Union Pacific Railroad Wayside Top of Rail Friction Control: Lateral Force and Rail Wear Reductions in an Extreme Heavy Haul Operating Environment

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ABSTRACT
Wayside TOR application of a friction modifier (FM) has been investigated for lateral force and rail wear reduction in an extreme Class 1 heavy haul axle operating environment. Twelve Top of Rail (TOR) wayside units applying friction modifier product were installed within an eight mile heavy curvature/heavy grade trial zone as part of a multi-unit zone application strategy. The required distance between units was determined through preliminary single unit directional spacing optimization work. This process generated a TOR unit spacing interval unique to this area's operating conditions, which maximized the benefit of the friction modifier for reduced lateral forces and reduced rail wear. Lateral force reductions, which ranged from 27-34%, were achieved bi-directionally during FM application. Due to premature termination of the rail wear monitoring period to allow for further TOR roll-out in the area, sufficient tonnage was not collected to obtain statistically significant rail wear rate measurements during the same period.

INTRODUCTION
Top of rail (TOR) friction control has produced significant reductions in rail wear rates, fuel consumption, and track structure degradation (1-3). Class 1 results have generally dealt with territories containing heavy curvature, but with lower grades and sustained train braking. Limited results have been published quantifying the effectiveness of applying TOR friction modifier in locations combining continuous heavy grade with moderate to severe curvature.
Consequently, some questions have been raised about the benefit of TOR in this environment with respect to product degradation from excessive wheel heat generated from continuous train brake application, or from heavy locomotive sanding. In an extreme operating environment, it remains of interest to more accurately ascertain the resiliency and effectiveness of FM performance.

This paper addresses the results of a TOR trial, that commenced in July 2005 on the Union Pacific Railroad, investigating the impact of wayside FM application on the heavy curvature/heavy grade operating environment of UP’s Moffat Tunnel subdivision. This single track region contains numerous curves $\geq 10^0$, and gradient up to 3.57%. Traffic is bi-directional, consisting of mixed freight and 286K unit coal trains generating 48 MGT annually. Loaded consists travel eastbound (downhill) into Denver, CO., which accounts for 36 MGT. Westbound (uphill) traffic is predominantly empties, which accounts for 12 MGT. This subdivision has a history of severe rail wear, accelerated tie/fastener degradation, extreme rail temperatures, and difficulty sustaining effective gauge face lubrication. Heavy sanding from westbound trains is prevalent. In consideration of these operating challenges, newly developed equipment spacing optimization strategies were implemented to maximize TOR coverage effectiveness and lateral force/rail wear reduction results.

**TRIAL ZONE CHARACTERISTICS**

The Moffat Tunnel Subdivision begins at Denver (MP 0), with approximately 50 miles of continuously ascending grade extending west to the Moffat Tunnel east portal in the Rocky Mountains. Track construction is wood tie with a mix of standard tie plate/spike and premium Safelok fasteners. Rail type is a mix of 133lb RE, 136lb RE, and 141 AB CWR.

An eight mile TOR-treated zone containing twelve applicators was established between MP’s 16 and 24, following single unit spacing optimization activities determining the ideal average unit spacing for optimized TOR coverage. TOR installation locations were selected incorporating current industry best practice recommendations (4-5). The approximate miles of curve track is five miles versus three miles of tangent track, which is 63% of the track being in curves. Over half of the total curvature is $> 6^0$ (2.71 miles or 54%).
Strain gauge instrumentation measuring vertical and lateral train forces was installed in the middle of the TOR area at MP 19.44 (Figure 1), within the sharper portion of a 7° 55′/-8° 20′/-1° 08′/-3° 04′ compound left-hand curve. Six application zone curves were selected for comparative rail wear monitoring to six control/non-TOR curves of similar degree, track construction, and operating conditions outside of the TOR area (MP’s 28 to 31). Rail wear monitoring was performed using a hand-held Greenwood Engineering MiniProf rail profilometer. A four mile buffer zone separated the test and control curve areas, ensuring residual FM transfer from conditioned rail wheels would not influence projected rail wear reduction results.

