauge corner, even at the bottom of the gauge face, in the first curve from the lubricator unit. Grease was being delivered through only one port. Grease clogging and a large amount of grease waste to the ballast required man-hours of maintenance. The plunger height is inconsistent due to wear, and therefore grease delivery to the bars is inconsistent and provides little control. At lower train speeds, the plunger does not get enough impact from the train wheel, so the grease quantity delivered is not reliable. There are eight RTE25 units within 30 km of track (main, plus branch line) in the Mt Larcom to Callemondah track section, and 25 units in the district.

Figure 4.4: RTE25 Mechanical lubricator unit at Mt Larcom, Aldoga section – grease waste, dry curve

A PW37 hydraulic lubricator unit with MC-3 bars (two bars on hi-rail) was operating on the Mt Larcom, Aldoga section, in the centre of a curve. The blade height relative to the top of the rail can be adjusted up and down to allow installation on 47, 53 and 60 kg rail. This unit experiences airlocks in the system. When the wheel hits the plunger, the hydraulic action activates the pump, and the pump delivers grease through the ports. Grease delivery is not precisely controlled. Large quantities of grease are wasted, there is grease leakage from the interface of the pump and hydraulic actuator and clogging of ports, and large quantities of grease are seen on the ballast at the transition to the body of the curve.

Figure 4.5: PW37 mechanical lubricator unit at Mt Larcom, Aldoga section, leaking from plunger connection and pump assembly, rainwater in the grease tan
Measurement of coefficient of friction in a currently operating hydraulic lubricator site (7 and 8 June 2010)
To investigate the current practice of friction management on the gauge corner, tribometer readings of the coefficient of friction ($\mu$) have been recorded at a typical working hydraulic unit. The site locations were the Fry–Mt Rainbow section (79.4 km and 79.9 km) and Mt Larcom section (564.298 km and 562.576 km). The average coefficient of friction for each curve is shown in Tables 4.2 and 4.3. The coefficient of friction data shows that both gauge corner and TOR are >0.25 COF, which indicates that the rail is fairly dry. This shows that grease doesn’t carry in the first curve. Even in the Fry–Mt Rainbow section, tribometer data was collected within 5 metres of the lubricator unit. A finger test (Figure 4.7) shows that the rails are totally dry. The grease ends up on the ballast around the lubricator site.

Table 4.2: Average coefficient of friction ($\mu$) data within first two curves from currently operating lubricator site (lubricator supplier A)

<table>
<thead>
<tr>
<th>Date</th>
<th>Location (Fry–Mt Rainbow section) (km)</th>
<th>Type of applicator bars</th>
<th>Suppliers</th>
<th>Grease</th>
<th>Rail condition</th>
<th>Average coefficient of friction (GF – high) at 60°</th>
<th>Average coefficient of friction (TOR – high)</th>
<th>Average coefficient of friction (TOR – low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>08.06.2010</td>
<td>79.4</td>
<td>2 short bar (MC3)</td>
<td>PW37</td>
<td>Rocol</td>
<td>Wet</td>
<td>0.32</td>
<td>0.36</td>
<td>0.37</td>
</tr>
<tr>
<td>08.06.2010</td>
<td>79.9</td>
<td>2 short bar (MC3)</td>
<td>PW37</td>
<td>Rocol</td>
<td>Wet</td>
<td>0.35</td>
<td>0.34</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Table 4.3: Average coefficient of friction ($\mu$) data within first two curves from currently operating lubricator site (lubricator supplier B)

<table>
<thead>
<tr>
<th>Date</th>
<th>Location (Mt Larcom) (km)</th>
<th>Type of applicator bars</th>
<th>Suppliers</th>
<th>Grease</th>
<th>Rail condition</th>
<th>Average coefficient of friction (GF – high) at 60°</th>
<th>Average coefficient of friction (TOR – high)</th>
<th>Average coefficient of friction (TOR – low)</th>
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</thead>
<tbody>
<tr>
<td>07.06.2010</td>
<td>564.298</td>
<td>2 short bar on each rail</td>
<td>B</td>
<td>Rocol</td>
<td>Wet</td>
<td>0.34</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>07.06.2010</td>
<td>564.576</td>
<td>2 short bar on each rail</td>
<td>B</td>
<td>Rocol</td>
<td>Wet</td>
<td>0.31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
At the 84.200 km location, a solar powered electric unit site observation showed that almost 50 per cent of the ports in each bar were blocked. After cleaning with high pressure water gun (Figure 4.6), the bars were still clogged. These will be removed and cleaned off track by the lubricator maintainer.

