REDUCING STRESS ON A LOW TRAFFIC DENSITY HIGHLY CURVED SYSTEM USING HI-RAIL TOR FRICTION CONTROL

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ABSTRACT

Kansas City Southern de México (KCSM) has experienced high track stress, tie cutting and rail wear in certain locations of their Tamasopo Division, which has extreme curvature and significant gradient. This paper reports a collaborative investigation by KCSM, Kelsan Technologies, and Rail Sciences of Top of Rail (TOR) friction control using Hirail spray application. Due to the low traffic on this line (six trains per day), Hirail spray can be practical and cost-effective for TOR application. A systematic investigation was undertaken using L/V measurements to 1) validate L/V reductions on this system, and 2) optimize spray application parameters.

Parameters examined included A) application to low rail only versus low and high rails, B) application rate, and C) application frequency. Key results included L/V reduction, retentivity (number of axles for which L/V was reduced compared to baseline), and net consumption.

Optimized Hirail application conditions were determined as 0.13 gal/mile/rail applied to the low rail only, daily. L/V reductions of 11% to 31% were recorded for downhill (empty) trains and 21% to 44% for uphill (loaded) trains. Film retentivity was approximately 1,200 axles.
KCSM has now instigated Hirail spray application of KELTRACK® as part of their routine operations, and anticipate resulting benefits in rail wear and track structure protection.

INTRODUCTION

Kansas City Southern de México (KCSM), Kelsan Technologies Corp. and Rail Sciences Inc. (RSI) collaboratively conducted a one-year investigation of freight hi-rail vehicle-mounted application of KELTRACK®, top of rail (TOR) friction modifier (FM), on the Tamasopo Division. The benefits of managing the wheel/rail interface using TOR FM have been documented through numerous freight and transit trials conducted globally. These benefits include lateral force and rail wear reductions ranging from 20 – 60% (1-6), corrugation growth reduction by a factor of 6 to 11 times (9-10), approximately 40% reduction in rail grinding due to reduced rolling contact fatigue (4,8), significant fuel savings (7) and wheel squeal noise reduction averaging 10 dB (11,12).

While TOR FM via wayside application has been extensively evaluated, the Tamasopo Division is the first to conduct a systematic optimization and evaluation of TOR FM via hi-rail application. This study found that significant L/V reductions were achieved under extremely challenging curve and grade conditions. The positive outcome of this study indicates that freight hi-rail vehicles can be a practical and cost-effective mode for FM application. To date, KCSM has incorporated TOR Hirail application as part of their routine
maintenance on the Tamasopo Division. KCSM is also exploring TOR implementation on their other divisions.

TAMASOPO DIVISION BACKGROUND

Kansas City Southern de México owns the concession to operate and maintain 2,645 track miles of railroad in Mexico. The “L” Line between San Luis Potosi (KP 225) in the central part of the country and the Gulf Coast port of Tampico (KP 678) presents one of the more challenging operating environments on the railroad. 52 kilometers on the eastern end of this line are characterized by continuous curves up to 21 degree curves (14 degree metric) and up to 3% grades. These segments run from KP 300 to 310, KP 430 to 465, and from KP 505 to 515.

The track structure in these segments had been recently upgraded to 136# head hardened CWR and 9' hardwood crossties. The upgraded fastening system utilized fully box-anchored 16" plates with cut spikes and CurvBloc® elements to prevent rail rollover. In spite of the upgrade, the track was exhibiting stress in the form of differential plate cutting and rail head deformation.

PROJECT SCOPE

Initial objectives were to devise an optimum Top of Rail Friction Modifier (TOR FM) application plan to reduce the lateral stress on the track. Prior to full-scale implementation, a trial would be conducted on a short 12.4 miles (20 km)
segment, KP 445 to KP 465, centering on a 21.8 degree (14.25 metric) curve at KP 454.2. This is one of the more severe curves on the Tamasopo.

KCSM engaged RSI to install and monitor a Truck Performance Detector (TPD) on the test curve to monitor L/V. Anticipated side benefits of the TPD included:

- Identification of bad actor cars
- Identification of overloaded cars
- Data to assist in recommending train makeup regarding locomotive placement and total train length and weight.