Figure 1. Lateral Force Site Schematic - MP 19.44 - Moffat Tunnel Subdivision

**FRICTION MODIFIER**

The top of rail friction modifier used for this project is a water-based liquid material known as KELTRACK® LT (6). This product contains a suspension of engineered solids producing the necessary frictional characteristics for the targeted contact rail surface area. Additional components that maximize product retentivity are also included. After water evaporation following application, a thin dry film remains providing an intermediate coefficient of friction (COF) in the 0.30-0.35 range at the wheel/rail interface. This dry film characteristic is particularly important for extreme gradient locations, mitigating negative impacts to locomotive traction typically encountered with conventional lubricants. The “LT” designation represents a “Low Temperature” service application for this product down to -15° C/5° F. This grade was selected in consideration of the historically cold area ambient temperatures expected for pending winter TOR application/monitoring.
WAYSIDE APPLICATION EQUIPMENT

Wayside FM application was performed using Portec Rail Protector® IV solar/electric applicators. Friction modifier was distributed to the TOR surface along each rail side through two adjoining, specially designed 48” TOR XL applicator bars (Figure 2). Product delivery is controlled through the combined adjustment of i) Axle count between pump activations and ii) Duration of each pump activation (secs). The selected hardware represents the current Class 1 heavy haul equipment standard for TOR wayside application, incorporating either short bars (24”), or long bars as used for this project. Although alternative TOR application systems exist in the form of locomotive, rail car, or hi-rail-based equipment, wayside application was selected as the preferred method best accommodating project cost and traffic density considerations.

Figure 2. Wayside TOR application site

TRIAL ZONE GAUGE FACE LUBRICATION

Gauge face lubrication quality was variable through the trial zone. Primary trackside system is a hydraulic unit with two 24” wiping bars. Average main track lubricator spacing through the FM-applicated region is approximately 0.75 miles, varying from 0.3 - 2.15 miles. Numerous locations of TOR surface grease contamination and extensive locomotive sand accumulations were present, typically near excessively outputting hydraulic GF lubricators. Both conditions can inhibit FM performance effectiveness.
PROJECT LATERAL FORCE AND RAIL WEAR REDUCTION TARGETS

Lateral Force (LF)

The majority of lateral force reduction data collected to date from North American Class 1 heavy haul freight trials is from operating environments without sustained conditions of combined extreme gradient and severe curvature. Average high and low rail LF reductions of around 30-60% have consistently been achieved for milder areas, using average TOR applicator spacings of 2-2.5 miles. In consideration of the extreme Moffat Tunnel Sub operating environment, a pre-trial spacing optimization process was incorporated to determine the TOR unit spacing interval unique to area operating conditions, and necessary to achieve similar 30-60% force reductions using a multi-unit zone application strategy.

Spacing Optimization Logic

Previous Class 1 trial results (1) suggest that the directional lateral force reduction result ($x_1$ or $2\%$) achieved by a single TOR unit, as quantified by an instrumented LF site, will be sustained if the same single TOR unit-to-LF site spacing (distance = $d_1$ or $2$) is doubled (i.e. $2d_1$ or $2$) and implemented between TOR applicators in a multi-unit setting (Figure 3 - Scenario 1). Additional Class 1 work has demonstrated that at least 2 units are required to achieve this effect (4). Conversely, it has also been found that the directional lateral force reduction result ($x_1$ or $2\%$) achieved by a single TOR unit can be doubled ($2x_1$ or $2\%$) if the same single TOR unit-to-LF site spacing (distance = $d_1$ or $2$) is implemented in a multi-unit setting (Figure 3 - Scenario 2).

![Figure 3. TOR Multi-unit Zone Application Spacing Logic](image)
In consideration of the multi-unit spacing logic/scenarios discussed, a project spacing optimization process was implemented incorporating a test matrix of single unit uphill/downhill spacings from the project lateral force site (Figures 4 and 5).

**Figure 4. Field Schematic for Single Unit Uphill/Downhill Spacing Optimization Process**

**Figure 5. Spacing Optimization Matrix to Establish Single Unit Uphill/Downhill Carry Distances**

### Lateral Force Reduction Targets

Progression through the spacing optimization matrix would determine the applicable multi-unit spacing logic to be applied, as derived from directional single unit % lateral force reductions. Target bi-directional lateral force reduction was 25-40% for eventual multi-unit zone application, similar to other Class 1 results applying identical spacing optimization logic. Heavier braking, hotter wheel eastbound/downhill trains were expected to produce lower LF reductions due to an anticipated more rapid burn-off of the FM. Consequently, the finalized spacing distance for
multi-unit rollout was expected to be a compromise of individual directional results biased to downhill performance. Due to limited tangent track installation options for the TOR applicators, initial single unit uphill/downhill spacings were relatively small (< 0.75 miles). This close proximity to the LF site suggested initial % reduction results would likely be close to the project target range, permitting incorporation of the increased TOR unit spacing scenario (Figure 3 - Scenario 1) previously discussed.