**Figure 4.6: Hydraulic unit, clogged ports, leaking grease and cleaning efforts with high pressure water gun**

**Figure 4.7: Lubricator site curve dry (>0.25) close to the lubricator unit. The shiny dry gauge corner remains unprotected throughout the downtime of the lubricator**
Figure 4.8: Out of order lubricator unit and dry curve
5. Recommendations on wayside lubrication best practice

Implementation of optimum lubrication practices was supported by field and laboratory investigations conducted by engineering staff from CQU.

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 was determined using the following criteria:

- installation into tangent track and simplicity of operation
- reliability of performance and ease of maintenance
- electronic controls to remotely monitor performance
- availability of spare parts
- high performance lubricant
- economic considerations.

CQU undertook an extensive literature review of the current lubricator technology to determine the best systems for industry to employ. The majority of wayside equipment in service today uses a mechanical contact or hydraulic activation system, in which wheels impact a plunger that in turn drives a motor. The experience of the field study 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 or off remotely using RPM systems 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.

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. The CQU research team is to test various commercially available lubricants from several manufacturers, with the objective of determining the optimal lubricant for field conditions. These tests can eliminate the necessity for expensive field testing of different lubricants.

QR 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 are:

- maintain top of rail friction coefficient differential, left to right < 0.1
- top of rail friction > 0.3 < 0.40
- gauge face of high rail coefficient ≤ 0.25.

CQU evaluated the optimal settings of the electronic lubricators by ‘splash’ testing for lubricant waste with passing trains. The optimal setting was found to be 0.25 seconds of activation every 12 axles for the long lubricator bars.
Summary

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 and climate. All these factors influence the transport and retentivity of the lubricant on the rail. CQU researched the latest information about optimal placement of lubricators to help optimise lubrication management. Controlled in-field testing by CQU is being undertaken to establish the reliability and efficiency of wayside lubricators. Many factors are being considered, including:

- the waste 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 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 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.

The optimal placement of lubricators is affected by numerous 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.

Field and partial lab trials show consistent results. The standardised practice for measuring effectiveness of lubrication is going to be part of best practice. The trials of long bar, effective lubricant and RPM were an excellent outcome of this research. An extensive trial is proposed in coal lines for validation of the initial findings, and for developing effective friction management practice for heavy haul lines.
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Appendix A: Field trial brief report

This is a brief report on the gauge face lubricator trial at Yarwun on the North Coast line.

Test objectives

1. To determine best practices in wayside gauge face lubrication for Australian heavy haul rail lines by:
   a. determining the best lubricant for the operating conditions
   b. determining the most efficient lubricator system and placement
   c. determining the most efficient lubricant application rates
   d. determining the most appropriate system.
2. To do a comparative test on the effectiveness of short lubricator bar technology used in the spiral of curves as compared to long bar technology in tangent track.
3. To develop and document a scientific formulae and methodology for the placement of lubricators on the coal lines.
4. To investigate the benefits of remote condition monitoring technology on the lubricator units.
5. To perform an economic analysis on the two trial systems, short bar technology and long bar technology, compared to the current number of lubricators on the coal lines.

This analysis is expected to include:

- the number of lubricators in place and required
- the volume of grease dispensed by the total number of units required
- the requirement to remove and re-install for the grinding program
- the maintenance requirements
- the labour required to maintain the units
- the benefits of remote monitoring of unit health and call for help on failure.

Test duration with lubricator supplier X equipment: April to July 2010

Lubricator units: lubricator supplier X GF units with grease guides and with RPM unit – both long and short bars

Grease tank capacity: 360 litres

Grease types tested: grease A, grease B, grease C, grease D

Test lubricators & site location:

Site 1: curve unit (2 short bars on hi-rail) at 553.908 km
Site 2: curve unit (2 short bars on hi-rail) at 553.440 km
Site 3: tangent unit (1 long bar on each rail) at 554 km

Friction levels greater than 0.25 on the gauge corner and mid-gauge area is considered poor lubrication.
Figure A1: 100% effective friction management targets on the high rail showing coefficients of friction on a wheel template

![Worn wheel template](image)

Summary of typical test activities and outcomes

26 April
- Installation of new units on 26 April — existing lubricators were turned off before the installation of new units.
- Placement of tank, hoses and two short bars in each curve unit site. Figures A2 and A3 show the installation process of lubricator and bars.

