Utilization of Top of Rail Friction Modifiers to Reduce Greenhouse Gas Emissions for the Freight Railroad Industry

Final Report Prepared for Transport Canada
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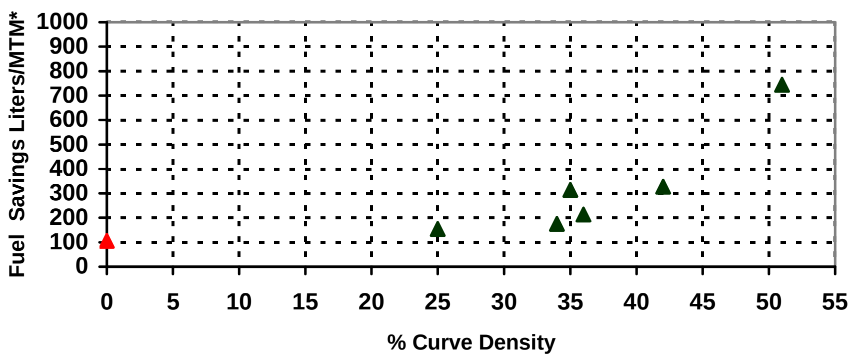
Executive Summary

This project consisted of equipping two BC Rail locomotives with prototype dispensing systems to spray a fluid onto the rail behind the trailing wheel on the tail end locomotive. The fluid (Kelsan KELTRACK®) controls the coefficient of friction between the rail and the wheels of the trailing 45 cars. Twenty test runs were completed, ten runs without the system spraying and ten runs with the system spraying. This project validated proof of concept for the spray systems and further validated benefits of KELTRACK® in reducing fuel consumption – quantified as a function of curve density.

This demonstration project was undertaken to assess the impact of Kelsan Technologies' Top of Rail (TOR) Friction Modifier Technology, KELTRACK®, on reducing fuel consumption/GHG emissions for a loaded 45 sulphur car test train traveling on BC Rail's Chetwynd subdivision between Chetwynd & Prince George. Measurable savings was based on monitoring changes in diesel fuel consumption, as well as mechanical drawbar forces. The project plan consisted of installing TOR dispensing equipment onboard two BC Rail high horsepower road locomotives (Dash 9-44CW). Specialized data acquisition equipment was installed onboard the main test locomotive, BCOL 4643, to monitor i) pertinent locomotive operating parameters, ii) location via an onboard GPS unit and iii) critical TOR dispensing parameters. Test Results indicate a strong correlation between curve density and fuel savings when the train is under tractive effort.

Highlights of the project include the following:

- Calculated savings ranged from 155 Liters/Million Ton-miles to a 744 Liters/Millions Ton-miles on track ranging in curve density from 25 to 51 percent due to the reduction in curving resistance. Earlier energy testing by the BNSF using a TOR product indicates savings of up to 2 % are possible on *tangent* track due to the reduction in rolling resistance and truck hunting. A broad assessment of this data results in a calculated savings of approximately 106 Liters/Million Ton-miles (red marker)



**Million Ton-miles*

- Calculated GHG Emission reductions (CO_2) ranged from 0.3 metric tonnes per million ton-miles to 2 metric tonnes per million ton-miles. Based on 2002 freight traffic data, the potential reduction in GHG emissions span from 114.6 kilotonnes to 167.5 kilotonnes annually or 2.1 % to 3.0 % of total freight railroad emissions. This is based on the premise that curve density for the entire track system lies somewhere in between 0 and 25 %.

- Application of a TOR friction modifier will not result in any fuel savings when a train is on a descending grade and in 100 % dynamic braking.

- Environmental monitoring indicated no build-up of TOR friction modifier product on ties or ballast.

Ancillary benefits determined were as follows:

- Improved truck steerability in sharp reversing curves was observed when the TOR friction modifier was applied.

- The TOR friction modifier was able to significantly reduce lateral forces when the train was under dynamic braking on descending grades. This work is ongoing.

- Ongoing field testing by BC Rail has shown that the TOR application rate from onboard a locomotive can be reduced by at least 40 % for the same benefit as compared to previous field testing.

TOR equipment performance was closely monitored over the entire project time frame, including through winter 2003/04. Highlights were as follows:

- No major issues developed, including when the TOR equipment was observed to perform down to temperatures of -30 °C.

- While a variety of equipment issues did arise, the most prominent being sticking solenoid valves, BC Rail, Kelsan and Lubriquip collaborated to design and implement solutions – the last of which are planned for implementation in April 2004. The field testing over the eleven months of this project was a major benefit in shaking down a prototype system and developing a commercial TOR system.

Recommendations are as follows:

1) Energy testing on transcontinental trains running predominantly on tangent track to confirm BNSF results on a macro scale as well as to determine the optimal TOR application rate/strategy.

2) Installation of multiple onboard units on a freight railroad to develop the following:
    a. Establish guidelines to optimize installation time of dispensing equipment
    b. Establish guidelines pertaining to logistical/operation requirements (ie reservoir refilling, application strategies etc)
    c. Establish equipment maintenance requirements (180 day, 360 day etc)

Future implementation of TOR technology should include analysis of BC Rail's ongoing experience with their two TOR locomotives.

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Project Overview

This demonstration project was undertaken to assess the impact of Kelsan Technologies' Top of Rail (TOR) Friction Modifier Technology, KELTRACK®, on reducing GHG emissions/fuel consumption for a loaded forty-five sulphur car (trailing tonnage approx 6,000 tons) test train traveling on BC Rail's Chetwynd subdivision (Figure 1) between Chetwynd and Prince George, British Columbia.

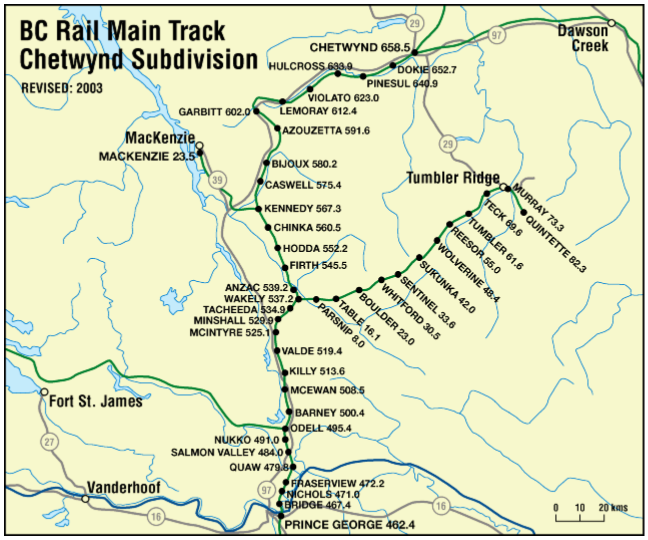


Figure 1: Chetwynd Subdivision

The primary function of a top of rail friction modifier is to reduce the curving resistance of the standard three-piece North American truck. Reducing the curving resistance results in less tractive effort required by the motive power to maintain a specific speed; this leads to lower fuel consumption and subsequently lower GHG emissions. In many respects, improving the steerability of these standard trucks by optimizing the coefficient of friction at the wheel/rail interface emulates the same behaviour of premium suspension (self-steering) trucks. On level tangent track, the use of TOR friction modifiers has been shown to reduce the intensity of truck hunting[1] as well as reduce rolling resistance[2]. Rather than present a single value representing the complete savings from Chetwynd to Prince George, the decision was made to divide the test subdivision into nine distinct segments based primarily on grade as well as curve density. The use of GPS technology in this demonstration project allowed us to segment the data accordingly (Table 1).

Segment	Length (miles)	Composite % Grade	% Curves (Distance)	Breakdown of curves in Segment
1	12	+0.30	34 %	< 5° (350 m): 17 < 5° (350 m) < 8° (218 m): 7 > 8°: (218 m) 6
2	8	+0.93	42 %	< 5° (350 m): 20 < 5° (350 m) < 8° (218 m): 11 > 8°: (218 m) : 2
3	5	+0.00	51 %	< 5°(350 m): 8 < 5°(350 m)< 8°(218 m): 5 > 8°(218 m): 0
4	10	-0.88	47 %	< 5°(350 m): 22 < 5°(350 m)< 8°(218 m): 13 > 8°(218 m): 10
5	25	+0.00	36 %	< 5(350 m)°: 46 < 5°(350 m)< 8°(218 m): 13 > 8°(218 m): 4
6	39	-0.03	34 %	< 5°(350 m): 61 < 5°(350 m)< 8°(218 m): 13 > 8°(218 m): 1
7	22	+0.02	25 %	< 5°(350 m): 14 < 5°(350 m)< 8°(218 m): 6 > 8°(218 m): 0
8	16	-0.53	15 %	< 5°(350 m): 8 < 5°(350 m)< 8°(218 m): 1 > 8°(218 m): 0
9	11	-0.05	35 %	< 5°(350 m): 14 < 5°(350 m)< 8°(218 m): 4 > 8°(218 m): 1

Table 1

Figure 2 provides an overall perspective of the elevation change of the trip between Chetwynd and Prince George.

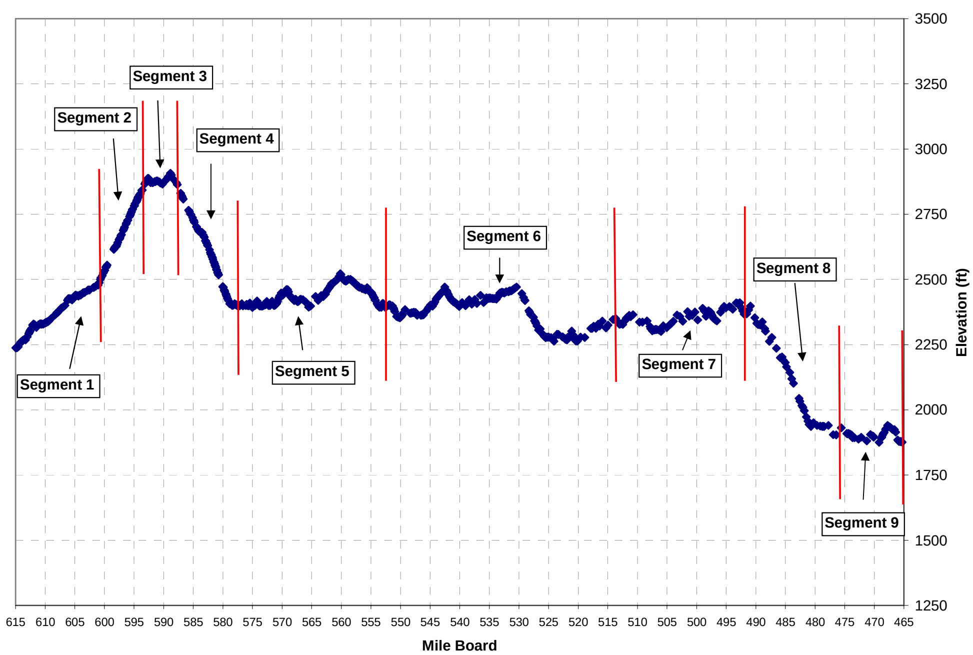


Figure 2: Division of test track into segments.

Use of segmented data would be of more value to the Canadian freight railroad industry as industry members could use the segment data to more accurately assess the potential savings for their own rail systems. Furthermore, the data can be used to assess correlations with respect to fuel savings/GHG emission reductions as a function of curve density.

Corollary objectives of this project were:

- To assess train handling;
- To assess the impact of TOR friction modifier technology on improving the steerability of trucks, especially in sharp reversing curves;
- To measuring lateral force reduction as a function of TOR application rate for full length trains (90+ cars);
- To assess the reliability of the TOR dispensing equipment, including operation in winter months in temperatures below -25 °C; and,
- To monitor TOR product build-up, if any, on ties and ballast.

Briefly summarizing, the project plan consisted of installing specialized dispensing equipment onboard two state of the art BC Rail high horsepower road locomotives (GE Dash 9-44CW). Specialized data acquisition equipment was installed onboard the main test locomotive, BCOL 4643, to monitor: i) pertinent locomotive operating parameters; ii) test train location via an onboard GPS unit; and, iii) critical TOR system dispensing parameters. The project consisted of two phases, each containing approximately five baseline runs and five TOR application runs for a total of twenty test runs. All data captured was reviewed and sorted by Kelsan Technologies and then packaged for distribution to the National Research Council Centre for Surface Transportation Technology (NRC-CSTT) for complete data analysis to derive fuel savings and corollary green house gas reduction.

BC Rail was responsible for marshalling the forty-five car unit sulphur trains and scheduling the test runs from the sulphur load-out site and/or nearby staging tracks and operating the test trains to Prince George. BC Rail, Kelsan and Triton Environmental Consultants were responsible for collecting and analyzing the environmental monitoring part of this project.