**Rail Wear Reduction Targets**

Several Class 1 heavy haul TOR multi-unit zone application trials have achieved 30-50% rail wear rate reductions in concert with similar % lateral force reduction results (4). As with lateral force data, the majority of Class 1 rail wear data has been obtained from locations with less severe operating conditions than the Moffat Tunnel subdivision.

A TOR project, similar to the Moffat Tunnel Sub initiative, remains ongoing through the Tehachapi loop segment of the UPRR Mojave Subdivision in California. This trial location contains sustained extreme gradient and severe curvature conditions similar to the Moffat Tunnel Subdivision. Phase 1 project results produced LF reductions of 31-58% and 0-18% for southbound/uphill trains and northbound/downhill trains respectively. Associated rail wear rate reductions were 58% for low rail vertical wear - high rail vertical and gauge face wear rates did not demonstrate significant change (7). The Tehachapi Loop was noted to contain conditions of heavy locomotive sanding and variable gauge-face lubrication similar to that observed for the Moffat Tunnel subdivision. In view of the operating similarities between regions, comparable rail wear rate reductions of 30-50% in low rail vertical wear and minimal impact to high rail gauge or vertical wear rates were initially expected for this project. These results would be subject to attainment of the established 25-40% project lateral force reduction target for EB and WB trains.

**SPACING OPTIMIZATION (SO) RESULTS**

Six separate SO sub-phases were monitored for bi-directional lateral force reduction, in pursuit of determining the optimum distance between TOR applicators for pending trial zone multi-unit rollout (Table 1).
Table 1. Spacing Optimization Trial Sub-Phases and Results

<table>
<thead>
<tr>
<th>SUB-PHASE</th>
<th># OF DAYS</th>
<th># OF TOR UNITS</th>
<th>UPHILL/DOWNHILL* FROM LF SITE</th>
<th>TOR UNIT LOCATIONS (MILEPOST)</th>
<th>UPHILL/DOWNHILL TOR UNIT DISTANCES FROM LF SITE (MILES)</th>
<th>WEST TO EAST SPACING BETWEEN TOR UNITS (MILES)</th>
<th>TOR UNIT SETTING (GAL/1,000 AXLES)</th>
<th>% LF REDUCTION AND DATA SIGNIFICANCE (Y=YES, N=NO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOR 1a</td>
<td>7</td>
<td>1ea. Uphill 1ea. Downhill</td>
<td>MP 20.16 MP 18.89</td>
<td>0.72 (Uphill) 0.55 (Downhill)</td>
<td>1.27</td>
<td>.15 gal/1,000 axles</td>
<td>0% (N - Both rails)</td>
<td></td>
</tr>
<tr>
<td>TOR 1b</td>
<td>9</td>
<td>1ea. Uphill 1ea. Downhill</td>
<td>MP 20.16 MP 18.89</td>
<td>0.72 (Uphill) 0.55 (Downhill)</td>
<td>1.27</td>
<td>.12 gal/1,000 axles</td>
<td>0-1% (N - Both rails)</td>
<td></td>
</tr>
<tr>
<td>TOR 1c</td>
<td>10</td>
<td>1ea. Uphill 1ea. Downhill</td>
<td>MP 20.16 MP 18.89</td>
<td>0.72 (Uphill) 0.55 (Downhill)</td>
<td>1.27</td>
<td>.15 gal/1,000 axles</td>
<td>0-7% (Y - Low rail) (N - High rail)</td>
<td></td>
</tr>
<tr>
<td>TOR 1d</td>
<td>18</td>
<td>1ea. Uphill 2ea. Downhill</td>
<td>MP 20.16 MP 18.89/18.87**</td>
<td>0.72 (Uphill) 0.55/0.57(Downhill)</td>
<td>1.27</td>
<td>.15 gal/1,000 axles</td>
<td>2-7% (Y - Low rail) (N - High rail)</td>
<td></td>
</tr>
<tr>
<td>TOR 1e</td>
<td>20</td>
<td>3ea. Uphill 2ea. Downhill</td>
<td>MP 19.61/20.26/20.83 MP 18.89/18.87**</td>
<td>0.17/0.82/1.39 (Uphill) 0.55/0.57(Downhill)</td>
<td>0.57/0.65/0.72</td>
<td>.15 gal/1,000 axles</td>
<td>19-23% (Y - Both rails)</td>
<td></td>
</tr>
<tr>
<td>TOR 1f</td>
<td>12</td>
<td>2ea. Uphill 2ea. Downhill</td>
<td>MP 20.26/20.83 MP 18.89/18.87**</td>
<td>0.82/1.39 (Uphill) 0.55/0.57(Downhill)</td>
<td>0.57/1.37</td>
<td>.15 gal/1,000 axles</td>
<td>12-18% (Y - Both rails)</td>
<td></td>
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</tbody>
</table>

* Uphill designation is west of the LF site - Downhill designation is east.