Rail Sciences gathered and pre-processed the data, then forwarded it to Kelsan for analysis and presentation. Paul Fettermen, engineering consultant to KCSM, coordinated the effort in the field and facilitated communications between the parties.

TRIAL ZONE CHARACTERISTICS

At the time of this study, the daily traffic consisted of six trains, approximately 200 axles in length, at maximum 5,000 tonnes each with five locomotives pulling at the front end. Empty traffic was directed downhill while loaded (80% to 90% loads) traffic was directed uphill. Annual tonnage was approximately 7 to 10 MGT.

Cell phone coverage and sunlight availability dictated, in part, which curve was to be instrumented. Test curve details, also found in Figure 1, were:
• Location: KP L-454.2
• Curve no. 264
• Left hand 21.8 degree curve (14° 15’ degree metric)
• 3% grade
• 1 ½” super elevation
• 10-15 mph train speeds

The selected curve at KP 452.2 was only accessible by hi-rail truck due to its remote location and required 24 hour security to protect the instrumentation equipment.

TEST CURVE INSTRUMENTATION

The high and low rail of the test curve were each instrumented with two strain gage cribs to measure the lateral and vertical forces of each car/axle passing over the test curve. By using two cribs, backup was provided in the event signals were lost from one crib. Furthermore, both cribs were averaged to provide the nominal forces for each axle. This eliminated anomalies due to wheel flats and truck friction forces.

RSI calibrated the site for accurate measurement of wheel loads and installed a pre-wired steel bungalow containing the necessary computers and signal conditioning equipment. The bungalow also contained a cell phone and antenna to allow communication for data transfer and troubleshooting. RSI also installed
a bank of batteries to power the site, with charging provided by a set of four solar panels.

The initial data collection plan called for the data to be transmitted by cell phone to RSI’s office in Atlanta. In addition, solar power was to be used as access to electricity was limited. Difficulties with the power demands of the TPD, with cost and reliability of the cell phone coverage, and with battery sizing led to a change in the plan. RSI provided a satellite hookup to transmit the data and the KCSM Signal Department provided new batteries that were better suited to the solar power arrangement. The Signal Department was also able to download the data in the event communication was interrupted.

**TOR FM HIRAIL APPLICATION SELECTION**

Initially, the KCSM track charts were reviewed to provide TOR application recommendations. Three methods are standard to choose from: wayside application, car-mounted application, or freight hi-rail vehicle-mounted application. Out of the three application modes, hi-rail application was selected as the most practical and cost-effective for the Tamasopo Division. Table 1 provides the benefits and disadvantages of each of the application methods. The characteristics at Tamasopo that make TOR Hirail favorable are:

- Daily train traffic is low.
- The required track coverage can be reasonably traveled by hi-rail vehicles.
TOR FM HIRAIL APPLICATION SYSTEM OVERVIEW

The TOR FM Hirail application system was assembled and installed by Portec Rail, Lumietri de México and KCSM in Mexpasa. The major components (Figure 1) of the TOR Hirail application system consist of the following:

- A control box located in the truck passenger compartment. The hi-rail operator can use the control box to choose to apply to one or both rails, flush the nozzle lines and monitor tank level and line flow status.
- An electrical box that houses the main electrical component assembly. The individual left and right pump setting dials for adjusting Hirail TOR application rates are also located here.
- A chart listing the left and right pump dial settings as calibrated to provide the proper application rate corresponding to a target hi-rail vehicle speed.
- Friction modifier reservoir
- Nozzle flush fluid reservoir
- Air compressor
- Two metering pumps
- Product circulation lines
- Spray nozzles with enclosures
- Line filters

TOR Hirail application consists of applying an atomized spray of KELTRACK® Hirail to the top of the rail. The water component in KELTRACK® Hirail rapidly evaporates, leaving a very thin and uniform film of friction modifier solids on the
railhead. Nozzle alignment can be adjusted to ensure the running band on the rail is adequate covered with the FM. KELTRACK® Hirail was specifically developed for this type of application. It has the following characteristics (15-16):

1. Viscosity and flow characteristics suitable for atomizing spray.
2. Minimal settling and agglomeration characteristics.
3. Maximum possible retentivity. This is critical for hi-rail application due to limited track access.