Figure A2: Installation of curve unit shows short applicator grease guide bars

![Installation process](image)
Placed tank on tangent unit site and 2 long bars were tested on the track on 1982 60kg worn rail.

**Figure A3: Long bar height measurement and positioning**

27 April

- Dry tribometer run — after three days dry down period, a dry tribometer run was conducted to measure the coefficient of friction and to confirm that the up track was completely dry. Figure 4 shows coefficient of friction measurement with tribometer at gauge face.

**Figure A4: Coefficient of friction (μ) measurement with tribometer**

<table>
<thead>
<tr>
<th>Date</th>
<th>Curve direction</th>
<th>Curve number</th>
<th>From (km)</th>
<th>To (km)</th>
<th>Length (km)</th>
<th>Bars</th>
<th>Condition of rail</th>
<th>Average coefficient of friction (GF – hi)</th>
<th>Average coefficient of friction (TOR – hi)</th>
<th>Average coefficient of friction (TOR – low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.04.10</td>
<td>R</td>
<td>2</td>
<td>553.664</td>
<td>553.93</td>
<td>265</td>
<td>Short</td>
<td>Dry</td>
<td>0.43</td>
<td>0.5</td>
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<td>27.04.10</td>
<td>L</td>
<td>3</td>
<td>553.176</td>
<td>553.488</td>
<td>313</td>
<td>Short</td>
<td>Dry</td>
<td>0.44</td>
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<td>5</td>
<td>552.613</td>
<td>552.72</td>
<td>107</td>
<td>Short</td>
<td>Dry</td>
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<td>0.66</td>
<td>0.63</td>
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<td>27.04.10</td>
<td>L</td>
<td>8</td>
<td>551.46</td>
<td>552.31</td>
<td>850</td>
<td>Short</td>
<td>Dry</td>
<td>0.52</td>
<td>0.62</td>
<td>0.56</td>
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<td>27.04.10</td>
<td>R</td>
<td>12</td>
<td>550.165</td>
<td>550.406</td>
<td>241</td>
<td>Short</td>
<td>Dry</td>
<td>0.52</td>
<td>0.44</td>
<td>0.53</td>
</tr>
</tbody>
</table>
Figure A5: Variation of average coefficient of friction (COF) at different curve in dry condition on up track

![Average COF, μ Vs. Curve Number](image)

- MiniProf measurement of rail profile was taken on the lubricator site and on few curves for rail-wheel interaction evaluation.
- Dye penetrant testing was conducted on different curves for RCF and crack evaluation.
- Splash test on curve unit site 2 (two short bars on hi-rail) at 553.440 km.

Figure A6: Splash test material set up, bar height measurement, TOR contamination & heavy splash before optimal setting
Figure A7: Dispensed grease mass measurement with electronic scale

30 April 2010 – short bar test results
- Wet tribometer run (coefficient of friction, μ measurement) was conducted at GF – hi rail (at 35°), TOR – hi rail and TOR – low rail on up track towards Gladstone.

Table A2: Average coefficient of friction at GF – hi, TOR – hi and TOR – low in different curves, wet condition (grease A)

<table>
<thead>
<tr>
<th>Date</th>
<th>Curve direction</th>
<th>Curve number</th>
<th>From (km)</th>
<th>To (km)</th>
<th>Length (km)</th>
<th>Bars</th>
<th>Condition of rail</th>
<th>Average coefficient of friction (GF – hi)</th>
<th>Average coefficient of friction (TOR – hi)</th>
<th>Average coefficient of friction (TOR – low)</th>
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</thead>
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<tr>
<td>30.04.10</td>
<td>R</td>
<td>2</td>
<td>553.664</td>
<td>553.93</td>
<td>265</td>
<td>Short</td>
<td>Wet</td>
<td>0.19</td>
<td>0.26</td>
<td>0.52</td>
</tr>
<tr>
<td>30.04.10</td>
<td>L</td>
<td>3</td>
<td>553.176</td>
<td>553.488</td>
<td>313</td>
<td></td>
<td>Wet</td>
<td>0.26</td>
<td>0.3</td>
<td>0.27</td>
</tr>
<tr>
<td>30.04.10</td>
<td>R</td>
<td>5</td>
<td>552.613</td>
<td>552.72</td>
<td>107</td>
<td></td>
<td>Wet</td>
<td>0.26</td>
<td>0.33</td>
<td>0.32</td>
</tr>
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<td>552.613</td>
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<td>Wet</td>
<td>0.34</td>
<td>0.37</td>
<td>0.38</td>
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<tr>
<td>30.04.10</td>
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<td>8</td>
<td>551.46</td>
<td>552.31</td>
<td>850</td>
<td></td>
<td>Wet</td>
<td>0.33</td>
<td>0.33</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Figure A8: Variation of average coefficient of friction at different curve in wet condition on up track

Average COF, μ Vs. QR Curve Number

CRC for Rail Innovation 23 July 2010 Page 39
On curve number 6 (right-hand curve), between 552.5 km and 552.613 km, the average coefficient of friction GF – hi rail was 0.34 and the gauge corner was dry.

