TOP OF RAIL FRICTION CONTROL FOR HEAVY HAUL: STATUS AND OPPORTUNITIES

Richard Stock, Kevin Oldknow, Davey Mitchell, Joel VanderMarel
L.B. Foster Rail Technologies, Burnaby, Canada

Summary

Top of rail (TOR) friction control is nowadays widely implemented in multiple heavy haul, mixed traffic and transit environments all over the world. A friction modifier (FM) consisting of a water-based suspension of dry solid materials with no liquid oil or lubricant content is applied (through wayside or on-board systems) to the TOR to provide an intermediate coefficient of friction (0.3-0.4) between wheel and rail. This paper will highlight the general benefits provided by this intermediate COF such as reduced lateral forces, improved wear and RCF behaviour of rail and wheel, as well as the potential for fuel savings. The technical and economic aspects of implementing TOR friction control on a larger scale with emphasis on the Australian heavy haul environment will also be discussed. Lastly strategies for implementing a sustainable and cost effective wheel-rail interface management program to provide the maximum benefit to the railway and vehicle operators will be highlighted.

.

1. INTRODUCTION

Top of rail friction control using friction modifier (FM) materials was first introduced in North America in the late 1980s in transit systems. In heavy haul it was intensely evaluated and widely implemented in the 2000s on US and Canadian Class 1 railways. In this arena it has become a widely accepted concept (in concert with gauge face lubrication) for management and optimization of the wheel-rail interface.
The key component for top of rail (TOR) friction control is the FM material that by definition adjusts the friction between the top of rail and the wheel tread to an intermediate level without adversely affecting safe train operations. Key drivers have included reduced train energy / fuel consumption, reduced wheel and rail wear, and reduced track maintenance costs (e.g. re-gauging and grinding). In Australia, while TOR FM has been implemented at selected sites, to date it has been primarily used for the purpose of local curve noise control (squeal and flanging). The purpose of this paper is to review the additional benefits that can be gained through wider use of TOR Friction Modifier in Australian heavy haul freight applications (beyond noise control), and ideally motivate a more substantial assessment of the corresponding technical and economic opportunities.

2. FRICTION MODIFIERS AND LUBRICANTS

A friction modifier consists of a water-based suspension of dry solid materials with no liquid oil or lubricant content. The water acts as a carrier and evaporates, leaving the dry FM particles in the third body layer between wheel and rail. These dry FM particles mix into the third body layer providing an intermediate coefficient of friction between the wheel and rail as indicated in figure 1. This intermediate friction level (0.3-0.4) is lower than dry rail but significantly higher than lubricated conditions [1]. Consequently lateral forces will be reduced, vehicle steering capabilities will be improved and damage on wheel and rail will be minimized without negatively impacting acceleration or braking capabilities. The Technology Transportation Centre Inc. (TTCI) in the US defines a friction modifier as a product designed to provide one intermediate friction level over a range of material application rates and/or hold the friction constant over a specific range of wheel-rail creepage [2]

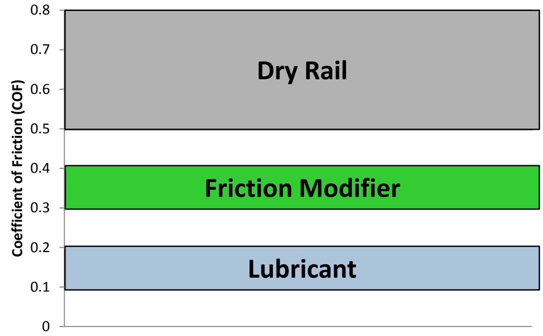

Figure 1: Friction levels for dry rail, friction modifiers, and lubricants.

An FM will also provide positive friction characteristics between wheel and rail over an extended creepage range as indicated in figure 2. This refers to a positive slope of the traction / creepage curve over all relevant creep levels. In dry contact conditions the negative slope of the traction-creepage curve can give rise to stick-slip oscillations at creep levels close to the maximum of the curve. Given certain boundary conditions (wheel-rail surface roughness, dynamic excitation) wheels can start to oscillate between these two creepage conditions causing noise issues (squealing noise) and damage development (corrugation) [3]. The positive friction characteristics of the FM will prevent this oscillating effect from happening.