For the trial at KCSM, the application equipment was mounted on an existing KCSM one ton Hi-rail truck and calibrated to apply product corresponding to 12.4 mph (20 kph) vehicle speed.

APPLICATION OPTIMIZATION PLAN

The optimization plan was designed to determine the optimized TOR FM application strategy, rate and frequency. The application zone consisted of 6.2 miles (10 km) either side of and including the test curve to promote wheel conditioning. Considered application strategies consisted of:

1. application to curves, low rail only
2. application to curves, low rail and high rail

Each strategy applied a series of application rates until maximum L/V reduction and maximum retentivity (explained below) were reached. Each strategy was then evaluated by:

- L/V
Retentivity: The number of axles L/V reduction is sustained after TOR application. This property is dependent on film strength and is most impacted by air brake usage.

- TOR FM quantity consumed.
- Required number of hi-rail trips.

Baseline re-evaluations were conducted in between TOR test phases to detect any changes in baseline conditions and ensure a valid baseline to TOR comparison. The detailed optimization plan can be found in Table 2.

**L/V ANALYSIS**

Collected L/V data was organized using the criteria below:

- Locomotives were filtered out to maintain a consistent car data set.
- Axles were numbered in sequence in between TOR applications (e.g. TOR application, axle 1, axle 2, axle 3…, TOR application, axle 1, axle 2, axle 3…) and so forth.
- Data was categorized into high rail, low rail, westbound (uphill), eastbound (downhill), again to maintain consistency.

Since the L/V distribution plots have a relatively normal distribution, the Student T-test was used to test if average L/V differences between baseline and TOR test phases were statistically significant. A 99% Confidence Level Margin of Error was also applied in calculating the differences (17).
HI-RAIL APPLICATION SYSTEM MONITORING

The hi-rail operator recorded:

- Climate
- Temperature
- KP chainage traveled
- Time of application
- Vehicle odometer
- Low rail vs. low rail and high rail application
- Vehicle speed
- Dial settings and equivalent application rate

The hi-rail operator was instructed not to apply the friction modifier during rain as it would be washed off the rails.

Routine maintenance and inspection criteria were established and performed every 6 months by Lumietri de México. During the trial, the application system functioned smoothly. The only equipment interruptions that occurred were due to the hi-rail vehicle wheel condition and not related to the application system.

RESULTS

Out of the TOR test phases from A to D, Phase B provided the best combination of minimized TOR FM consumption and L/V reduction. L/V reductions ranged from 11% to 44%. Figures 3 to 6 illustrate the L/V reductions achieved by each test phase. It was noted that Baseline #4 was much lower than the other
baselines (most seen in Figures 4 to 6), possibly due to residual product from Phase C not being fully eliminated.

Likewise, TOR Phase B L/V distribution plots (Figures 7 to 10) illustrate a distribution of lower L/V values compared to baseline. Finally, L/V distribution plots were generated for locomotives only (Figures 11 to 12). These plots also show a pronounced L/V distribution shift to the left with TOR application.

**Repeatability**

TOR Phase B was repeated twice to verify that the observed lateral force reductions achieved with TOR application are repeatable. As shown in Figures 13 to 14, TOR Phase B clearly demonstrates a consistently significant drop in L/V compared to baseline.

**Retentivity**

Low rail and high rail L/V data were plotted against the corresponding axle sequence number. The axle sequence number where the L/V data appears to center on the baseline mean indicates that TOR Phase’s film retentivity. TOR Phase B, B2 and B3 were collectively evaluated to quantify retentivity. While 8 out of the 12 retentivity plots indicated that retentivity was not reached, the remaining 4 plots demonstrated a retentivity of 1,000 to 1,400 axles. Figures 15 to 17 illustrate three examples where retentivity was reached. To further establish the retentivity value, TOR Phase C and Phase D were included in the
retentivity analysis. For TOR Phase C, only 1 out of 4 retentivity plots showed that retentivity was reached (Figure 18). Interestingly, TOR Phase D, which used twice the amount of TOR Phase B but applied every two days instead of daily, yielded low retentivity values ranging from 500 to 800 axles. Figure 19 shows the plot for the 500 axle retentivity. Based on these results, Phase B TOR FM daily application was recommended for KCSM. To be conservative, retentivity was estimated at 1,200 axles. Incidentally, this retentivity value matches the estimated retentivity value from another TOR FM study conducted at BC Rail (1).