** MP 18.87 TOR unit is located in the west end of Rocky Siding.

Raw lateral force detector data was filtered based on the following criteria:

- Freight cars only - No locomotives
- Direction (Westbound/uphill and Eastbound/downhill)
- Lead axles > 25 kips vertical force
- Trains with greater than 20 lead axles > 25 kips vertical force
- WB and EB train speed filters (WB: 15-25mph inclusive; EB: 17-30mph inclusive)

The noted filtering criteria were implemented to ensure project focus on vehicles imparting the most problematic lateral forces to the track structure, while concurrently optimizing data comparability.

The first three SO sub-phases (TOR’s 1a-1c) did not produce statistically significant lateral force reductions for both high and low rails from baseline, as assessed using a Student statistical t-test (8). These initial phases incorporated single unit uphill/downhill spacings of 0.55-0.72 miles. Varying application rates ranging from 0.12-0.15 gals/1,000 axles were instituted in response to reduced % head contact area of transposed rail at both sites inhibiting optimized FM transfer at the rail/wheel interface. A fourth SO phase (TOR 1d), introducing a third TOR unit in a downstream siding for enhanced WB/uphill traffic coverage, suggested improved but minimal force reductions.
In response to the poor results achieved during the initial four SO sub-phases, a quasi-multi-unit zone configuration was instituted to determine if any effective degree of LF reduction was possible for Moffat Tunnel Sub operating conditions. Three TOR units were placed uphill/west of the LF site - The single main track unit and adjacent siding unit remained in place downhill/east of the LF site (Figure 6). Upstream TOR unit spacings for EB/downhill trains were 0.17-0.65 miles - Downstream spacings for WB/uphill trains were 0.55-0.57 miles.

**Figure 6. Spacing Optimization Trial Sub-Phase TOR 1e - TOR Unit Configuration**

Significant lateral force reductions of 19-23% were achieved using this configuration, confirming multi-unit zone application would provide improved lateral force reduction effectiveness for area operating conditions.

In consideration of the possible positive influence to EB results, from having a TOR unit in close proximity to the LF site (0.17 miles), a supplemental spacing optimization phase was run (TOR 1f) with the closest upstream TOR unit deactivated. Similar significant lateral force reduction results of 12-18% were achieved for EB/WB trains, incorporating TOR unit spacings of 0.55-0.82 miles. Application rate for the TOR 1e and TOR 1f phases was 0.15 gals/1,000 axles.

**Spacing Interval Determination for TOR Multi-unit Zone Application**

Given the lower Phase TOR 1e and 1f lateral force reduction results compared to the project 25-40% target range, multi-unit spacing logic Scenario 2 (Figure 3) was incorporated to determine the optimized TOR unit spacing for area operating conditions. Applying this logic, instituting a similar Phase TOR 1f spacing value (0.55-0.82 miles) for multi-unit rollout should potentially double achieved TOR 1f results (i.e. within the 25-40% project target range). A finalized TOR unit spacing of 0.75 miles, as partially dictated by trial zone tangent availability, was subsequently
introduced for multi-unit zone rollout and lateral force/rail wear monitoring. A smaller entry “step-up” unit spacing (0.33 miles) was incorporated at the trial zone west end for the loaded, heavier braking EB/downhill trains.

It is important to emphasize the critical role of the trial spacing optimization process towards comprehensively identifying Moffat Tunnel Sub operating conditions in advance of multi-unit rollout with potential to adversely impact TOR effectiveness (i.e. transposed rail conditions, operation through sidings, etc.). An “industry best practice” approach using TOR unit spacings derived from available Class 1 trial data or similar commercial ventures may not effectively consider all conditions unique to a given operating area. Implementation of a comprehensive spacing optimization strategy prior to multi-unit zone rollout will maximize TOR effectiveness, and reduce or eliminate the need for corrective maintenance action (i.e. TOR unit relocations) resolving application strategy shortcomings.