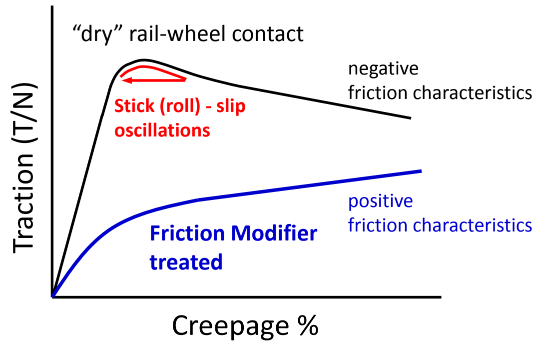

Figure 2: Traction creepage characteristics for dry and FM treated contact. An FM treated rail-wheel contact will reduce the friction level and will provide a positive traction-creepage relationship thereby preventing stick-slip oscillations from happening.

Recently, alternative materials that are lubricant based (oil, grease, hybrid) and therefore provide inherently low coefficient of friction (<0.2) have also been promoted for TOR application. These materials are not friction modifiers as they provide completely different friction mechanisms between the wheel and rail. This material type provides reduced friction conditions through a boundary or mixed lubrication mechanism [4] where the achievable friction value is strongly dependent on the amount of material present between wheel and rail. Such materials do not dry under normal conditions but rather are consumed by the wheel-rail contact conditions. Consequently for these non/slow drying materials there is presumably always a liquid phase present between the wheel and rail until the material has been completely consumed.

3. LATERAL FORCE REDUCTIONS

In railway vehicle dynamics, the resultant lateral curving forces acting on the track result from a number of factors including creep and flanging forces, load balance (vis a vis speed and cant), centrifugal forces, coupler forces, and other train dynamics. High lateral forces may cause excessive track structure degradation, high rates of wheel and rail wear and other unwanted effects. The extent of lateral forces can be influenced by train handling, track geometry, steering ability of bogies, and wheel-rail profiles. The optimised coefficient of friction (provided by the FM) can be directly translated into the reduction of lateral forces acting between rail and wheel.

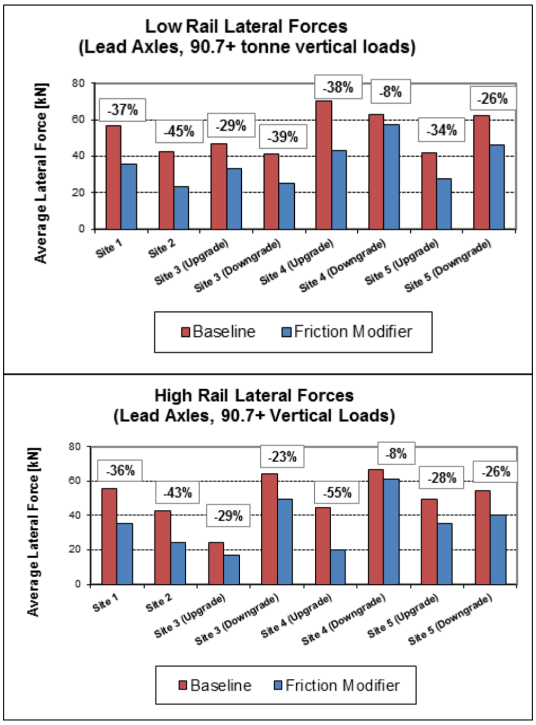

Figure 3: Example of lateral forces at different test sites for the high and the low rail in curves: baseline without Friction Modifier (control zone) vs. Friction Modifier applied and corresponding % reduction.