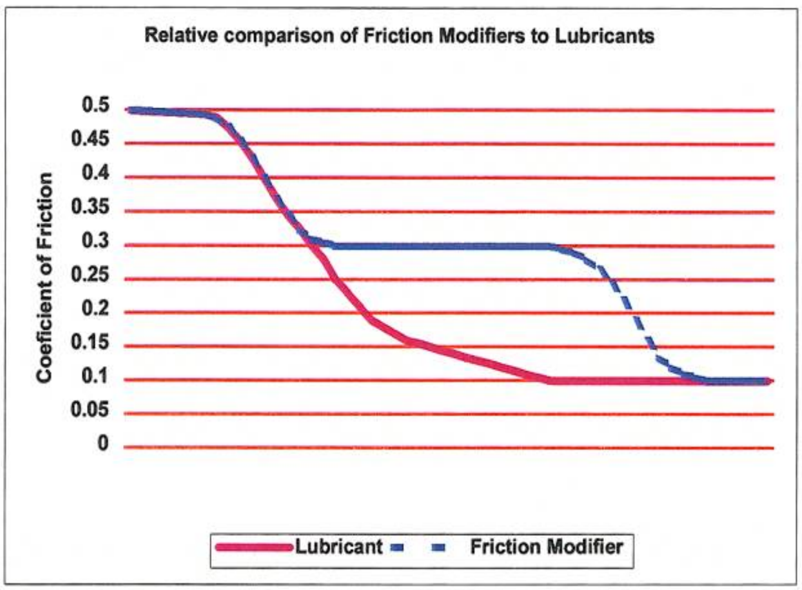
Overview of TOR Friction Modifier Technology

Top of rail friction management is not a new concept. It has been employed since reports of the ability to dramatically reduce fuel consumption with TOR lubrication appeared more than a decade ago. But since the operating and maintenance challenges associated with lubricating the running surfaces of rails have not been overcome, development has continued and new technologies like TOR friction modifiers have evolved. Engineered TOR friction modifiers have emerged from the conceptual stage and moved into the commercial stage over the past several years. As with any new technology there are questions about the nature of TOR friction modifiers: What do they do? How do they work? How do they compare with traditional lubricants? While the application procedures and delivery systems for TOR lubricants and friction modifiers are similar, the performance characteristics of the two materials are fundamentally different.

Lubricants vs. Friction Modifiers

In simple terms, lubricants, which include oils, greases and synthetic polymers reduce friction levels rather than control friction levels. Friction modifiers, like KELTRACK®, are composed of engineered, dry composite solids suspended in a water-soluble mixture and are able to reduce, control, and maintain friction at an optimal level. This distinction is significant, given that in order to enhance vehicle performance, without negatively impacting traction and braking performance, optimal TOR friction levels must be maintained at the point of application (typically behind the locomotives) and at the last axle of the train. In their report, "Top of Rail Lubrication Implementation Issues" (RS 00-001 July 200), Rieff, Gage, & Robeda accurately defined "friction modification" as follows:
"Friction modification products are designed to provide one friction level over a range of material thickness and/ or hold friction over a specific range of wheel/ rail creepage."

Figure 3 illustrates this concept graphically with respect to the difference between a Top of Rail friction modifier and a lubricant. What is interesting to note is that a true friction modifier will maintain an intermediate coefficient over a range of application rates. Although the graph, postulates that at some maximum application rate a friction modifier will behave as a lubricant, we have yet to observe this behaviour in the field.



Note: Non-dimensional increase of friction modifier/lubricant thickness/amount left to right.
Figure 1. Conceptual Performance of a Lubricant and a Friction Modifier

Figure 3: Comparison of a TOR Lubricant vs. a TOR Friction Modifier

What do the differing frictional attributes of these two materials mean with respect to train performance and wheel/rail interaction? The answer lies in examination of the performance characteristics of the materials in typical onboard application approaches on freight railroads.

Lubricant based TOR systems

In a locomotive mounted onboard TOR lubricant system, a stream of lubricant is applied on top of the rail behind the trailing axle of the trailing locomotive. The placement is crucial to enhancing the performance of the cars within the train without affecting locomotive adhesion. The following graph (figure 4) illustrates the frictional changes that occur through the axles of sequential freight consists.

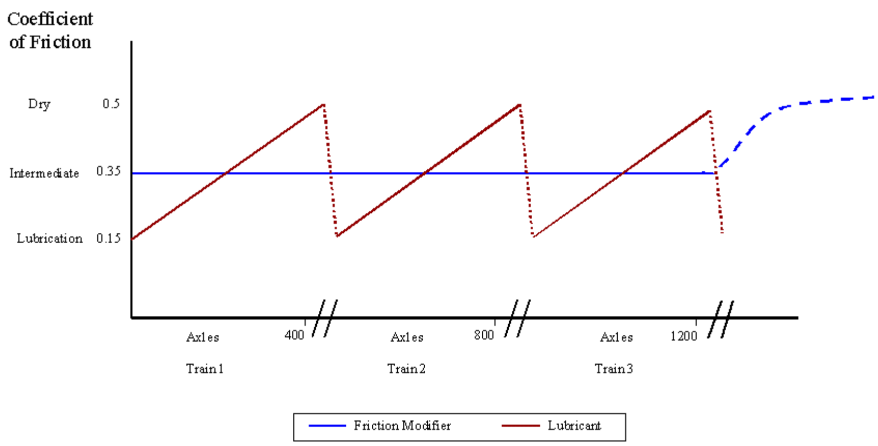


Figure 4: TOR Friction Behaviour comparing a lubricant with a friction modifier

With application of a lubricant, friction levels will vary as subsequent wheels pass over the material but steadily increase throughout the length of the train as evaporation or oxidation occurs. This non-controlled friction level can have potential consequences such that:

- Wheels within the first part of the train may experience a lower than optimal COF, potentially leading to braking problems or skid flats on these cars.
- Wheels within the later part of the train may experience a higher than optimal COF leading to higher lateral loads.

An additional consequence of TOR lubrication is that in order to ensure adequate adhesion for the locomotives of subsequent trains, all of the lubricant must be evaporated or burned off by rail/wheel interaction so that friction levels return to 0.35 or greater by the last wheel of the train. This requires a sophisticated control system that is capable of adjusting the application rate to accommodate varying conditions. It further requires a control system that is capable of ensuring that enough lubricant is applied to the rail to accommodate the last wheel of the train but not so much that the lubricant remains on the rail after the last wheel has passed – a condition that could result in too low a friction level for the next train and therefore potential adhesion problems for the following locomotive consist. Given the wide range of operating variables that may influence the rate of lubricant removal, this represents a significant control challenge.

Friction Modifier based TOR Systems

Unlike lubricants, friction modifiers are able to reduce the COF of dry rail and maintain the desired intermediate level of friction over a given number of trains or wheel passes. Friction modifiers formulated for freight applications contain no oils, greases or other liquid lubricant components.

They are composed of engineered composite solids that are mixed with water and deposited on top of the rail in liquid form. When the water evaporates, the remaining thin dry film maintains an optimal intermediate coefficient of friction. Kelsan Technologies has developed a line of proprietary friction modifiers that, when applied to the top of the rail will control friction in the intermediate range of 0.3 +/- 0.05 µ. A water-based KELTRACK® liquid friction modifier is applied to the top of rail behind the last driving wheel of the trailing locomotive. The water-soluble material is applied as a fine atomizing spray to ensure rapid drying and production of a thin uniform film on TOR. The water in the material is quickly evaporated under the action of the first few wheels and the dry 0.45 COF is reduced to about 0.35, a level that is maintained throughout the length of the train. Since this intermediate level of friction can be maintained, the material need not be dissipated or removed by the last wheel on the train. In fact, the residual KELTRACK® left on the rail can actually benefit a subsequent train by reducing lateral forces and energy consumption even if the subsequent train has no friction modifier delivery system of its' own onboard. With no need to remove residual material from the rail, compensation for the range of such operating and environmental conditions as speed curvature, creepage, temperature etc is much less critical. As a result, the friction modifier's control system is greatly simplified as compared to the control system required by a TOR lubricant.

Fuel Savings: Calculations & Analysis

Overview

Prior to commencing the analysis, let us first examine where the potential fuel savings are in applying a TOR friction modifier to reduce curving resistance. Figure 5 provides a general overview where the potential savings are in relationship to the following parameters:

- Curve density (tangent, low, medium, high)
- Grade (Ascending, flat, descending)
- Train Handling (Re dynamic & air braking)

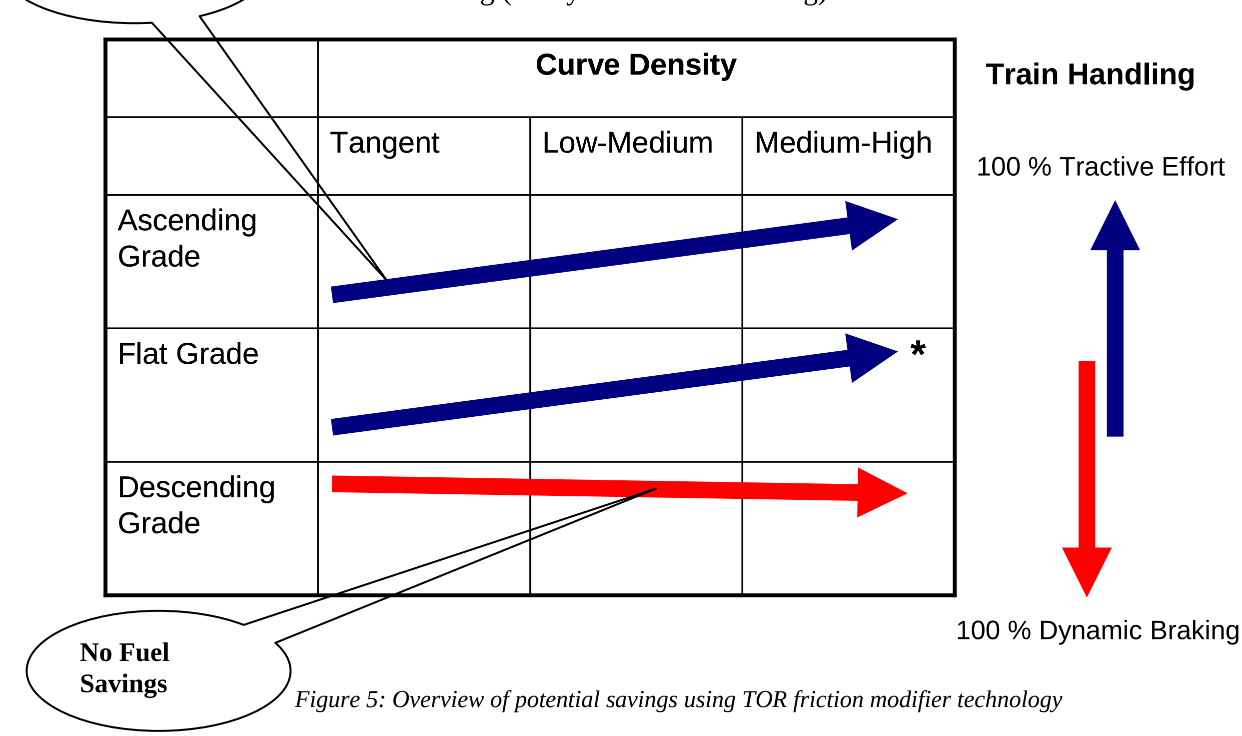


Figure 5: Overview of potential savings using TOR friction modifier technology

To briefly summarize, the figure demonstrates that:

i) (Increasing) fuel savings [**blue arrow**]are obtained when the train, under tractive effort, encounters (increasing) curve "density" typically defined by the number/length of curves within a given segment as well as the degree of curvature.

ii) On descending grades, fuel savings through the application of a TOR friction modifier will be essentially zero if the consist is in DB for the majority or 100 % of the time [**red arrow**].

iii) With respect to trains traversing a flat grade, fuel savings are possible both for tangent track as well as track with increasing curve density. *However*, fuel savings will be modified/influenced by the change in train handling behaviour, namely variations in tractive effort/dynamic braking work which can occur on a flat grade.

Presentation and analysis of the fuel data will be done in the aforementioned context.

Influence of Curve Density on Fuel Savings

To determine savings as a function of curve density, the data was filtered to remove all traces of dynamic & air braking. In other words, the consist would be *under 100 % tractive effort.* In calculating fuel savings, it is important to determine the change in train momentum due to the application of a TOR friction modifier. Correcting the fuel consumption for changes in the speed profile is also important in order to eliminate any (speed) variation due to differences in operator handling. The calculation primarily assesses the change in kinetic and potential energy (momentum) of the train. Introduction of dynamic braking, as well as air braking, distorts the calculation as the energy balance now includes a term where energy has been converted to heat (through braking).

Both mechanical work & fuel savings have been calculated. Two methods were used to calculate fuel savings:

1) GE Model: **Fuel usage derived from Q-TRON data and Locomotive fleet design (calibration) information**

GE has indicated that fuel consumption can be accurately measured by examining the data from the event recorders (i.e., notch settings), and by measuring barometric pressure and ambient temperature. This method bases its' fuel consumption model derived from a "fleet" engine. In doing so, it assumes that all engines are equal in terms of fuel consumption and power output. In reality though, there will always be some variability from one engine to the next. The variability becomes much larger in older locomotives, because it is dependent on the state of maintenance of the engine, the number of hours of operation since the last overhaul, etc. Since the same pair of engines (BCOL 4647 & BCOL 4643) was used for all test moves though, the *relative* fuel consumption between the two measurements would give a good comparative result.