With subsequent bar height changes, the COF could not be improved for significant rail coverage down the track. The short bar test was abandoned until such time as the bar height could be reviewed by the supplier.

On curve number 8 (left-hand curve), it looked like the gauge face was dry, and there was no grease up to the bottom of the gauge face. Only dry graphite was present. Evidence of RCF was seen on the gauge corner.

**Figure A9: Dry graphite in gauge face and RCF on curve number 8**

![Figure A9: Dry graphite in gauge face and RCF on curve number 8](image)

The following figure shows the completely dry gauge corner on hi-rail in curve number 8.

**Figure A10: Dry gauge corner on hi-rail on curve number 8**

![Figure A10: Dry gauge corner on hi-rail on curve number 8](image)

4 May 2010 – long bar test results

- A tangent unit with one long bar on each rail was installed and splash test materials were installed on site at 554 km.
Figure A11: Two Long bars in tangent track at the 554 km

Figure A12: Long bar with grease beads. Uneven distribution of bead sizes found to be due to a faulty gasket. Both gaskets changed out

Figure A13: Gauge face of curve at 550.383 km with dry gauge corner
From 4 May, grease was dispensing at .25 sec per 12 axles through the single long bar on each rail at 554 km. There was site contamination around 20 m distance on the ballast and TOR. COF was being measured using a tribometer on top of two rails and the gauge face at 35, 45, 50 degrees. Track was inspected from 554 to 550 km, rail gauge face and mid-gauge was considerably dry.

Grease carry evaluated to be 1.2 to 1.3 km for left and right curves.

**Table A3: Average coefficient of friction at GF – hi, TOR – hi and TOR – low in different curves wet condition (grease A)**

<table>
<thead>
<tr>
<th>Date</th>
<th>Curve direction</th>
<th>Curve number</th>
<th>From (km)</th>
<th>To (km)</th>
<th>Length (km)</th>
<th>Bars</th>
<th>Condition of rail</th>
<th>Average coefficient of friction (GF – hi)</th>
<th>Average coefficient of friction (TOR – hi)</th>
<th>Average coefficient of friction (TOR – low)</th>
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</thead>
<tbody>
<tr>
<td>06.05.10</td>
<td>R</td>
<td>2</td>
<td>553.664</td>
<td>553.93</td>
<td>265</td>
<td>Long (1+1)</td>
<td>Wet</td>
<td>0.19</td>
<td>0.29</td>
<td>0.31</td>
</tr>
<tr>
<td>06.05.10</td>
<td>L</td>
<td>3</td>
<td>553.176</td>
<td>553.488</td>
<td>313</td>
<td>Long (1+1)</td>
<td>Wet</td>
<td>0.21</td>
<td>0.32</td>
<td>0.29</td>
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<tr>
<td>06.05.10</td>
<td>R</td>
<td>4</td>
<td>552.72</td>
<td>553.017</td>
<td>297</td>
<td>Long (1+1)</td>
<td>Wet</td>
<td>0.23</td>
<td>0.29</td>
<td>0.32</td>
</tr>
<tr>
<td>06.05.10</td>
<td>R</td>
<td>5</td>
<td>552.613</td>
<td>552.72</td>
<td>107</td>
<td>Long (1+1)</td>
<td>Wet</td>
<td>0.25</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>06.05.10</td>
<td>L</td>
<td>8</td>
<td>551.46</td>
<td>552.31</td>
<td>850</td>
<td>Long (1+1)</td>
<td>Wet</td>
<td>0.3</td>
<td>0.32</td>
<td>0.33</td>
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<td>Long (1+1)</td>
<td>Wet</td>
<td>0.28</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>06.05.10</td>
<td>R</td>
<td>12</td>
<td>550.165</td>
<td>550.406</td>
<td>241</td>
<td>Long (1+1)</td>
<td>Wet</td>
<td>0.26</td>
<td>0.32</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Figure A14: Variation of average coefficient of friction at different curves in wet condition on up track

Test results for grease carry distance were considered unsatisfactory.
A few examples are shown below.