This positive impact on lateral forces has been extensively investigated and demonstrated at multiple locations worldwide. Figure 3 summarizes results from multiple trials at different North American Class 1 railroads [5]. The tested conditions covered a wide variety of track conditions (upgrade, downgrades, river/rolling grade), curvature and distances from the application site. Typically a 30% reduction in lateral forces could be achieved by treating the rail-wheel contact with the FM. The noticeable exception of test site no. 4 (downgrade) can be related to heavy downhill tread braking operations that led to abrasive removal of the FM from the rail-wheel contact, in combination with a relatively large distance from the FM applicator to the Lateral / Vertical force measurement site under these conditions. It has since been determined that applicator spacing and application rate can be adjusted accordingly to compensate for this effect.

As noted in figure 3 above, the reported force levels correspond to the average levels of peak lateral force exerted by leading axles of heavy axle load vehicles (as measured by strain-gauge based Lateral / Vertical force measurement sites).
Besides the impact of curve radius, the achievable lateral force reductions also strongly depend on vehicle and bogie design. Advanced bogie designs (e.g. self-steering bogies) will improve steering and thereby push the boundary of saturated steering conditions to sharper curve radii. Also wheel maintenance practices (e.g. actively maintained wheel profiles) will impact lateral forces by improving steering. Consequently, considering all of these factors for optimising lateral forces in a holistic approach will provide the highest technical and economic benefit. This can provide a viable area of application for FM in the Australian heavy haul environment.

4. WEAR AND RCF

As described above, TOR Friction Modifier application has the effect of reducing friction at the wheel tread / TOR interface to a controlled level and consequently reducing lateral curving forces. The reduction in wheel / rail friction levels has a direct beneficial impact on wear and rolling contact fatigue development at this interface through a corresponding reduction in energy spent at the contact patch. Furthermore, the reduction in lateral curving forces leads to a reduction in flanging pressure and consequently to a reduction in wear and RCF at the wheel flange / gauge face interface. The benefits of a Friction Modifier in reducing rail wear (and extending rail life) were first reported in 2003 [6] and subsequently studied and verified across a range of track structures and heavy haul operating conditions [5,7,8,9].

In order to further study the effects of a TOR Friction Modifier on rail wear in combination with RCF development and growth, a series of tests was conducted at the full scale rail-wheel test rig of voestalpine Schienen in Austria [10,11]. This test rig allows testing of real rail wheel contact conditions (high pressure and creep) in a laboratory environment. Figure 4 compares a new rail coupon with three different rails coupons used for testing at the test rig. The second coupon represents dry contact conditions after heavy haul loading for 100,000 wheel passes. Both wear and RCF damage (head checks at the gauge corner) are clearly visible. Under the same loading conditions, rail with FM application developed no cracks or head checks after 100,000 (coupon 3) and even 400,000 wheel passes (coupon 4) at the test rig.

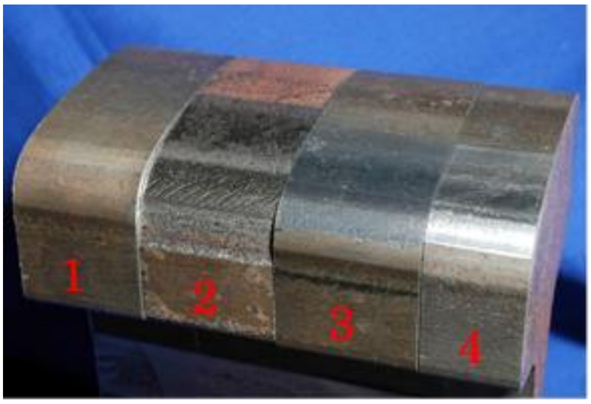

Figure 4: Rail head surface images after RCF and wear tests on a full scale rail wheel test rig at voestalpine: (1) - new rail; (2) - rail sample after 100,000 wheel passes dry; (3) - rail sample after 100,000 wheel passes with FM; (4) - rail sample after 400,000 wheel samples with FM. Significant reduction in wear and RCF development can be seen with FM application.