The accuracy of this method is also dependent on train handling. Changing notch settings frequently will cause a difference in fuel consumption determined analytically (as compared to fuel consumption measured via flowmeters). The average time spent in a notch appears to be approximately 2.5 minutes, and notch changes at this frequency have a negligible effect on fuel consumption calculations.
If the notch changes are happening every 60 seconds or less, then they start to have an effect of fuel consumption calculations. More specifically, changes in notch settings are not *instantaneous*; rather

there is some delay in achieving the targeted fuel consumption rate. Frequent changes in notch setting will mean that the specified fuel consumption rate is usually not achieved.

2) Fuel Consumption derived from Mechanical work.

The basis of this methodology was to derive a conversion factor for each of the test runs to convert the mechanical work into a fuel consumption value. Unlike the aforementioned method which uses discrete notch settings to derive a (discrete) fuel value, a *composite* fuel consumption is calculated for a specific distance which would include a range of different notch settings employed in the specified segment. Calculation of the fuel savings follows the same methodology employed by the GE method (ie correction for temperature, pressure, & parasitic losses). The total fuel consumed for the segment would then be plotted as a function of the calculated mechanical work derived from the load pin. It is important to note that the conversion data is based only on segments which have been filtered for dynamic & air braking.

For example, the following figure (6) shows the correlation between fuel consumption & mechanical work for the 3rd baseline test train in segment 1. Note the excellent correlation.

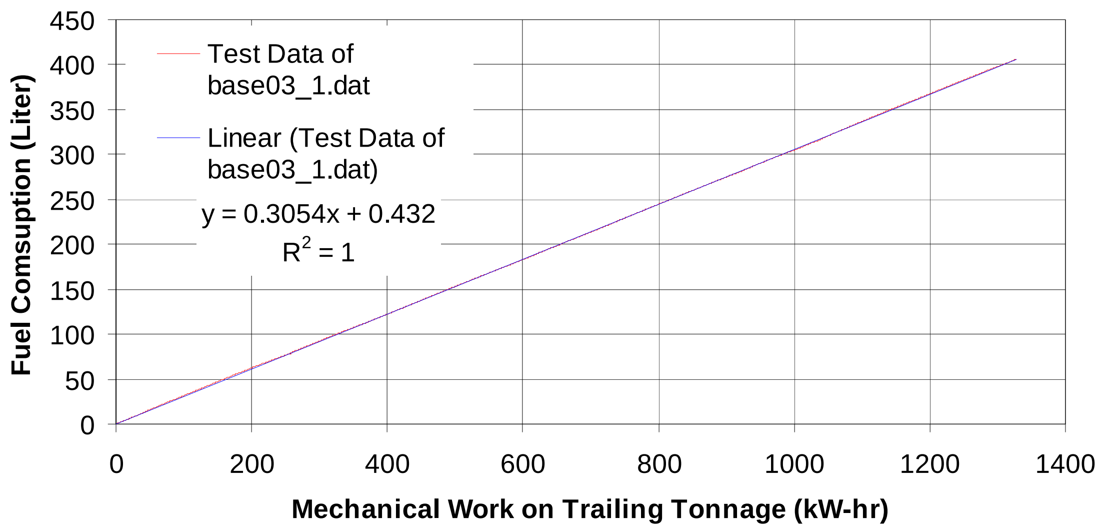


Figure 6: Correlation of Fuel Consumption (liters) & Mechanical Work (KWHr)

The downside of this method is the critical need to ensure the load pin accuracy for measuring mechanical work. This methodology was included after the interim report as a means to address the possible effect of frequent notch settings

Although data was collected to calculate savings based on electrical energy (tractive effort) consumption, the decision was made not to perform these calculations; instead, further attention was focused on the fuel consumption which can be directly related to GHG emission reductions. Further focus on the fuel consumption calculations allowed us to eliminate variability in train handling, associated with different operators, by the incorporation of a correction for the train speed profile. As a result, the need to plot the fuel consumption as a function of averaged train speed was eliminated.

Data Used for Calculations/Sources of Error

A total of 21 test trains were run; ten baselines & eleven TOR. (Conductor's report may be found in **Appendix A)** Two of the initial baseline test trains were not used in the calculations due to problems associated with the data acquisition equipment. The baseline data was collected in two phases, a set of 5 TOR test trains was run between the two baseline phases. After a delay of approximately six weeks, a further six TOR runs were collected after the final baseline phase (mid October – mid November). Unfortunately, this latter set of TOR runs were not used in the data calculations due to the following reasons:

- An offset appeared in the mechanical load pin which distorted mechanical work calculations (Calculated savings would have shown a *dramatic* increase as compared to first set of TOR test data).
- Weather conditions had changed (early onset of winter in interior of BC)
- Indications of higher fuel consumption for same mechanical work when the motive power was in a notch 8 setting, primarily in segment 2 (significant ascending grade).

For further information please refer to **Appendix B.** Raw data from the remaining 13 runs (eight baseline & 5 TOR) was collated and forwarded to the NRC for analysis.

Mechanical Work Savings

Table 2 & Figure 7 highlight the results from the mechanical work calculations for the eight baseline & five TOR test trains. These calculations were performed by the NRC; please refer to **Appendix C** for further details.

Segment	% Curve Density	Mechanical Work Savings (KWHr/MTM[1])	% Savings
1	34 %	387	1.93%
2	42 %	824	2.06%
3	51 %	2,857	12.40%
4	47 %		Descending Grade
5	36 %	1,059	4.68%
6	34 %	689	3.68%
7	25 %	626	3.56%
8	15 %	Descending Grade	
9	35 %	1107	4.27 %

Table 2: Mechanical Work Savings

Note 1:MTM- Million Ton-Miles

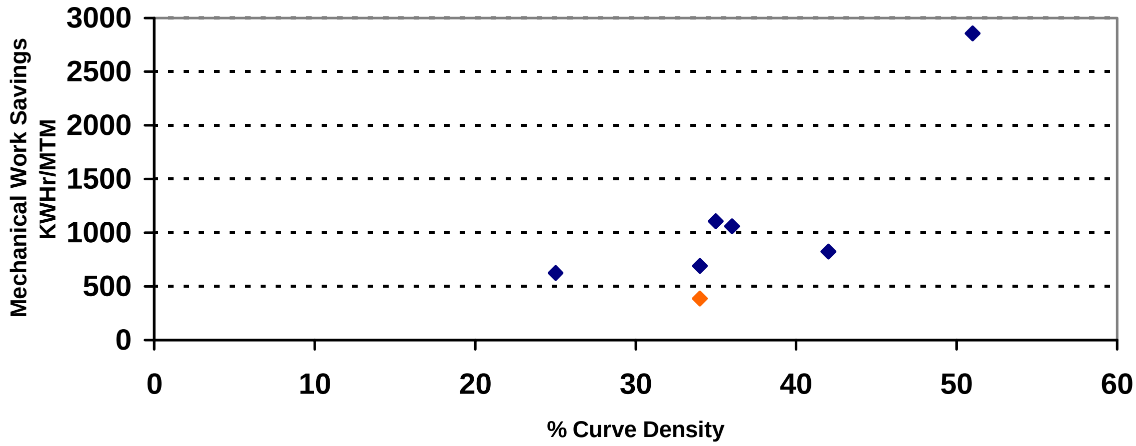


Figure 7: Mechanical Work Savings:

Although the data point for segment one (orange marker) has been included in figure 7, it should be noted that the TOR system was turned on immediately at the start of this segment. As a result, the low value is likely due to insufficient time for the friction modifier to work through the entire length of the test consist. In reviewing the remaining results, there does appear to be a general relationship between increased mechanical work savings and increased curve density among the other segments.

Fuel Savings

Fuel savings calculated by both methods are presented in both tabular (table 3) and graphical form (figure 8). GE Model calculations were performed by the NRC; please refer to **Appendix C** for further details. The Mech work fuel conversion values were calculated by Kelsan Technologies based on the mechanical work calculated by the NRC, please refer to **Appendix D** for further details.

		GE Model		Mech-Fuel Conversion		Average	
Segment	**Curve Density**	**Fuel Savings (L/MTM)**	**% Savings**	**Fuel Savings (L/MTM)**	**% Savings**	**Fuel Savings (L/MTM)**	**% Savings**
1	34 %	128	2.17%	149	2.36%	139	2.3 %
2	42 %	287	2.30%	367	2.74%	327	2.5 %
3	51 %	608	8.92%	880	12.06%	744	10.5 %
4	**47 %**	Descending Grade					
5	36 %	115	1.77%	312	4.35%	214	3.1 %
6	34 %	155	2.81%	195	3.29%	175	3.1 %
7	25 %	129	2.48%	181	3.25%	155	2.9 %
8	15 %	Descending Grade					
9	35 %	310	4.00 %	318	3.88 %	314	3.94 %

Table 3: Calculated Fuel Savings

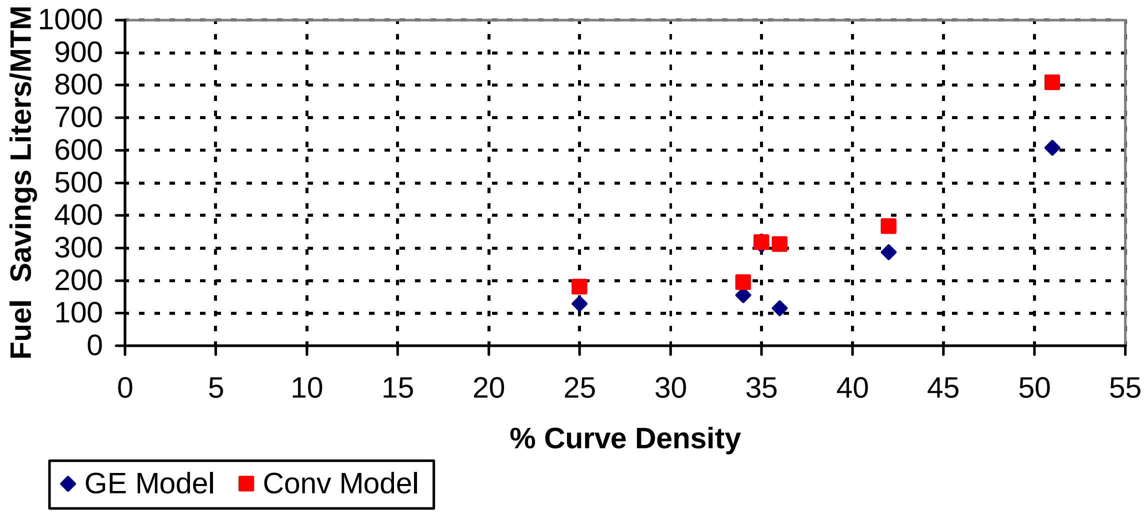


Figure 8: Fuel Savings

In reviewing the data from figure 8, there appears to be a strong relationship between fuel savings and degree of curvature for both models. Some discrepancy was observed for data generated from segment 5 (36 % curve density). Figure 9 shows the relationship when the results from the two methods are averaged.

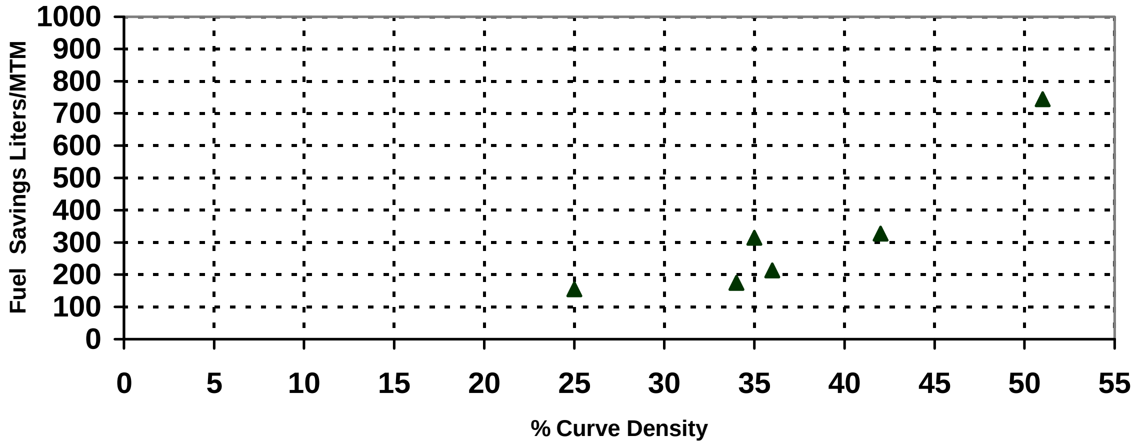


Figure 9: Averaged Savings combining both methodologies

Tangent Track:

Although the focus of the analysis has been on quantifying the relationship between fuel savings & curve density, the question has arisen as to what would be the fuel savings on tangent tack, an example would be a freight train traveling through the flat prairies where curves (and subsequent curving resistance) are few and far between. Recently, BNSF have completed studies where they have investigated the effect of a TOR product, in this case a lubricant, on reducing truck hunting and rolling resistance on a section of tangent track. A different methodology was employed in which the test train was allowed to "coast down" a section of tangent track at various speeds.