CONCLUSION

Despite a challenging test environment, solid results were obtained in this evaluation of TOR FM Hirail application by KCSM, Kelsan and Rail Sciences. L/V reductions ranged from 11% to 44%. The optimized application rate specific to this site was identified as 0.13 gal/mile/low rail (311 ml/km/low rail) on a daily basis with a retentivity of 1,200 axles. This trial validates TOR Hirail application can be a suitable choice for friction modifier application.

ACKNOWLEDGEMENTS

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Without their significant contributions and tremendous field support, this trial would not have been possible.

REFERENCES


<table>
<thead>
<tr>
<th></th>
<th>Benefits</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wayside</strong></td>
<td>• Application to every train ensures continuous and consistent train coverage.</td>
<td>• DC (solar panel option) powered units available for no AC source. However, DC installation sites are limited to sufficient sunlight areas and the solar panels are more prone to theft</td>
</tr>
<tr>
<td>KELTRACK®</td>
<td>• Optimizes wheel conditioning</td>
<td>• Numerous wayside units can be a very large capital investment</td>
</tr>
<tr>
<td>Trackside</td>
<td>• Utilizes equipment similar to wayside gauge face lubrication, allowing for smooth integration into existing track maintenance practices</td>
<td>• Numerous wayside units requires more filling and maintenance</td>
</tr>
<tr>
<td>Freight (13)</td>
<td>• Well suited for high non-captive fleet traffic frequency and large territories</td>
<td></td>
</tr>
<tr>
<td><strong>Hi-rail</strong></td>
<td>• Requires less hardware compared to multiple wayside units</td>
<td>• Limited by logistics i.e. it cannot apply once every train. Each train consumes some amount of KELTRACK®. KELTRACK® application must be sufficient that effectiveness and consumption balance.</td>
</tr>
<tr>
<td>KELTRACK®</td>
<td>• Allows off-site or off-track maintenance of TOR FM application system</td>
<td>• Required track coverage and frequency may be unfeasible for hi-rail.</td>
</tr>
<tr>
<td>Hirail (1)</td>
<td>• Optimizes rail conditioning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Well suited for low traffic frequency</td>
<td></td>
</tr>
<tr>
<td><strong>Freight Car-Mounted</strong></td>
<td>• TOR equipped car continues providing revenue, typically using only 15-20% carrying capacity</td>
<td>• For higher train speeds and localized weather conditions, nozzle contamination can require enhanced service intervals</td>
</tr>
<tr>
<td>KELTRACK®</td>
<td>• Optimizes rail conditioning</td>
<td></td>
</tr>
<tr>
<td>AutoPilot (14)</td>
<td>• Multiple FM application modes enables FM optimization based on train operating conditions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Typically lower application rates can be used compared to wayside and hi-rail TOR FM application systems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Maintenance activities do not require track access</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Large FM reservoirs extend product filling intervals in train service</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Well suited for high frequency captive fleet traffic areas</td>
<td></td>
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Table 1. Comparison of the Three Standard TOR FM Application Systems
<table>
<thead>
<tr>
<th>Phase</th>
<th>Strategy</th>
<th>Application Rate</th>
<th>Dates</th>
<th>Consumed</th>
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<tbody>
<tr>
<td>Baseline 1</td>
<td>None</td>
<td></td>
<td>Mar. '07 to Nov. '07</td>
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<tr>
<td>TOR Phase A</td>
<td>Curves, LR, Daily 9.5 miles (15.3 km)</td>
<td>0.079 gal/mile/rail (186 ml/km/rail)</td>
<td>Nov. 16' 07 to Dec. 10 '07</td>
<td>0.74 gal/day (2.8 L/day)</td>
</tr>
<tr>
<td>Baseline 2</td>
<td>None</td>
<td></td>
<td>Dec. 22 '07 to Dec. 25 '07</td>
<td>None</td>
</tr>
<tr>
<td>TOR Phase B</td>
<td>Curves, LR, Daily 9.5 miles (15.3 km)</td>
<td>0.13 gal/mile/rail (311 ml/km/rail)</td>
<td>Dec. 26 '07 to Jan. 9 '08</td>
<td>1.3 gal/day (4.8 L/day)</td>
</tr>
<tr>
<td>Baseline 3</td>
<td>None</td>
<td></td>
<td>Jan. 19 '08 to Jan. 21 '08</td>
<td>None</td>
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<tr>
<td>TOR Phase C</td>
<td>Curves, LR and HR Daily 19.0 miles (30.6 km)</td>
<td>0.079 gal/mile/rail (186 ml/km/rail)</td>
<td>Jan. 22 '08 to Feb. 5 '08</td>
<td>1.5 gal/day (5.7 L/day)</td>
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<tr>
<td>Baseline 4</td>
<td>None</td>
<td></td>
<td>Feb. 06 '08 to Feb. 09 '08</td>
<td>None</td>
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<tr>
<td>TOR Phase D</td>
<td>Curves, LR and HR Every 2 days 19.0 miles (30.6 km)</td>
<td>0.13 gal/mile/rail (311 ml/km/rail)</td>
<td>Feb. 09 '08 to Feb. 23 '08</td>
<td>2.5 gal/every 2 days (9.5 L/every 2 days)</td>
</tr>
<tr>
<td>Baseline 5</td>
<td>Dry</td>
<td></td>
<td>Feb. 24 '08 to Feb. 26 '08</td>
<td>None</td>
</tr>
<tr>
<td>TOR Phase B2</td>
<td>Curves, LR, Daily 9.5 miles (15.3 km)</td>
<td>0.13 gal/mile/rail (311 ml/km/rail)</td>
<td>Mar. 5 '08 to Apr. 11 '08</td>
<td>1.3 gal/day (4.8 L/day)</td>
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<tr>
<td>Baseline 6</td>
<td>None</td>
<td></td>
<td>Apr. 12 '08 to Apr. 14 '08</td>
<td>None</td>
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<tr>
<td>TOR Phase B3</td>
<td>Curves, LR, Daily 9.5 miles (15.3 km)</td>
<td>0.13 gal/mile/rail (311 ml/km/rail)</td>
<td>Apr. 15 '08 to Apr. 26 '08</td>
<td>1.3 gal/day (4.8 L/day)</td>
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</table>