Importantly, it can be observed in the results shown above that FM application had the effect of simultaneously reducing both wear and RCF development. This can be explained by the reductions in creep forces and contact pressures, which are common underlying factors for both wear and RCF. These laboratory findings were confirmed at a heavy haul trial at Union Pacific Tehachapi site in

North America [12]. A "control zone" with GF lubrication only was compared with a "TOR zone" with active FM application and GF lubrication. Both sides experienced the same amount of traffic, had optimised track structure conditions and similar curvature so that the only identifiable difference was the FM application in the "TOR FM" zone.

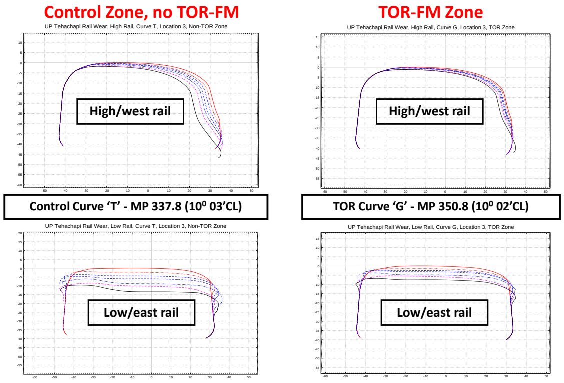

Figure 5: Union Pacific Tehachapi trial. Wear comparison of "control zone" (without TOR FM) and "TOR FM zone". A clear reduction in wear for the "TOR FM zone" for both high and low rail is visible after 165MGT.

Figure 5 shows the positive impact on the wear development after 165MGT. In curves with comparable curvature the wear rate in the TOR zone is drastically reduced for both the high and the low rail. A similar picture can be seen for RCF development after 90 MGT (figure 6). The application of a FM allowed for a minimum 15% grinding interval extension due to reduced damage in the "TOR FM" Zone.

The impact of an FM on grinding cycles was also analysed by TTCI at the Western Megasite at UP [13]. Figure 7 shows results for two curves with similar curvature where a preventive grinding strategy was compared with a combination of preventive grinding and FM application. The combined "grinding and FM" curve showed significantly slower rail material loss and a reduced number of grinding cycles while effectively preventing RCF development. The projected rail life was increased to 5700 MGT in the friction control curve from 4335 MGT in the preventive grinding curve.

Figure 6: Union Pacific Tehachapi trial. RCF development at 90 MGT – significant reduction in low rail RCF for the "TOR FM zone" compared to the "control zone".

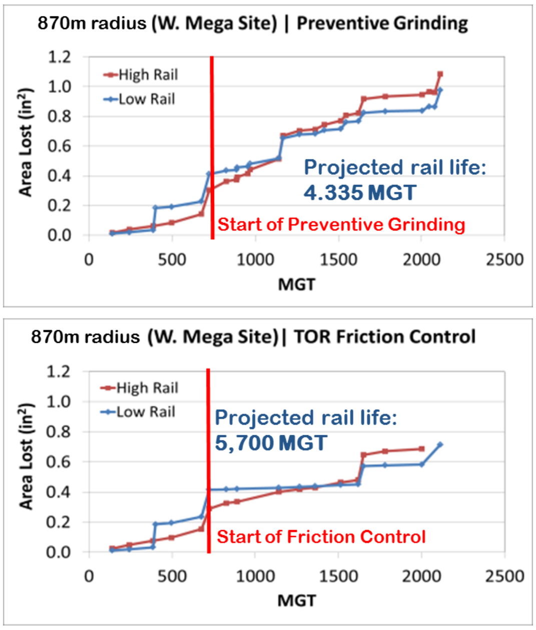

Figure 7: Preventive grinding strategy compared with TOR friction control. Projected 1300MGT rail life extension for TOR friction control.

Recent studies are also focusing on wheel life extension [14] by TOR friction control. A comprehensive test was conducted at a North American class 1 railroad comparing coal trains equipped with on-board TOR equipment with non-equipped coal trains. Although these trains were servicing different utilities (Utility A, Utility B) they shared 90% of identical track (approx. 950 miles each direction). A baseline (BL) phase without any FM application (phase I) was compared with an FM phase where several Utility B trains were spraying a water based, drying FM onto the track (phase II). Figure 8 compares wheel tread wear results for both utilities in both phases. TOR FM equipped Utility B trains show a clear reduction of tread wear during the FM phase (phase II). Even the non TOR FM equipped Utility B trains show some reduction in tread wear. It is hypothesised that this reduction is caused by retentive benefits of the spraying trains going to Utility B.