A load pin was used to measure the resistance of the trailing cars. The resistance data was subsequently fitted to a curve (Davis Equation) as shown in figure 10. Further information may be found in **Appendix E.**

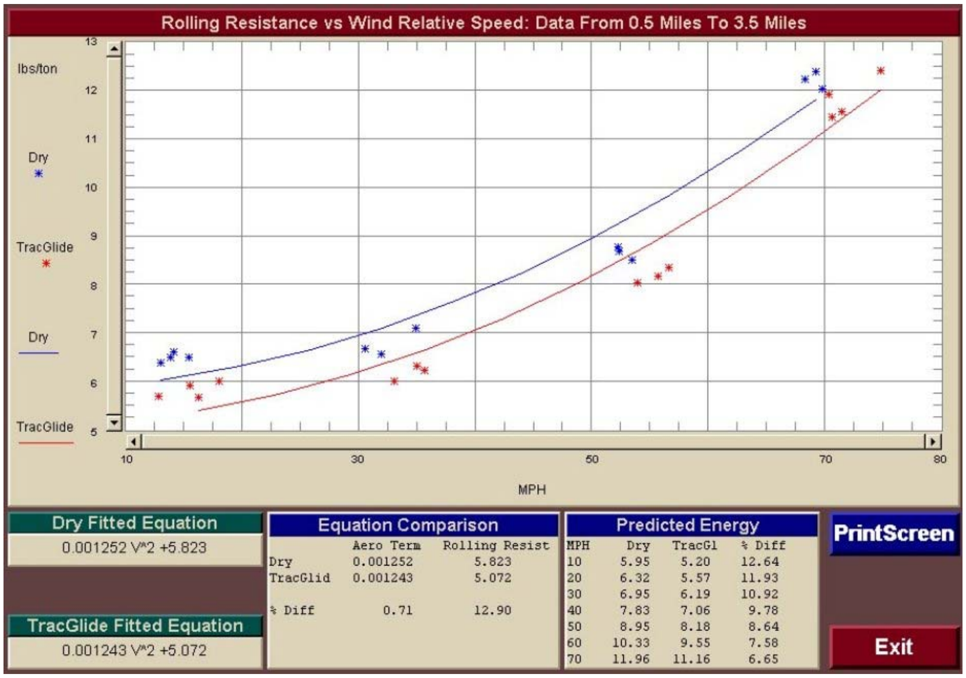


Figure 10: BNSF Coast Down Test Results

Based on BNSF's interpretation of this data, savings of approximately 2.1 % are possible due to reduction in rolling resistance (1.75 %) and truck hunting (0.21 *%).* For BNSF this represented potential fuel savings of approximately 93 million liters, based on 2002 fuel consumption data. *One must note that this does exclude any additional savings due to reduction in curving resistance.* Unfortunately, due to the different test methodology employed, we cannot convert the percent savings to an absolute savings (ie L/MTM) based on data obtained from this specific trial. However, we can attempt to determine an absolute savings based on a macro analysis of system wide fuel savings & system wide ton miles traveled in 2002. According to BNSF's 2002 annual investor report, total gross ton miles for the fiscal year was determined to be 873,335 million ton miles. By dividing the calculated fuel savings with the GTM value a savings of approximately 106 L/MTM was determined. For comparative purposes this data point has been added to the fuel savings data generated from this demonstration project (figure 11).

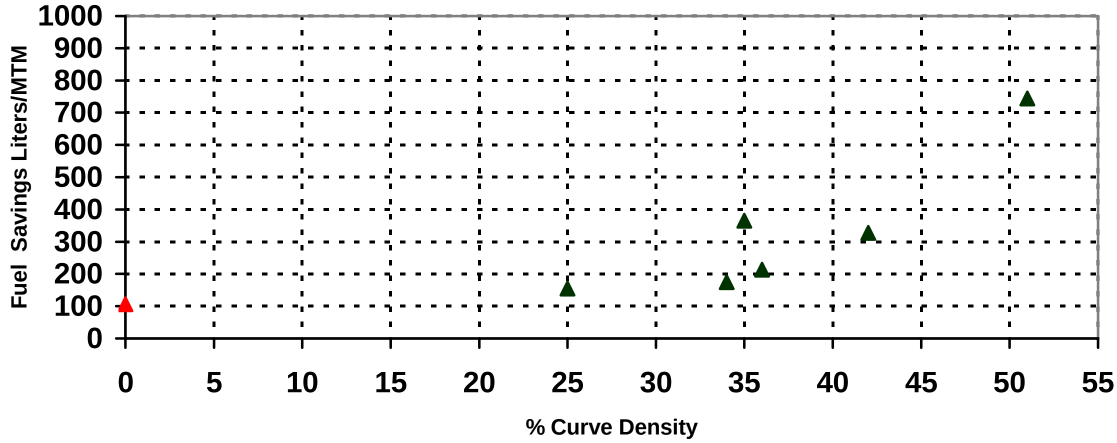


Figure 11: Fuel Savings including tangent data

The fuel savings data for tangent track does appear to follow the general trend of the data. Lower savings are expected, in comparison to sections of track with significant curvature; however, the savings are potentially significant due to the impact of truck hunting & rolling resistance at the elevated train speeds that are common on flat tangent track.

Dynamic Braking

In our effort to accurately define the relationship between fuel savings & curving resistance, dynamic braking was filtered out of the data. In this section, the impact of TOR friction modifier application, with respect to dynamic braking will be discussed in further detail. The discussion will focus on two distinct cases, the use of dynamic braking on flat and descending grades.

Descending Grades:

Fuel Savings/GHG Emissions reduction on descending grades will be *essentially zero*. If anything, there might be a slight *increase* in fuel consumption as the reduction in curving forces would lead to a *higher* use of dynamic braking in order to retard the train. In reality though, it is hard to quantify as air brakes are also used extensively to assist dynamic braking on descending grades. Furthermore, the amount of fuel consumed when a consist is in dynamic braking is extremely small as compared to the train under tractive effort.

From an economics perspective, the TOR dispensing equipment does have the option of *inhibiting* application when dynamic braking has been activated. Under these operating rules, no friction modifier is applied when the train is on a descending grade.

However, during the course of the demonstration project, it became obvious that other ancillary benefits, namely lateral force reduction, can be derived when the TOR friction modifier is applied on descending grades with sharp curves. Test data from the lateral force site located near mile-board 211 (Clinton BC) indicated significant lateral force reduction when a loaded 10,000 ton consist was in dynamic braking through a 12° (146 m) curve. Results from these tests will be discussed in further detail later in the report.

Flat Grade

Referring back to figure 5, one will notice that both the tractive effort & dynamic braking arrows were found in the area designated flat grade. In reality, on flat sections of track, there will be both tractive effort & dynamic braking employed for train handling purposes. When comparing baseline & TOR conditioned segments, analysis of DB data shows a general *increase* in the length of time and the distance applied that dynamic braking has been employed. The data has been summarized in figures 12 & 13:

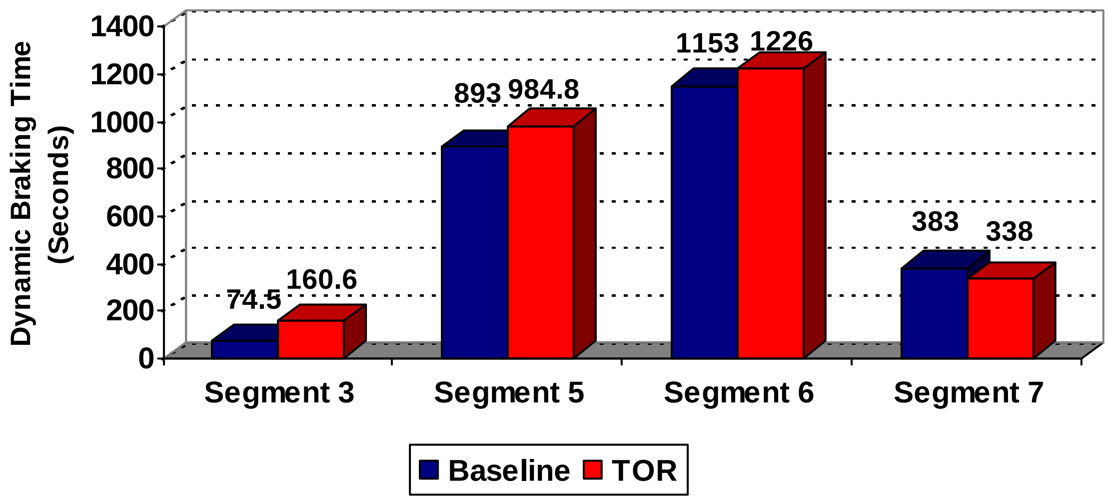


Figure 12: Segment Dynamic Braking Time (Seconds)

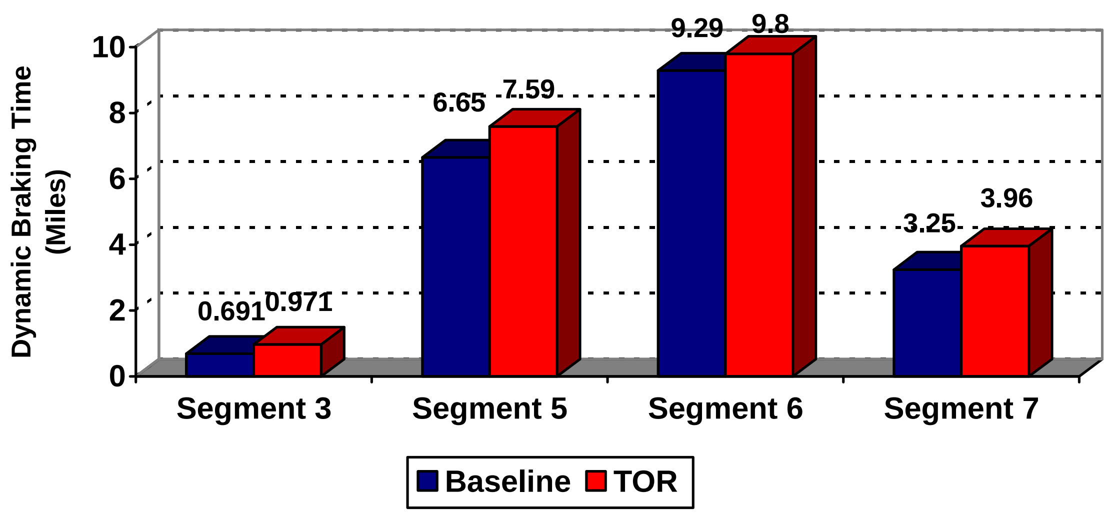


Figure 13: Segment Dynamic Braking Distance (Miles)

In assessing how DB influences the calculated savings for the data collected in flat segments where DB was present, the time & distance as well as trailing tonnage was used to calculated a dynamic braking fuel consumption value (L/MTM). This amount was then added to the calculated fuel consumption when the test consist was under tractive effort.

The calculation was simplified by assuming that the average fuel consumption for each locomotive while under dynamic braking was 24.4 L/hr. Since the train is under braking, no consideration has to be given to changes in train momentum. Please refer to table 4 for the modified fuel savings:

		GE Fuel Model		Conv Model	
Segment	**% Curve Density**	**Fuel Savings (L/MTM)**	**Fuel Savings inc DB (L/MTM)**	**Fuel Savings (L/MTM)**	**Fuel Savings inc DB (L/MTM)**
1*	34 %	128	128	149	149
2*	42 %	287	287	367	367
3	51 %	608	517	880	789
4	**47 %**	**Descending Grade**			
5	36 %	115	124	312	322
6	34 %	155	143	195	185
7	25 %	129	133	181	185
8	**15 %**	**Descending Grade**			

Table 4: Estimated Fuel Consumption per MTM for Dynamic Braking

* Note data remains unchanged as there was no reported Dynamic Braking

For most of the segments there was either a slight increase or decrease in fuel savings. In segment 3 a significant reduction in fuel savings was observed due to increased dynamic braking.

GHG Emission Reductions: Calculations & Analysis

Based on the Emission factors obtained from the "Locomotive Emissions Monitoring Program 2002" **(Appendix F)** the calculated emission reductions (Metric Tonnes per million ton-miles) were determined. The data is present in table 5. The CO_2 reductions have also been graphed in figure 14.