TOR MULTI-UNIT ZONE APPLICATION RESULTS

Lateral Force

Lateral force monitoring of project TOR multi-unit zone application (Phase TOR 2 = 12 TOR applicators) was performed over a 5 month period (Nov. 23, 2005 to Apr. 28, 2006). A rail grind of the MP 19.44 instrumented curve was completed Feb. 23, 2006 without an associated “dry”/non-TOR re-baseline period to determine revised baseline lateral forces for the newly re-profiled rail. Lateral force reduction results reviewed in this report will thus cover data recorded prior to the rail grind only. Comparison of lateral force data collected after the rail grind to project commencement “dry” baseline values does not provide an accurate ongoing representation of LF reduction results, due to possible differences in detector site rail profiling, rail-wheel contact geometry, and associated in-track forces.

Statistically significant bi-directional lateral force reduction results of 27-34% were successfully achieved using 12 TOR applicators in multi-unit zone service at an average 0.75 mile spacing (Figure 7). An application rate of 0.15 gals/1,000 axles (.35 sec. x 16 axles) was used for Phase TOR 2 monitoring, as retained from earlier spacing optimization work. Only one sustained period (3 days) of overnight temperature lows below the recommended FM operating limit ($5^\circ$ F/$-15^\circ$ C) was experienced during the TOR 2 monitoring period.
FM multi-unit zone application also positively impacted per train average lateral force values. Notable reductions were achieved in force categories > 10 kips typically imparting a greater degree of track structure degradation (Figures 8-11). Although there are slight differences in train counts between the baseline and TOR phases for each respective operating direction and rail side (WB - 203/202 baseline trains vs. 194/195 TOR trains and EB - 646/640 baseline trains vs. 661/660 TOR trains), the data demonstrates an obvious and significant downward trend for trains with average lateral forces falling with the 10-15 kips and 15+ kips force categories. The % of EB/loaded trains falling within these two higher force categories was reduced by a factor of 2, from an initial baseline range of 86-94% to only 35-48% during TOR application. The % of WB trains falling within the same force categories was reduced by a factor of 4 (Baseline: 35-64% - TOR: 4-15%).

**Figure 7. Phase TOR 2 Multi-unit Lateral Force Reduction Results**

**Figure 8. WB/Low Rail Per Train Average Lateral Force**

**Figure 9. WB/High Rail Per Train Average Lateral Force**
Rail Wear

Due to unforeseen changes, it was not possible to obtain sufficient tonnage to determine changes in rail wear rates (if any) with TOR FM application. An expansion of area TOR coverage necessitated termination of rail wear monitoring after only 5 months/16 MGT of service tonnage. A minimum 25 MGT is recommended for low tonnage areas like the Moffat Tunnel Subdivision to provide definitive rail wear reduction results, assuming differences in wear rates between the control and test cases of around 30%. Smaller differences would require even greater tonnages to provide statistically meaningful comparisons. The variable and non-optimized GF lubrication conditions noted during this trial can also affect FM rail wear results, as documented during other Class 1 trials (1,7). No adverse impacts to TOR zone rail surface conditions were observed during FM application.

CONCLUSIONS

Wayside TOR zone application of a friction modifier has been successfully performed in an extreme Class 1 heavy haul operating environment containing severe gradient up to 3.57% and numerous curves $\geq 10^\circ$. A spacing optimization process was incorporated in advance of multi-unit zone rollout. This procedure provided a critical and necessary means to determining the ideal TOR unit spacing for area operating challenges, ensuring optimized FM lateral force and rail wear reduction effectiveness. Bi-directional lateral force reductions of 27-34% were achieved under non-optimized field conditions containing heavy locomotive sanding, continuous train braking, and TOR surface grease contamination. No statistically significant rail wear rate reductions were recorded during FM application due to low service tonnage and non-optimized gauge face lubrication conditions. FM performance evaluation in a variety of mild to severe North American Class 1 heavy haul operating environments remains
ongoing. This ever-expanding database of information will be used for future development of a comprehensive mathematical model quantifying the ideal TOR unit placement strategy for a given operating area.

REFERENCES


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Figure 3. TOR Multi-unit Zone Application Spacing Logic Scenario 2

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Figure 5. Spacing Optimization Matrix to Establish Single Unit Uphill/Downhill Carry Distances

Figure 6. Spacing Optimization Trial Sub-Phase TOR 1e - TOR Unit Configuration

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Figure 8. WB/Low Rail Per Train Average Lateral Force

Figure 9. WB/High Rail Per Train Average Lateral Force

Figure 10. EB/Low Rail Per Train Average Lateral Force

Figure 11. EB/High Rail Per Train Average Lateral Force