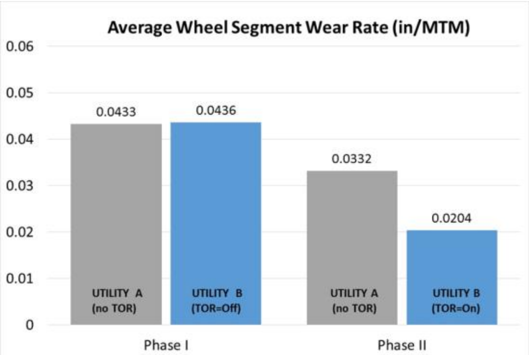

Figure 8: Wheel tread wear comparison. TOR FM equipped trains (Utility B) exhibit a clear wheel life increase compared to non-equipped trains (Utility A) and to baseline phase I.

Further analysis also showed a clear reduction in high impact force wheel change-out numbers in the FM phase II for Utility B compared to the BL phase I. As this work is still ongoing, more refined results are expected to be published in the near future.

As indicated above, both wear and RCF are strongly driven by a combination of contact pressure and creepage conditions [10]. Rail and wheel maintenance practices (optimised profiles, preventive maintenance) will reduce contact pressures, advanced materials (e.g. hypereutectoid rail steels) will delay the RCF damage development of rail and wheel, and optimising friction management will impact the creepage conditions in the rail wheel contact. Consequently, a system level approach (by combining all these measures) will help extending asset life and optimise rail system economics [15].

5. IMPACT ON FUEL

The use of TOR FMs to reduce fuel consumption has been proven on multiple occasions. In addition to gauge face lubrication, top of rail friction control can provide typical (diesel) fuel savings of 3% - 8% over a range of territories[16,17] (i.e. a total savings of 10% - 20% can be expected through the combination of gauge face lubrication and top of rail friction control vs. dry conditions).

In a comprehensive greenhouse gas study conducted in collaboration with the National Research Council of Canada (NRC-CSTT), fuel savings ranging from 3-4% were reported for a unit sulfur train monitored in the field [17]. This work identified that fuel savings were highly dependent on the terrain. Savings increased proportional to a territory's percentage of curved track. No savings were obtainable when the train was in dynamic braking. As an output of the greenhouse gas study, a model relating specific fuel savings (litres per million-ton-miles) to curve density was developed. The model was used to quantify the potential fuel savings on the mountainous route (high curve density) between Vancouver and Calgary, Canada on CP track. Estimates using the model determined fuel savings between 3-4% for friction management using wayside application of TOR materials, as well as, effective and optimised GF lubrication. After implementing friction management along the route, the physical results showed higher fuel savings than what had been shown in the model, with energy consumption reduced by an average of 5% [18].

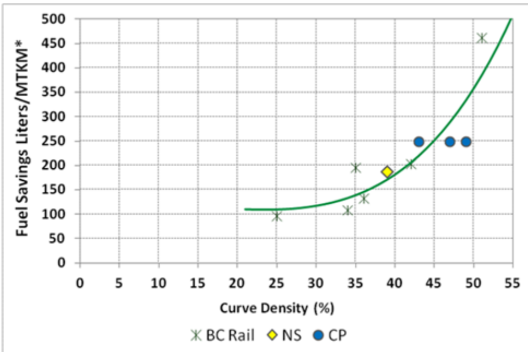

Figure 9: Combined fuel savings data with respect to curve density for multiple TOR FM trials (MTKM = Million Ton Kilometres). Relationship of achievable TOR FM fuel savings with curve density.

Norfolk Southern has also verified that the fuel savings predicted by the model mentioned above are conservative, and demonstrated the available savings with wayside deployment of an FM in revenue service [19]. The physically measured fuel savings of multiple trials are compiled in figure 9 highlighting the above mentioned relationship between curve density and achievable fuel savings.