		Curve Density						
Emission	Emission Factors (g/L)	Tangent Track (Tonnes/MTM)	25 % (Tonnes/MTM)	34 % (Tonnes/MTM)	35 % (Tonnes/MTM)	36 % (Tonnes/MTM)	41 % (Tonnes/MTM)	51 % (Tonnes/ MTM)
NO_x	54.69	0.0058	0.0085	0.0096	0.0172	0.0117	0.0179	0.0407
CO	10.51	0.0011	0.0016	0.0018	0.0033	0.0022	0.0034	0.0078
HC	2.73	0.0003	0.0004	0.0005	0.0010	0.0006	0.0009	0.0020
SO_x	2.54	0.0003	0.0004	0.0004	0.0009	0.0005	0.0008	0.0019
PM	1.30	0.0001	0.0002	0.0002	0.0005	0.0003	0.0004	0.0010
CO_2	**2,709**	**0.2872**	**0.4199**	**0.4741**	**0.8506**	**0.5784**	**0.8858**	**2.0155**

Table 5

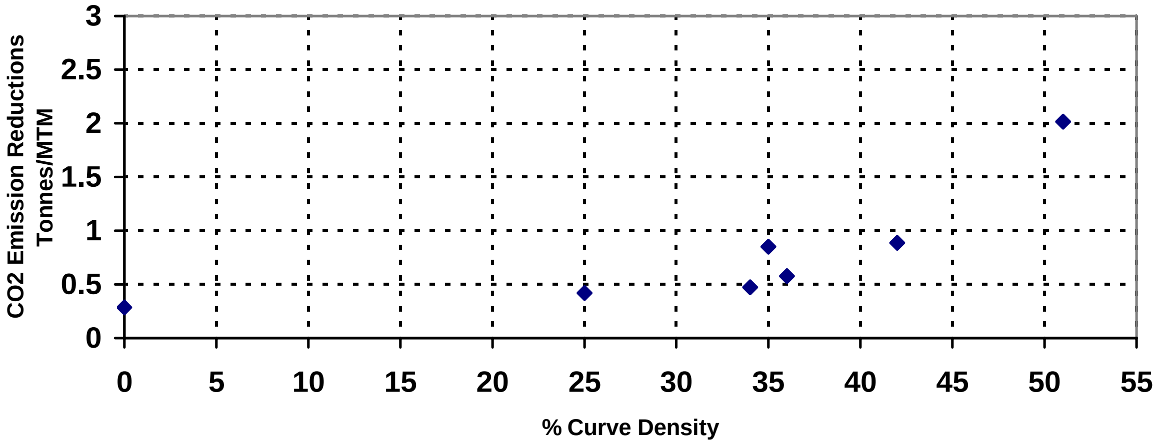


Figure 14: GHG Emission Reduction per Million Ton Mile

Based on 2002 freight traffic data, the potential reduction in GHG emissions ranges from 114.6 kilotonnes to 167.5 kilotonnes annually, or 2.1 % to 3.0 % of total freight railroad emissions. This is based on the premise that curve density for the entire Canadian freight track system lies somewhere in between 0 and 25 %. In mountainous terrain only, where there is significant curving resistance, the percentage savings is expected to increase. Further calculations will be required to ascertain an accurate reduction based on specific regional geography & traffic density.

In our demonstration project proposal, Kelsan Technologies Corp. stated that GHG emission reductions of up to 6 % were achievable in mountainous terrain. Analysis of the data does indicate that a significant *absolute* reduction in GHG emissions is possible in areas where there is considerable curving resistance. On a percentage basis though the amounts appear to vary; further analysis indicates that the presence of grade resistance significantly distorts the *percentage* savings; especially comparing it to a segment where there is no grade resistance.

Train Handling

During the course of this project no train handling issues were reported by the train crews or even observed by the crew when interviewed on trips when the TOR friction modifier was applied.

This includes:

- When the TOR product was applied during dynamic braking on descending grades to reduce lateral forces in curves.
- For trains following the TOR test train
- When air braking was used to decelerate a train. It should be noted that application of the TOR friction modifier was inhibited during activation of the air brakes.

In reviewing the locomotive Q-Tron event recorder data some differences in train handling were observed between the baseline and TOR test trains.

Specifically an increase in air brake usage was observed. For example, when assessing air brake and dynamic brake data for the five mile section of track designated as segment three (table 6) , additional use of air braking for TOR applying test trains was observed as compared to the baseline test trains where only dynamic braking was used. Data for all segments may be found in **Appendix G.** In most cases, a minimum air brake setting was used as means to control the train in conjunction with dynamic braking.

Baseline Test Trains	Braking Conditions	TOR Test Trains	Braking Conditions
Base 3	**DB,NAB,NS**	TOR 1	**DB,NAB,NS**
Base 4	**DB,NAB,NS**	TOR 2	**AB 591-592,S**
Base 5	**DB,NAB,NS**	TOR 3	**AB 591-592,NS**
Base 6	**DB,NAB,NS**	TOR 4	**DB,NAB,NS**
Base 7	**DB,NAB,NS**	TOR 5	**DB,NAB,NS**
Base 8	**DB,NAB,NS**	TOR 7	**DB,NAB,NS**
Base 9	**DB,NAB,NS**	TOR 8	**AB 588-589, 591-593,NS**
Base 10	**DB,NAB,NS**	TOR 9	**AB 588-589, 591-592,NS**
		TOR 10	**AB 588-589, NS**
		TOR 11	**AB 590-591, 592-593,NS**

Table 6

Key	
DB:	Dynamic Braking
AB:	Air Braking
NAB:	No Air Braking
NS:	No Stops
S:	Stops

Ancillary Benefits

As mentioned in the initial project proposal submitted to Transport Canada, the application of Top of Rail friction modifiers provides several other measurable economic and safety benefits, primarily in the areas of improved truck steerability, reduced lateral forces, as well as reduced rail wear. The GHG demonstration project provided us with the opportunity to measure ancillary benefits in the following areas:

- Improved truck steerability
- Reduced lateral forces on descending grades

Improved truck steerability:

The application of TOR friction modifiers can improve the steerability of standard North American trucks in intermediate & sharp curves. Field-testing included monitoring one test train during each track condition. Test data collected was used to identify truck steering differences between baseline and TOR treated conditions. The main criteria used in selecting the field test site were the presence of a sharp reversing curve (curvature above 8° (218 m)), wooden ties and standard cut spike fastening. The track conditions listed above were selected because they were expected to provide the maximum amount of rail deflection for comparing baseline and TOR treated conditions. Improvements in curve negotiation due to improved truck steering from TOR treatment were expected to be most apparent as the freight cars transitioned into the main body of the reverse curve section of the site.

After reviewing BC Rail's track profile and operating personnel, a suitable site located at mile 598 meeting track requirements with suitable track access was selected. The general test site layout is shown below in figures 15 & 16.

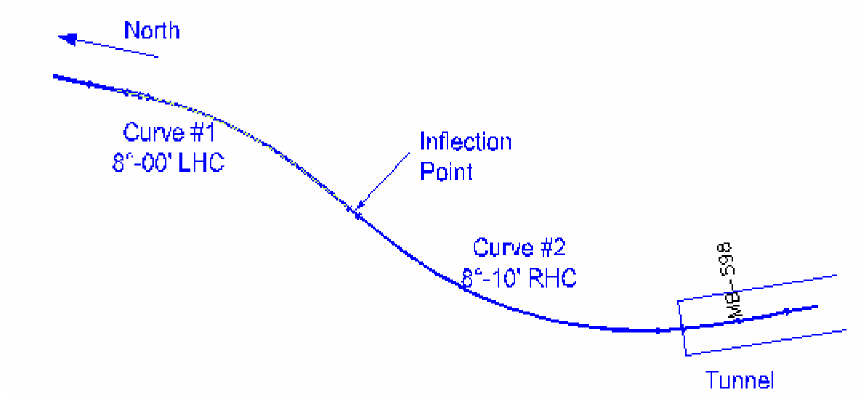


Figure 15 GHG Field Test Site Track Layout

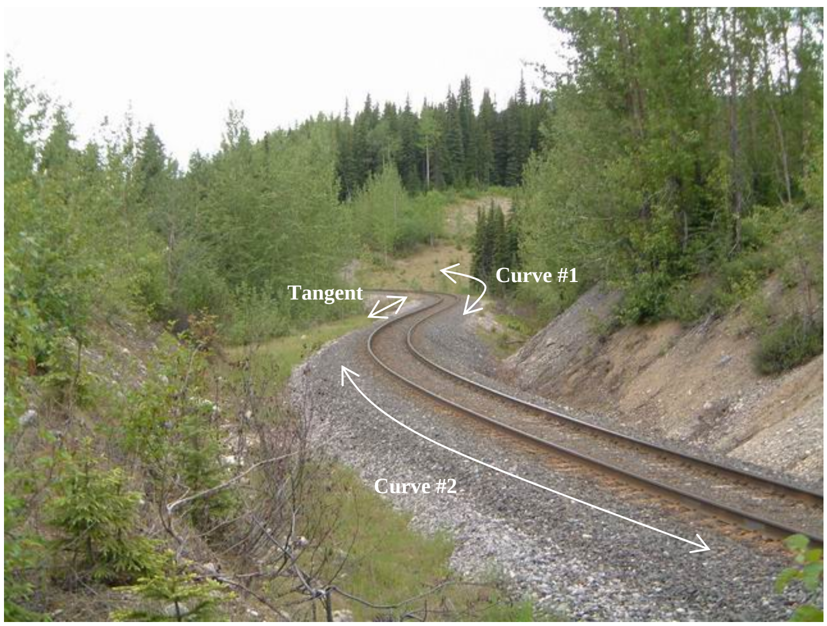


Figure 16

GHG test site track details:

- Curve #1: 8°- 00 (218 m) LHC, 430 feet in length (start 0-00 ft, end 4-30 ft)
- Tangent track between curves: 65 feet in length
- Curve #2: 8°-10' (214 m) RHC, 835 feet in length (start 4-95 ft, end 13-30 ft)
- Track: 115# weight, CWR
- Rolled plates, standard cut spikes, and rail anchors
- Mix of softwood and hardwood ties (HW every 3-4 ties in curves)

Rail Deflection Gauge (RDG) data for a baseline train (no TOR) are shown in figures 17 & 19 for tangent & curved track. Speed of test train was approximately 20-21 mph**.** Rail deflection results for TOR test train are shown in Figures 18 & 20 for tangent & curved track. Speed of test train was approximately 20-21 mph

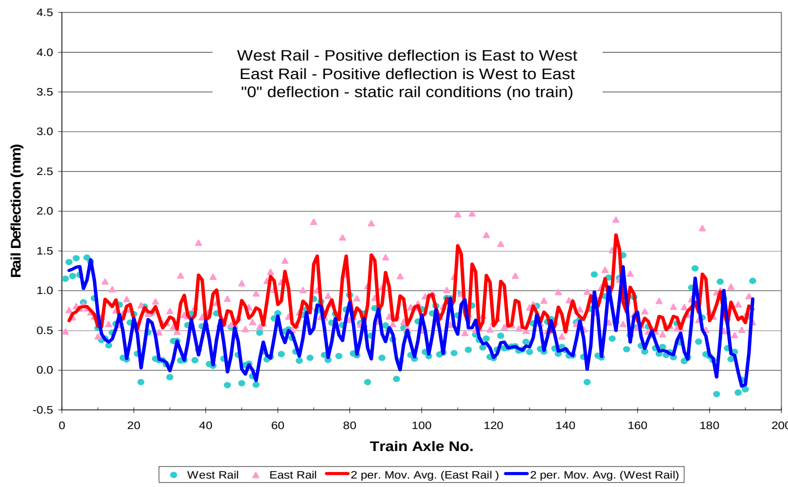


Figure 17 – Baseline Train RDG Data Tangent Section

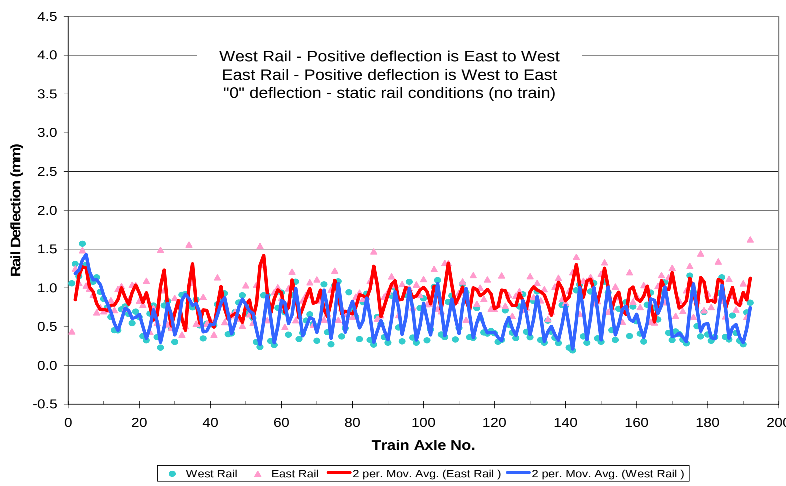


Figure 18 – TOR Train RDG Data Tangent Section

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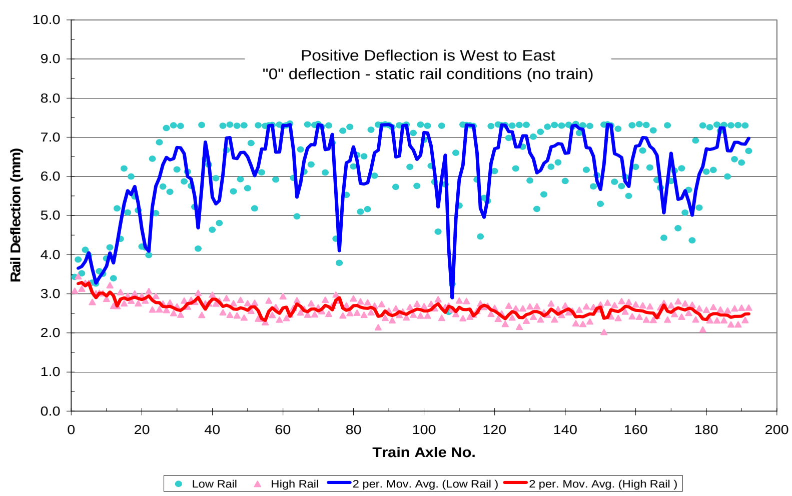


Figure 19 - Baseline Train RDG Data Curve #2

Figure 20 - TOR Train RDG Data Curve #2

Comparing low rail deflection results from curve #2 (Figures 19 & 20); the rail deflection and its variability were both significantly reduced with TOR application. Although the TOR application high rail deflection was slightly increased from 2.62 mm to 3.20 mm, the deflection variability (standard deviation) was also reduced over the baseline condition. The rail deflection data collected supports the findings that TOR treatment improved truck steering through the reversing curve #2. By providing uniform low and high rail friction conditions, improvements in truck steering were evident by the reduction in low rail deflection. The higher low rail deflection and variability during baseline conditions were attributed to increased truck warping that was reduced through the application of the TOR friction modifier. A detailed report outlining this field work may be found in **Appendix H.**

Lateral Force Reduction (BC Rail Lateral Load Detector Site @ Clinton, B.C.)