**Figure A15:** Pump volts and ambient temperature vs. time in dates

**Figure A16:** Product level in the tank vs. time in dates

**Figure A17:** Wheel count vs. time in dates
- Air lock discovered in the unit. This was shown on the RPM system as a change in amps drawn by the motor.

Figure A19: Motor amps variation throughout the dates due to air lock in the unit

- Curve 9 gauge face shows cleaned spot and dry graphite on surrounding gauge face, which means very poor lubrication on the gauge corner and gauge face.
19 May 2010

- Dry COF for several curves was measured with tribometer on TOR and gauge face. Rail was dry on gauge corner at 45 degrees and at 60 degrees.
- Four long bars were installed with short hoses and shut off valves for easy priming of each bar. Bars now set at 5/8 inch below top of rail. Dura valve can control grease flow direction and flow rate for each individual bars.

Splash test materials were set up to optimise grease delivery rate based on grease splash and top of rail contamination.
24 May 2010

- After 42,627 axles, there was considerable splash on the white linoleum, and evidence of lots of train sanding for 30 metres down the track. Lubricator supplier X advised to reduce the pump activation seconds to reduce the bead size, and also to reduce the wheel count to get more wheels covered (e.g. 0.2 secs and 8 wheels, or 0.15 sec and 4 wheels). A tangent unit was operating with four long bars (two long bars on each rail) and grease A was being used.
- COF was measured on curves down the track in up line. Grease was evident on the worn gauge corner of a curve 1.2 kms away. However, the COF was > 0.3 to 60 degrees. There was dry graphite on the gauge face. Below the gauge face, there was residual wet grease being pushed down the gauge corner. There was evidence of this excess grease being dropped to the foot of the rail. This shows the grease is carrying on the wheels, but it is burning off very quickly.

Table A4: Average coefficient of friction at GF – hi at 60°, TOR – hi and TOR – low in different curves at wet condition (grease A)

<table>
<thead>
<tr>
<th>Date</th>
<th>Curve direction</th>
<th>Curve number</th>
<th>From (km)</th>
<th>To (km)</th>
<th>Length (m)</th>
<th>Type of applicator bars</th>
<th>Grease</th>
<th>Rail condition</th>
<th>Average coefficient of friction (GF – hi) at 60°</th>
<th>Average coefficient of friction (TOR – hi)</th>
<th>Average coefficient of friction (TOR – low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.05.2010</td>
<td>R</td>
<td>2</td>
<td>553.664</td>
<td>553.93</td>
<td>265</td>
<td>4 Long bars (2+2)</td>
<td>Grease A</td>
<td>Wet</td>
<td>0.19</td>
<td>0.34</td>
<td>0.41</td>
</tr>
<tr>
<td>24.05.2010</td>
<td>L</td>
<td>3</td>
<td>553.176</td>
<td>553.488</td>
<td>313</td>
<td>4 Long bars (2+2)</td>
<td>Grease A</td>
<td>Wet</td>
<td>0.30</td>
<td>0.38</td>
<td>0.33</td>
</tr>
<tr>
<td>24.05.2010</td>
<td>R</td>
<td>4</td>
<td>552.72</td>
<td>553.017</td>
<td>297</td>
<td>4 Long bars (2+2)</td>
<td>Grease A</td>
<td>Wet</td>
<td>0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24.05.2010</td>
<td>R</td>
<td>5</td>
<td>552.613</td>
<td>552.72</td>
<td>107</td>
<td>4 Long bars (2+2)</td>
<td>Grease A</td>
<td>Wet</td>
<td>0.28</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>24.05.2010</td>
<td>L</td>
<td>8</td>
<td>551.46</td>
<td>552.31</td>
<td>850</td>
<td>4 Long bars (2+2)</td>
<td>Grease A</td>
<td>Wet</td>
<td>0.33</td>
<td>0.39</td>
<td>0.37</td>
</tr>
</tbody>
</table>
Figure A23: Variation of average coefficient of friction at different curves in wet condition on up track

![Average COF, \( \mu \) Vs. QR Curve Number (Wet Condition)](chart)

- Bars were removed to dry down the track and make it ready for the next phase of the test.
- The total wheel count was 174,159.

Figure A24: Splash after 42,627 wheel pass through the long bar site and abrasive wear due to sanding

Figure A25: Residual grease below gauge face and presence of dry graphite in the lower gauge corner
Test results for grease carry distance are unsatisfactory.