At North American class 1 railraod, mobile (Train Mounted) on-board application of an FM was demonstrated to yield significant fuel savings for unit coal train operation in mildly curved territories [20], with percent savings in specific test segments reaching as high as 12%. This is supported by recent work in field assessment and modelling of fuel savings [21] that shows significant fuel savings to be obtained across a wide range of territories and operating conditions, including large territories made up almost entirely of tangent track and shallow curves. Train mounted systems have proven particularly well suited to providing meaningful fuel savings and economic benefits in these conditions. This would open up the application of TOR FM for fuel saving purposes to transcontinental type routes or closed loop systems like ore or coal lines as can be typically found in the Australian heavy haul environment.

6. APPLICATION STRATEGY

The selection of the appropriate application strategy is a key factor for an effective friction management program. For the heavy haul environment two possible approaches are available – wayside application or on-board application.

A typical wayside system (solar powered system consisting of tank, battery, precise pump and digital control box with remote performance monitoring capabilities) delivers precisely controlled amounts of FM through application bars to the TOR. The train wheels will pick up the FM and will carry it a certain distance through the track. Application is controlled using a non-contact active wheel sensor and digital controller. Unit spacing and application rates can be specifically adjusted to meet local operation conditions.

On-board technology uses a spray system (tank, digital control with remote monitoring capabilities, pumps and spray nozzles) to accurately deliver precise amounts of FM to the rail surface. Typically these systems can either be locomotive or vehicle mounted and can be equipped with heating capabilities for cold climate conditions. Based on train location (provided by GPS) the system can be activated/deactivated and application rates can be specifically adjusted (figure 10).


Figure 10: Example for an on-board TOR FM spray system for coal cars.

Local track and operating conditions will determine the selection of the appropriate application system. Wayside systems are suitable for treating all trains (independent of train type or train operator) in a specific (e.g. high curvature) track segment or territory. On-board technology can be used to protect specific trains or train types (e.g. ore trains, coal trains…) over a long distance and/or different routes.

On-board technology is also suitable for treating closed loop systems (e.g dedicated ore lines) or systems with single type (or near single type) traffic (e.g. coal routes). Furthermore, the ability to integrate FM-application systems into current maintenance practices and procedures needs to be factored in. Track and wayside application system accessibility (location, traffic density) or vehicle availability at a depot or yard will impact the operational efficiency of an FM application strategy.

7. CONCLUSIONS

It has been shown in this paper that friction management and especially the application of TOR FM can provide a wide number of benefits to the railway system. By choosing the appropriate application system (wayside or mobile/on-board) an FM will positively impact lateral forces in curves, wear and damage (RCF) of wheels, rails and other system components as well as fuel consumption of trains. This would provide a viable opportunity for the Australian heavy haul environment to expand TOR FM application beyond noise mitigation measures.

Friction Management, however, must not be seen as a standalone solution. As part of a wider system it will interact with and influence other factors such as rail and wheel metallurgy, rail and wheel profiles, track geometry as well as maintenance activities (e.g. rail grinding). Consequently a holistic approach will allow friction management to play a key role in optimizing the railway system. This will help to extend the asset life while delivering maximum economic benefit to the Australian railway operators and their customers.

8. REFENRENCES

[1] Eadie DT, Kalousek J. Spray it on, let 'em roll. Railway Age. June 2001.

[2] Reiff R, Gage S, Robeda J. Top of Rail Lubrication Implementation Issues, Transportation Technology Center Inc. Research Summary. July 2000; RS 00-001.

[3] Eadie D.T, Kalousek J, Chiddick KC. The role of high positive friction (HPF) modifier in the control of short pitch corrugations and related phenomena. Wear. 2002; Volume 253; Issues 1–2: 186-88.

[4]: Stribeck R. Die Wesentlichen Eigenschaften der Gleit und Rollenlager. Zeitschrift des Vereines deutscher Ingenieure. 1902; 45 (36):1341-48; 1432-38; 1463-70.