In the demonstration project proposal, examples of lateral forced reduction of up to 50 % in sharp curves were provided for freight applications. One example of lateral forces reductions obtained from an onboard locomotive application is shown in figure 21. This data is shown courtesy of the Transportation Technology Centre Inc (TTCI) of TOR testing performed at CSX involving Kelsan Technologies Corp. KELTRACK® TOR friction modifier.

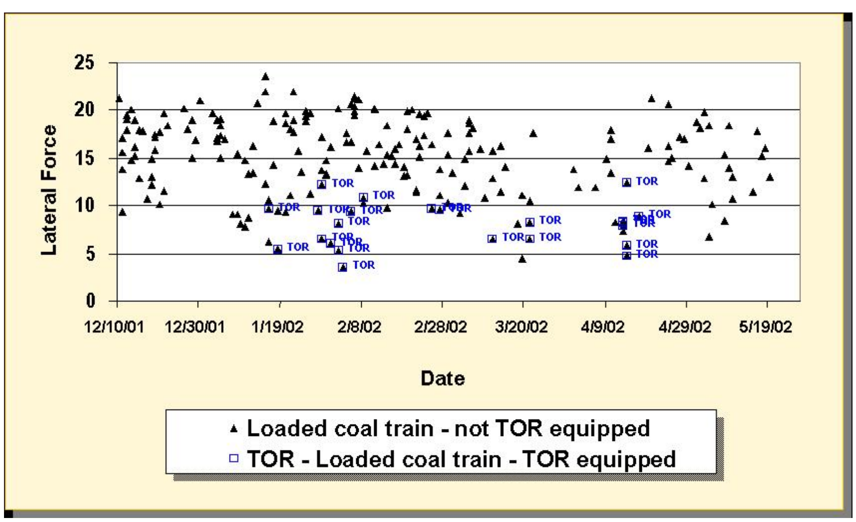


Figure 21: Lateral Force Reduction

Kelsan Technologies Corp. has been able to demonstrate effectively that its' TOR friction modifier can significantly reduce lateral forces. However, what has not been investigated is lateral force reduction for loaded trains on descending grades.

Lateral force reduction for loaded trains on descending grades

As mentioned earlier in the report, there are no tangible fuel savings/GHG emission reductions to be realized when a train is in dynamic braking (ie on a descending grade). From this perspective, the TOR equipment should not be dispensing on descending grades. However from a safety point of view, application of the TOR friction modifier on descending grades will help to reduce lateral forces on mild, intermediate and sharp curves. Furthermore application on descending grade will treat the TOR to benefit subsequent trains operating in the opposite direction.

BC Rail maintains an instrumented 12^{o} (146 m) curve near Clinton (MP 212) to measure lateral & vertical loads. This site, for loaded southbound trains, is on a descending grade that results in the use of dynamic braking (as well as occasionally, air braking). This site was south of Prince George and thus application of the TOR friction modifier would not affect ongoing primary testing north of Prince George (GHG emission reduction). For example, Figure 22 shows a significant reduction in lateral load reduction for the TOR treated 90 car 10,000 ton test southbound train.

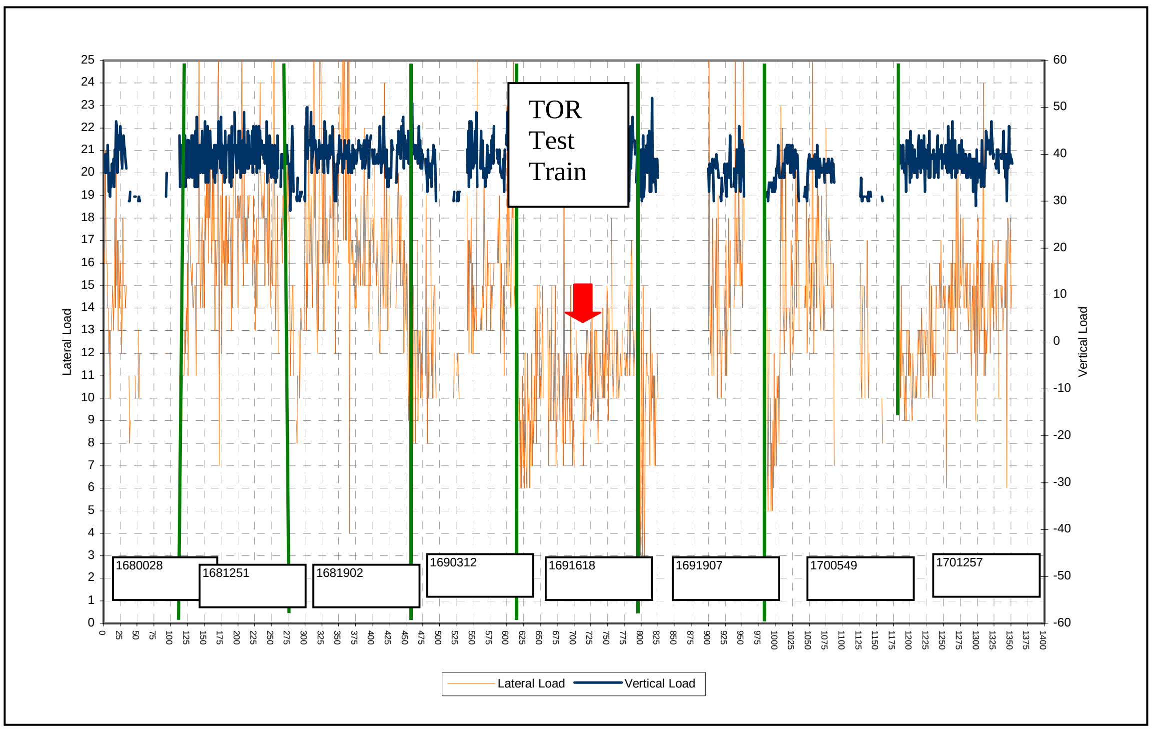


Figure 22: Lateral force reduction on a 12 degree curve on a descending grad; Train in DB.

Ongoing Field Work

Defining an optimal TOR application rate for a single 90 car 10,000 ton consist

In Figure 22, effective lateral force reduction was achieved with an application rate of 0.1 L/mile in curves and 0.04L/mile in tangent track. **This represents a reduction of over 40 % in the application rate compared to previous field testing.** Although effective in reducing the lateral forces by controlling the top of rail coefficient of friction in the 0.3 – 0.35 range, the question arises can the same friction control be obtained using a lower application rate? Referring back to Figure 3, one can observe that a true friction modifier can maintain an intermediate coefficient of friction over a range of application rates. Since lateral force is a function of the coefficient of friction at the wheel – low rail interface; increasing the application rate *will not* result in a change in the coefficient of friction (and subsequently lateral force reduction) if the entire train is being treated. What is likely to occur though will be an increase in *residual* TOR product after the consist has passed through the curve. For example, Figure 23 demonstrates how the TOR friction modifier effectively controlled the TOR coefficient of friction at a value around 0.35. This data was taken during field trials with the forty-five car sulphur test train. Note the variation of the higher baseline (dry) condition. It should also be noted that the TOR measurements were taken *after* the TOR test train had passed through the test zone. What is actually being measured is the *residual* TOR product remaining on the rail head.

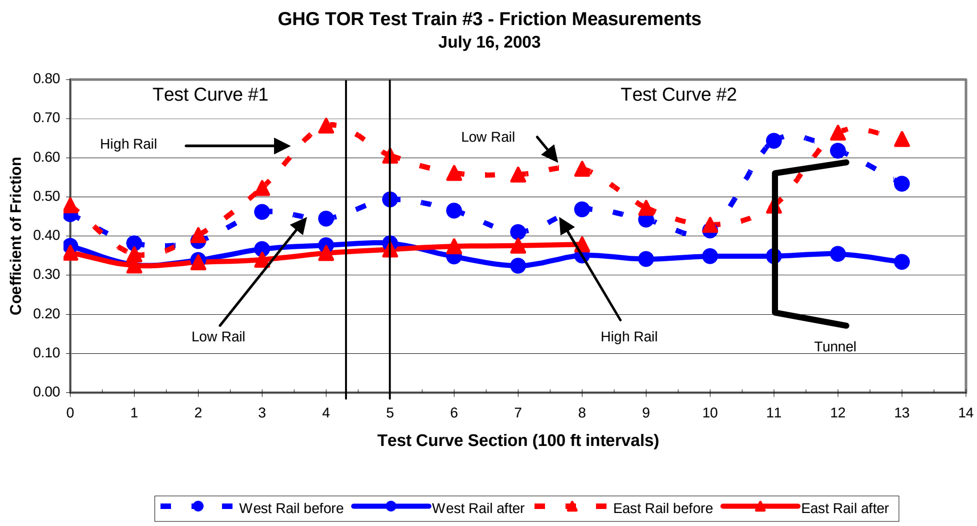
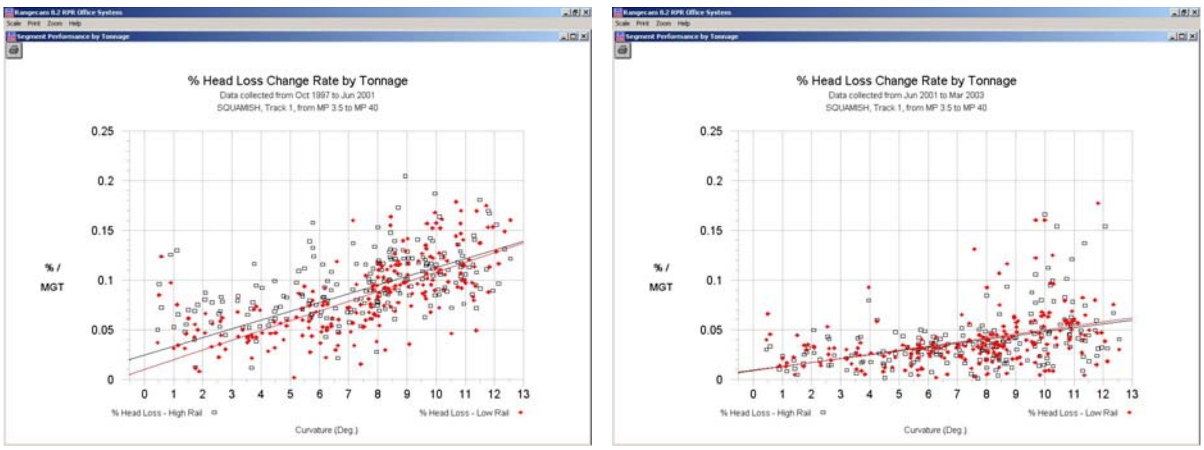


Figure 23: TOR Friction Control

To leave residual TOR product or not is a question of the individual railroad's application strategy. Purposely leaving residual product can provide further economic benefit *as every train does not need to be outfitted with a TOR system in order to provide continuous top of rail friction management*. The primary benefit would include lower initial capital cost requirements to outfit the road locomotive fleet. On the other hand, tailoring the application rate to effectively minimize any residual product would lead to a longer reservoir life. There is probably an optimum between the two options. BC Rail is currently continuing testing to determine the "optimal" application rate to condition a 90 car 10,000 ton consist to effectively reduce lateral forces.

Rail wear

No rail wear measurements were taken during the demonstration project. However, rail wear measurements were taken on BC Rail's Squamish subdivision where the application of Kelsan Technologies Corp. TOR friction modifier has been applied via a track maintenance vehicle for the last three years. This data was recently published in 2003 IHHA proceedings "Top of Rail Friction Control for Energy savings and Lateral Force Control in Heavy Haul freight application". Results (figure 24) have conservatively demonstrated that rail wear reductions of up to 50 % are possible. Similar savings would be expected with the TOR friction modifier product applied via an onboard system. Other field trials are currently ongoing which will add to body of test data in this area.



Baseline *TOR Conditioned*

Figure 24: Reduction in wear rate (head loss) on a 15 MGT line

TOR Equipment Installation, Reliability & Maintenance

Installation

Installation of equipment commenced Monday, April 28, 2003 at the BC Rail Locomotive Shop in Prince George, British Columbia. Two General Electric Dash 9-44CW locomotives were selected for the installation. A team from BC Rail (Jay Roberts, Dave Johal, Lloyd Sopel), Kelsan Technologies (John Cotter, David Elvidge) and Lubriquip (Jim Wollbrink, Mike Malone, and Carl Gedeon) supervised the installation of the Lubriquip dispensing systems on both locomotives BCOL 4643 and 4641 (figure 25). Please refer to **Appendix I** for more detailed information regarding the installation.