26 May 2010
- After the 24 May wet tribometer reading for grease A, the track was dried down for two days, and a dry tribometer reading was taken to confirm that the track was fairly dry. The coefficients of friction at gauge face hi-rail, TOR – low rail and TOR – hi rail were above 0.40.

Figure A26: Dry gauge face on hi-rail at curve 5 and curve 8 on up track

- After the dry tribometer run, grease A was replaced in the tank with grease B up to tank level 20%.
- All the hoses and bars were thoroughly cleaned to avoid contamination with grease A.
- The system was primed with grease B, as there was only the last metre of hose and the bars that had to be pumped through with grease B (completed in 3.5 hours under traffic). Prussian Blue has been applied to distinguish between old grease and new grease in delivery through ports.
- Applicator bar damage and a train blocking the track restricted the access to collect data, and it is planned to repeat the test for lubricant B after the field trial with lubricant C and D.

9 June 2010
- Changed to Lubricant C.

15 June 2010
- Wet tribometer data was collected. Carry distance was 4.5 km.

17 Jun 2010
- Changed to Lubricant D. Wet tribometer data to be collected on 22 June 2010.
Appendix B: Summary of field trip to Callemondah and Mt Larcom

Callemondah site
Solar powered electronic lubricators were installed on Callemondah site in the transition of the bidirectional track. The unit contains 90 kg of grease, and has two applicator bars on each rail, which deliver lubricant at 0.35 sec per 18 axles. Two units are also installed at Mt Rainbow. An electrical unit has an advantage over RT 25 hydraulic units, which have lots of problem with grease flying, wheel rubbing, plungers wearing out, blocking holes, bending, clogging and sand clogging. The RT 25 needed a pump adjustment to adjust plunger position, and has less reliability and control in grease application. In this district, summer and winter need different grease, depending on viscosity, which makes a big difference in ports.

- Rocol -1 is the grease used in winter rail curve and wheel flange lubrication. 180 kg drums are available. It is softer and a lot easier to pump and operate. It is graphite-based with mineral oil. Temperature range – 10 to 150 °C. RT 25 gets very little blockage with this.
- Rocol-2 is used in summer, but it becomes thicker in winter and hard to pump.

In Rocol grease, graphite is used as a lubricating solid, clay as thickener and vegetable oil as base oil. NLGI number is 1 and temperature range – 10 to 150 °C. Weekly, 1.5 drums, or 270 kg, of lubricant are needed for 60 lubricators for the whole district.

Due to impurities in the grease, clogging occurs. Old types of lubricator bars are hard to adjust. Problems with Molybdenum-based grease are that it becomes harder in the hose and reservoir, and has an effect on the environment.

The North Coast line has 10 to 50 trains a day, and sometimes no trains for four hrs. On this line, sanding equipment is installed in front of the driving wheels on locomotives. Squeal in the network occurs due to top of rail friction.

Mt Larcom site (Lincoln lubricator)
Temperatures rise in summer up to 56 °C. The curve radius is 543.026 m. Lincoln lubricators with short bars were active on the section.

Lincoln lubricators deliver grease with a progressive divider valve to both short bars at the same time, with same number of delivery hoses (thin) so that precise application can be ensured instead of excessive grease application. It has been installed in Mt Larcom. Delivery rate is 2 sec per every 32 axles when the wheel sensor activates the pump, and is electronically controlled. Every bar has six ports. 30 loaded trains containing 400 axles for wagons and also locomotives axles travel per day through this section.

Sited total axle number was 3,413,574. Axle set up was put at four for testing lubrication application rate on the trip. The lubricator tank capacity is 37 kilo having tank level indicator & Operating pump pressure is 40 bars. Both bars deliver grease through the same number of bars at a time. The wheel sensor can sense both directions of traffic.

It has no high maintenance issue except grease leakage at the end of the blade. There were some clogging problems also. The wear rate difference before and after lubricator set up is important to know. This Lincoln lubricator has a grease leak problem from the applicator bar. The applicator blades do not have any barrier at both ends, so the grease continually builds up on the ballast. There is top of rail and ballast contamination. The maintenance crews put Enratec on the grease, which is an absorbent material. It absorbs grease like gel, and is then taken away with the waste grease.
Figure A27: Components of Lincoln lubricators with short bars (control panel – axle counter, wheel sensor, progressive divider valve, applicator bar, reservoir & solar panel)