[5] Eadie DT, Oldknow K, Maglalang L, Makowsky T, Reiff R, Sroba P, Powell W. Implementation of wayside top of rail friction control on north American heavy haul railways. 7th World Congress on Railway Research Proceedings. 2006; Montreal.

[6] Eadie D, Vidler B, Hooper N, Makowsky T. (2003) Top of Rail Friction Control: Lateral Force and Rail Wear Reduction in a Freight Application. Proceedings of the International Heavy Haul Association, Fort Worth, Texas, May 2003.

[7] Eadie, D., Maglalang, L., Vidler, B., Lilley, D. and Reiff, R. Trackside Top of Rail Friction Control at CN, Proceedings of the IHHA Conference, Rio de Janeiro, Brazil, June 2005.

[8] Sroba P, Oldknow K, Dashko R, Roney M. Canadian Pacific Railway 100% Effective Friction Management Strategy. Proceedings of the IHHA Conference. Rio de Janeiro; Brazil; June 2005.

[9] Reiff R , Makowsky T, Gearhart M. Implementation Demonstration of Wayside Based TOR Friction Control. Union Pacific Railroad – Walong, CA. TTCI Technology Digest TD-05-018; July 2005.

[10] Eadie D, Elvidge D, Oldknow K, Stock R, Pointner P, Kalousek J, Klauser P. The Effects of Top of Rail Friction Modifier on Wear and Rolling Contact Fatigue: Full Scale Rail-Wheel Test Rig Evaluation, Analysis and Modelling. Wear. October 2008; Volume 265; Issues 9–10: 1222–30

[11] Stock R, Eadie D, Elvidge D, Oldknow K. Influencing rolling contact fatigue through top of rail friction modifier application – a full scale wheel-rail test rig study. Wear. May 2011; Volume 271; Issues 1–2: 134–42.

[12] Reiff R. Top of Rail Friction Control on Rail Surface Performance and Grinding. TTCI Technology Digest TD-07-039. November 2007.

[13] Davis D. Effectiveness of New Friction Control Materials- Vehicle Track Systems Research. Presentation at 2015 Annual AAR Research Review. March 31st – April 1st 2015.

[14] Peters J, Elvidge D. The Effect of Train Mounted TOR-FM on Wheel Life and Defects. Presentation at the 21st Annual Wheel Rail Interaction Conference. Atlanta; May 2015.

[15] Raman D, Chattopadhyay G, Spirigian M, Sajjad M. Research Methodology for Evaluation of Top of Rail Friction Management in Australian Heavy Haul Networks. Proceedings of the 10th International Heavy Haul Association Conference. New Dehli; India; February 2013: 342-48.

[16] Cotter J, Eadie D, Elvidge D, Hooper N, Roberts J, Makowsky T, Liu Y. Top of Rail Friction Control: Reductions in Fuel and Greenhouse Gas Emissions. Proceedings of the International Heavy Haul Association Conference. Rio de Janeiro; Brazil; June 2005.

[17] Cotter J, Elvidge D, Liu Y, Roberts J. Utilization of Top of Rail Friction Modifiers to Reduce Greenhouse Gas Emissions for the Freight Railroad Industry. Final Report Prepared for Transport Canada. April 2004.

[18] Roney M, Eadie DT, Oldknow KD, Sroba, P, Caldwell R, Santoro M. Total Friction Management on Canadian Pacific. Proceedings of the 9th IHHA Conference. Shanghai; China; 2009

[19] Conn K. FOR SALE — TOR/ATW FM. Proceedings of the 2010 Wheel Rail Interaction Conference. Chicago; USA; May 2010

[20] Reiff R. Mobile-based Car Mounted Top of Rail Friction Control Application Issues – Effectiveness and Deployment, TTCI Technology Digest TD-08-039. October 2008

[21] VanderMarel J,Eadie DT, Oldknow KD, Iwnicki S. A predictive model of energy savings from top of rail friction control. Wear. Volume 314; Issues 1–2; June 2014: 155-61