Figure 25: BCOL 4641 &, 4643 at Prince George Locomotive Shop

Figure 26: Reinforcement at Short Hood End

The dispensing nozzles (one per side) had to be located on the long hood (rear) end of the locomotive rather than the short hood end. The presence of reinforcement at the short hood end (for snow loads, figure 27) prevented the installation of the metering boxes on the back of the front pilot. As a result, both the metering boxes and the dispensing nozzles were relocated to the long hood end of the locomotive. Locating the nozzles at the long hood end of the locomotive is not ideal for BC Rail as it would permanently require specialized dispatch of the motive power.

Typically, the trailing locomotive is orientated "short hood" trailing (providing back-to-back locomotives) that eliminates the need to wye (turn) the motive power at a destination yard in order to have a cab facing in the return direction. Mounting the TOR system on the long hood end of the BC Rail locomotives was acceptable for the purposes of the demonstration project, but would be not be acceptable for larger scale fleet implementation due to the negative impact on operations. *Subsequent to the installation of these units, Lubriquip has redesigned the metering boxes to allow them to be installed on the short hood end of a BC Rail GE Dash 9-44CW locomotive where there is less space available due to reinforcement for snow loads. Examples of the original & modified [smaller] metering box designs may be found in figures 27 & 28.*

Figure 27: Original Metering Box

Figure 28: Smaller metering box

Of special interest to the Canadian railroad industry was the fact that these TOR dispensing units were also equipped with a prototype heat tracing system to allow the water-based TOR friction modifier to be applied at the normal low temperature (-30 °C) extreme of Canadian winters. The heat trace system is automatically activated when the ambient temperature drops below five (5) degrees Celsius. All of the critical TOR system components (except the product hoses & lines which were foam covered and tape-wrapped) were insulated with a spray-on polyurethane foam that cured when exposed to air. Examples are shown in figures 29 & 30.

Figure 29: Insulated Reservoir Tank

Figure 30: Insulated Metering Box & Insulated/Heat Traced Product Lines

TOR Equipment Reliability

As of April 1, 2004, which marks eleven months of TOR operation, there have been no major reliability issues with respect to the TOR dispensing equipment. Most of the TOR system has been trouble-free:

- Interface with locomotive controls
- TOR system control (automatic operation)
- Onboard reservoir level control & filling
- No clogging or debris contamination of TOR dispensing nozzles
- Robust nozzle design – able to sustain light impacts without permanent damage
- Critical mechanical components (recirculation & metering pumps) performed to expectations.
- Consistent flow accuracy & excellent nozzle spray quality
- Effective heat trace control of heating & maintaining TOR system temperatures

Three components have required repeated replacement on both locomotives:

- Parker solenoids that control TOR product flow in each metering box are not reliable in warm operating conditions;
- Capacitors mounted on several circuit boards on each locomotive were susceptible to vibration damage; and,
- PLC drive boards in the LLIC control box were susceptible to vibration damage.

Two aspects of the TOR automatic control system have been identified for improvement:

- Date & time stamping of LLIC warning & error messages to aid in troubleshooting; and,
- Low pressure system shut-off to avoid unnecessary TOR product loss should a leak develop.

BC Rail, Kelsan and Lubriquip have worked to address redesigning and/or replacing all three components identified above as well as to implement changes to the TOR system control software to address the two areas identified for improvement:

- New Parker poppet-type solenoids will replace the original spool-type solenoids based on Kelsan lab testing that predicted significantly reduced failure rate of the poppet-type solenoids in warm weather service. **(**Refer to **Appendix J)**
- New circuit boards were fabricated with vibration-damped capacitors to reduce susceptibility for vibration-induced failure.

- New PLC drive boards were fabricated with more rugged connectors to reduce susceptibility for vibration-induced failure.
- Date and time stamping of LLIC warning messages is not possible given the current parameters of the PLC design. This is not a critical drawback; rather it would assist troubleshooting of TOR system problems.
- A low pressure system shutoff is being investigated by Lubriquip for resolution prior to the end of April 2004.

Improved TOR system components (such as solenoids, capacitors, product strainers, and some wiring connectors) will be installed in April 2004 along with some minor upgrades to the TOR system software. Software upgrades to both TOR systems should permit better user-customized TOR recirculation operation and more refined control of TOR application in dynamic braking. BC Rail also learned that maintaining optimum nozzle height above top-of-rail (2 ½ inches) requires mileage-based attention to avoid nozzle contact with top-of-rail as locomotive wheels wear.

BC Rail has identified other key areas for improvement should additional TOR systems be purchased, but these areas are for the most part not feasible for upgrading on the current two locomotives. These areas include:

- A larger onboard reservoir as the capacity of the current TOR reservoir is the minimum acceptable.
- Improved heat tracing of the TOR reservoir in order to maintain desired TOR product temperature.
- Nozzles mounted at the short-hood end of the locomotive to facilitate the usability of the locomotive in TOR operation.

Continued TOR testing may also determine whether reduced TOR application rates can be achieved to extend reservoir life between fillings. Alternately, future TOR installations may relocate the onboard TOR reservoir to a different location on the locomotive.

The TOR system on BCOL 4643 (main test locomotive utilized for this demonstration project) operated reliably for 100% of the twenty test runs. However, this was accomplished only as a result of BC Rail's scheduled 15-day locomotive trip inspections and reasonable, albeit significant, supervision by both BC Rail and Kelsan. While each locomotive received its normally scheduled mechanical inspection, the TOR system on each locomotive also received an inspection. This permitted early diagnosing of system or components issues and preventative repair where required.

It is difficult to predict longer-term reliability of the TOR systems in the absence of actual experience monitoring equipment operation. Ongoing testing will continue to validate the reliability and durability of the TOR systems.

Winter Reliability

Of special concern to the Canadian freight railroad industry is how this equipment will perform in winter months. Prior to monitoring the equipment performance in the field, Kelsan Technologies Corp, with assistance from Lubriquip, fabricated a simplified version of the TOR dispensing equipment in order to assess the performance of the critical mechanical components under simulated winter conditions (Figure 31).

1) Lab Testing

The primary objective was to determine if the system would properly function down to temperatures of -30 °C and to identify components that could be an issue. Of interest was the impact of low temperature and wind chill on the TOR nozzle (Figure 32). To this end, a wind tunnel was fabricated to simulate wind speeds of up to 100 km/hr.

Figure 31: -30 °C Cold Temperature Chamber

Figure 32: Insulated TOR Nozzle

Results obtained during three days of cold chamber testing of the winterized TOR system at sustained temperatures at or below -28°C revealed no major operational issues. Other than a few minor equipment items, current methods for winterizing KELTRACK® product against freezing worked as intended consistently providing TOR product delivery during all test conditions investigated.

Other key testing results found during lab testing included:

- Winterized TOR equipment maintained KELTRACK® product in the system lines, circulation pump, metering box and TOR nozzle during idle conditions (no wind) at or above 5°C.
- After providing additional localized TOR nozzle heating, nozzle temperatures of 10°C were easily maintained during spray testing in 30 mph wind with no impact on nozzle flow rates or atomized spray patterns.
- Below ambient -25°C, the tank product temperature was only maintained by circulating product warmed after passing through heat traced circulation lines back to the tank. During extended periods with the circulation pump shut off, tank product temperatures dropped steadily.
- TOR system operating line pressures were not adversely impacted by cold temperatures with freeze protection equipment operating. Without heat tracing, line pressures increased dramatically at reduced temperatures during circulation and spraying due to increased product viscosity.
- After interrupting freeze protection electrical supply, TOR system lines froze within 3-4 hours rendering the system inoperable. Conversely, system lines could be thawed within six hours after re-establishing heat tracing with no apparent equipment damage.
- The existing non-insulated product strainer was found to be vulnerable to freezing during sustained temperatures below -25°C without product circulating. Adding insulation to the plastic strainer body reduced vulnerability to freezing.

2) Field Monitoring during winter 2003/2004

Locomotive data collected over the winter period indicated the winterized TOR system remained operable during all weather conditions experienced including very cold periods below -25°C. During each locomotive inspection to download test data, TOR nozzle spray tests were performed. No equipment issues related to TOR spray activation were encountered. In general, no LLIC equipment alarms associated with failure of the cold temperature protection system were observed with the exception of one event that occurred in mid February 2004. During this period, one of the locomotives was stored [dead] outdoors with all electricity shut off to the TOR system. Temperatures dropped well below the standard onboard product freezing point (-9°C) and as a result of expanding product during freezing, the plastic product strainer bowl cracked. As noted earlier, this item had been identified as a potential problem. As a part of the equipment upgrade to occur in late April 2004, the plastic strainer will be replaced with a metal strainer to better withstand potential freezing damage.

Field operation during the winter period for the winterized TOR system installed on the BC Rail TOR locomotive to-date is summarized below;

- TOR system heat tracing on the product tank, metering box, product lines and TOR nozzle operated reliably whenever ambient temperatures dropped below the designated 5°C activation temperature
- For ambient temperatures above -10°C, internal metering box components were maintained at or above 5°C, metering box product lines were maintained between 15-20°C and product tank temperatures were 10°C-15°C; below -25°C, metering box line temperatures were maintained, but data indicates the reservoir tank temperatures dropped well below 0°C.
- Installed TOR nozzle-heating system worked as designed maintaining TOR nozzles between 3°C and 12°C during the coldest winter testing period for both idle and moving trains in temperatures below -20°C.
- Consistent TOR system line pressures between 50 and 60 psi were recorded which agreed with cold chamber testing results providing additional indication that the TOR winter system was operating as intended. Had this not been the case, high pressure alarms would have been recorded by the LLIC system and observed in the logged circulation loop pressure data due to decreased product temperature increasing viscosity as seen in the cold chamber testing.

Figure 33 provides an example of the operation of the TOR system during a period in January 2004. BCOL 4643 was extensively instrumented with thermocouple transducers to monitor fluid temperature. Note the low ambient temperature during this time frame as well as the excellent control of the nozzle & metering box temperature.

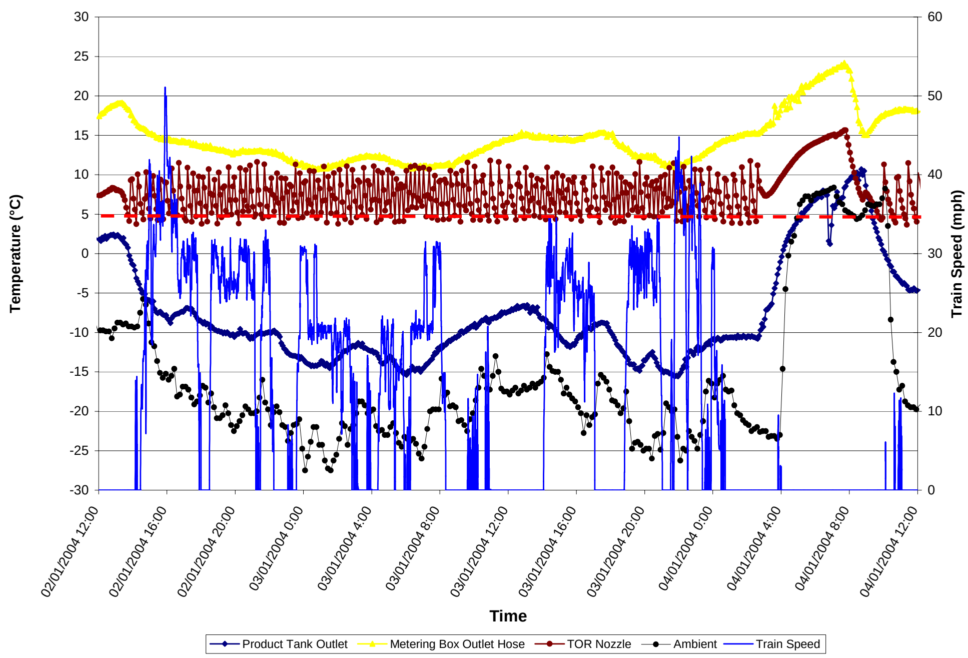


Figure 33: Sample of Field Monitoring Data of TOR Equipment over winter 2003-2004

A detailed report outlining this work in monitoring equipment performance over the winter months may be found in **Appendix K.**

TOR Equipment Maintenance

The onboard TOR systems have proven simple to maintain. It is fair to suggest that good reliability has minimized the requirement for unscheduled maintenance, yet frequent scheduled inspections have contributed to the good reliability. BC Rail demands high availability from its locomotive fleet and there was initial concern that the onboard TOR systems may impact that availability. Fortunately the concerns were unwarranted as neither TOR system has affected locomotive availability or performance.

An ideal system would operate maintenance-free, however most mechanical systems require intermittent inspections to ensure proper function and it was known that the onboard locomotive TOR systems would require filling of the onboard TOR product reservoir. The important requirement for BC Rail was that the onboard TOR equipment not cause either locomotive to be taken out of service. In other words, this required that the TOR systems meet (at a minimum) the standard BC Rail locomotive inspection cycle. The BC Rail motive power fleet was cycled through Trip Inspections at fifteen-day intervals. Therefore the TOR equipment, including the onboard TOR fluid reservoir had to meet this fifteen-day cycle before the onboard TOR reservoir could be refilled or before TOR system components could be inspected and/or repaired. Significant repairs would have to be deferred until the locomotive was scheduled for more extensive 180- or 360-day inspections.

At the same time as the TOR equipment was installed on the locomotives in April 2003, time was taken to familiarize electricians and mechanics working both Day Shift and Night Shift at BC Rail's Prince George Motive Power Shop. This enabled BC Rail to 'certify' a minimum number of staff as familiar with the TOR equipment and therefore qualified to inspect and service the TOR equipment.

A simple and concise fifteen-day inspection sheet was created to guide staff on the TOR components to inspect as well as a checklist to record and report any defects as well as the onboard reservoir level and confirmation that the reservoir was filled. Over the past eleven months since this project commenced, most of the staff at BC Rail's Prince George Motive Power Shop became familiar and qualified to service the TOR equipment. A copy of all TOR fifteen-day inspection reports is attached in **Appendix L** as well as the maintenance manuals developed for the equipment (**Appendix M).**

Scheduled maintenance involved a simple visual system inspection, filling the on board reservoir as required, and performing a TOR spray test. No other scheduled maintenance was required. (I.e., no adjustments or fine tuning of any kind have been required.) Unscheduled maintenance has been the exception, but has included the aforementioned solenoid and capacitor replacements, metering pump replacement, minor leaks, replacement of the protective (sacrificial) nozzle shrouds and a single incident of damaged heat tracing. BC Rail and/or Kelsan staff usually supervised the unscheduled maintenance in order to better understand the problem areas and to permit detailed root cause analysis.

The 15-day TOR inspections permitted early diagnosing of the few problem areas that occurred and permitted both timely and preventative equipment repair as well as tracking of equipment performance. Furthermore, combining TOR inspections with locomotive inspections minimized extra labour costs. However more operating time beyond the eleven months of this project is required before long term maintenance can be realistically predicted.

Cost Benefit Analysis

In an attempt to quantify the economic benefits of TOR friction modifier technology, Kelsan Technologies Corp. has developed a number of business models to assess savings with respect to the following:

- Fuel savings
- Rail wear savings
- Wood tie (sleeper) replacement
- Track regauging (due to track spreading forces predominantly on track structures with wood ties with cut spikes/plate fastener systems)

In many cases, the model is *specific* to a subdivision as items such as fuel savings & rail wear are based chiefly on traffic density & tonnage. Furthermore, ongoing field work has suggested that the TOR application rate can be further optimized (re reduced) which will have an impact on the business model.

With respect to developing a business model for transcontinental lines with principally tangent track, a specific application strategy will also have to be developed. It is expected that the rate will be low(er) as the absence of wheel rail creepage, found in curves, will result in less product being forced out of the wheel-rail interface. As a result, a lower product application rate will be required to control the coefficient of friction at the wheel rail interface.

To demonstrate though that there are economic benefits to be derived, figure 34 exhibits the net savings based on the *calculated fuel savings only*. As mentioned in the demonstration project proposal, TOR friction modifier technology is one of those few technologies where GHG emission reductions can be achieved with an additional economic benefit, rather than cost, for the freight railroad industry. Net savings for tangent track based on the BNSF results have not been included as no TOR application rate strategy has yet been determined. To simplify the data, the savings for the segments with 34 %, 35 %, & 36 % have been averaged. The sum of each bar represents the total savings which have been divided into product cost and net savings.

Model Assumptions are as follows:

- *10,000 ton train travels 100 miles = 1 MTM*
- *TOR product applied 100 mL per track mile in curves and 40 mL per track mile in tangent track over a 100 mile distance cost based on BC Rail field studies.*
- *Fuel cost of $Cdn 0.378/Liter based on 4Q 2003 data*
- *TOR friction modifier cost of $USD 5.05/Liter ($0.75 exchange rate)*

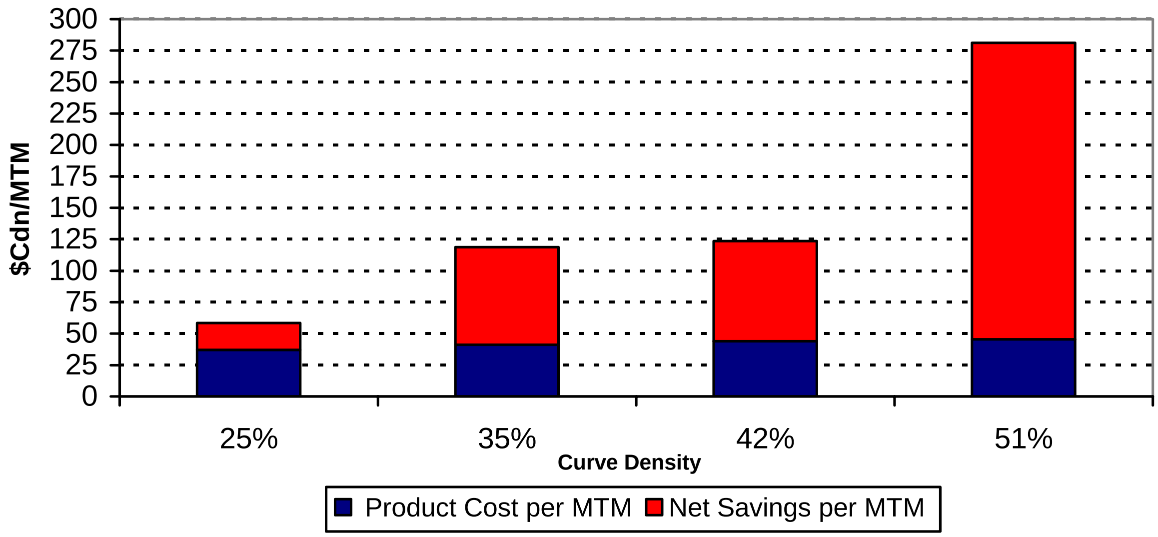


Figure 34: Net Savings

As one can observe there is a net positive cash inflow for each of the segments evaluated. To reiterate this does not include ancillary benefits such as rail wear reduction, reduction in infrastructure cost due to reducing the state of stress in the track structure, wheel savings, as well as reduced probability of derailments etc.

If further information is required, or a company wishes to develop a business model, they are encouraged to contact Kelsan Technologies Corp.

Environment Monitoring

Part of the demonstration project mandate was to monitor the test zone for build up of the TOR friction modifier on the ties/ballast. Triton Environmental Consultants, based in Prince George BC were hired to install & monitor transect sites on a section of track where the test TOR trains would traverse. The site located was approximately 20 miles outside (North) of Prince George (figures 35 & 36). A control site was also selected on the Mackenzie subdivision (no TOR test trains would traverse this track). The transects contained either distilled water or sand.

Figure 35: Test Zone (Spring) *Figure 36 Test Zone (Summer)*

Environmental monitoring transects were installed on May 2 and were left capped until the start of GHG project. For baseline testing, the transects remained capped to prevent water evaporation in the summer heat. Once the TOR testing phase commenced, the caps were removed and replaced with a mesh to prevent any wildlife from crawling into the transects (figures, 37 & 38). A total of 36 transects were installed. 50 % contained water & 50 % contained sand.

Figure 37: Installation of Transects *Figure 38: Transect with wire mesh filter*

After the end of the first round of TOR testing, the first set of transects were removed and forwarded to CANTEST for analysis. An inorganic constituent of the formulation was provided to Triton to allow them to test for the presence of the TOR friction modifier. **The results from the first round of testing indicated no traces, whatsoever, of the inorganic constituent in either the water or sand transects samples.** As expected no traces of the constituent was found in the control samples as well. Please refer to **Appendix N** for a copy of the ICP test performed.

The remaining transects were then recapped for the second phase of baseline testing. In late October, the caps were removed when the second round of TOR testing commenced. Unfortunately, winter arrived early in the interior of BC resulting in a blanket of snow covering the transects (figures 38 & 39; the transects containing water were also observed to be frozen. As a result, no further data was obtained from the remaining transects.

Figure 39:Zone in early November

Figure 40: Transects covered by snow

On another note, the site was vandalized several times. In each case, it appears that some of the transects were removed and discarded by the side of the track. To briefly summarize, the results indicated over the first phase of testing (5 trains) there was no apparent build-up of TOR product in and around the track as applied from onboard a locomotive. Kelsan Technologies Corp. has also performed leachate & bioassay studies on its TOR friction modifier, KELTRACK®, in which to study its' impact on the environment; these studies may be found in **Appendix N** as well.

Summary & Recommendations

Based on 2002 freight traffic data, the potential reduction in GHG emissions range from 114.6 kilotonnes to 167.5 kilotonnes annually or 2.1 % to 3.0 % of total freight railroad emissions. This is based on the premise that curve density for the entire Canadian freight track system lies somewhere in between 0 and 25 %. In mountainous terrain only, where there is significant curving resistance, the percentage savings is expected to increase**.** Further calculation will be required to ascertain an accurate reduction based on specific regional geography & traffic density.

The following outlines the "lessons learned" during the course of the demonstration project:

How does weather affect the performance of the TOR friction modifier technology?

As the core of the TOR friction modifier technology consists of an engineered composite of inorganic solids, its' ability to control friction is not affected by temperature. Precipitation in the form of rain or snow is also unlikely to affect the technology's ability to control friction. As the product is applied immediately behind the driving wheels of the locomotive, the product is being applied to essentially dry rail. Extensive field testing has also been performed with the TOR friction modifier, applied via wayside units, in all types of weather.

As the product is water-based, focus of technology development has been in the area to expand the temperature range in which to allow the product to be dispensed to the top of the rail. This has included the development of patent pending technology that lowers the freezing point of the TOR friction modifier product without impacting its' ability to control friction. Equipment manufacturers, such as Lubriquip, have also developed and proved out ancillary equipment to maintain a reasonable product temperature to allow it to be pumped and atomized.

Impact of gradient, degree of track curvature, & tonnage on the technology?

- Analysis of the test data demonstrated a strong correlation between calculated reduction in GHG emissions and curve density.
- Significant (absolute) GHG reductions can be achieved on ascending grades with significant curvature. On a percentage basis, the amount will be lower due to the inclusion of fuel to overcome grade resistance.
- No fuel savings will be achieved on descending grades when the train is in 100 % dynamic braking. However reductions in lateral forces are possible (in the absence of air braking).
- The basis of TOR friction modifier technology is that it controls the coefficient of friction at the wheel rail interface regardless of tonnage; as a result, it is effective for trains of all tonnage.

Viability of TOR friction modifier technology

Kelsan Technologies Corp. TOR friction modifier technology, KELTRACK®, has been commercialized since 2002. It is currently being tested by all of the North American Class 1 railroads. Several are in the process of implementation. The predominant method of applying the TOR friction modifier is through the use of strategically located wayside units. Another commercial form of the KELTRACK® product line is applied using a track maintenance vehicle.

It should be noted that the core technology in each of the different methods of application, including from onboard a locomotive is the same. Thus, a zone of strategically located wayside units should provide similar GHG emission reductions as compared to applying it from onboard a locomotive.

Ideally, the industry would like the ability to apply this technology from onboard a locomotive as it would be a more efficient use of capital.

Potential barriers to the use of TOR friction modifier technology (from onboard a locomotive)

Although the demonstration project has successfully verified that GHG emission reductions are possible by applying a TOR friction modifier from onboard a locomotive, its' implementation faces several barriers:

- Retrofitting the existing locomotive fleet with TOR dispensing equipment: Installing TOR equipment on the existing locomotive fleet presents a challenge due to the different types & series of road locomotives currently in operation. Each type/series of locomotive would require some engineering design modifications in order to install the TOR equipment. The problem can be reduced by only installing the equipment on newer locomotives as well as installation of the equipment by the OEM at the factory. Further modifications to the design could also help to minimize installation time across a range of type/series of locomotives.

- Equipment reliability & maintenance: The operating conditions onboard a locomotive are severe (extreme temperature range, vibration etc). Although significant strides have been made to improve the equipment in this area during this demonstration project, additional work is required to meet the stringent requirements of the freight railroad industry for fleet wide implementation based on their current operating practices. With respect to equipment maintenance, further over the road experience is required in order to develop comprehensive maintenance procedures. It's a "catch 22" situation as such procedures cannot be developed solely in a lab environment.

- Establishing fleet-wide logistical/operational requirements: How are the onboard reservoirs going to be filled? Where will the infrastructure be placed? How many units will be installed? These are some example questions of what a freight railroad would face when addressing these issues.

To summarize, it is unlikely that the freight railroad industry will adopt this technology on a fleet wide basis based on a limited trial using two TOR equipped locomotives. An interim step is recommended where a multiple number of units (10 – 20) are installed onboard locomotives to better address the aforementioned barriers.

Recommendations for future testing:

1) Energy testing on transcontinental trains running predominantly on tangent track to confirm BNSF results on a macro scale as well as to determine the optimal TOR application rate/strategy.

2) Installation of multiple onboard units on a freight railroad to:
    d. Establish guidelines to optimize installation time of dispensing equipment
    e. Establish guidelines pertaining to logistical/operation requirements (ie onboard reservoir refilling, application strategies, etc)
    f. Equipment maintenance requirements (180 day, 360 day, etc)

Future implementation of TOR technology should include analysis of BC Rail's ongoing experience with their two TOR locomotives.

References

1: Assessment of Wheel/Rail Interaction and Vehicle Dynamics at BHP Iron Ore (**Appendix O)**
S. Marich, A Cowin, G. Offereins, M. Moynan,

2: Top of Rail Friction Modification Studies on the BNSF (**Appendix E)**
Glenn Bowen