Table 2. Detailed TOR FM Application Optimization Plan
Figure 1. Trial Zone and Instrumented Test Curve

Figure 2. Overview of TOR Hirail FM Application Equipment

1. FM Reservoir
2. Flush Fluid Reservoir
3. Air Compressor
4. Metering Pump
5. Electrical Box
6. Spray Nozzle Enclosures
Trains to Tampico (Eastbound, Downhill), High Rail, Leading Axle, Cars Only
Baseline versus TOR Average L/V

Baseline #1  Baseline #2  Baseline #3  Baseline #4*
TOR Phase A  TOR Phase B  TOR Phase C  TOR Phase D
2.8 L/trip/day  4.8 L/trip/day  5.7 L/trip/day  9.5 L/trip/2 days
LR only       LR only       LR and HR    LR and HR
[-7% to +2%]  [-24% to -31%]  [-16% to -26%]  [-2% to +9%]

Figure 3. High Rail Average L/V for Downhill Trains

Trains to Tampico (Eastbound, Downhill), Low Rail, Leading Axle, Cars Only
Baseline versus TOR Average L/V

Baseline #1  Baseline #2  Baseline #3  Baseline #4*
TOR Phase A  TOR Phase B  TOR Phase C  TOR Phase D
2.8 L/trip/day  4.8 L/trip/day  5.7 L/trip/day  9.5 L/trip/2 days
LR only       LR only       LR and HR    LR and HR
[-9% to -12%]  [-11% to -20%]  [-4% to -17%]  [+28% to +58%]

Figure 4. Low Rail Average L/V for Downhill Trains

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Trains to San Luis Potosí (Westbound, Uphill), High Rail, Leading Axle, Cars Only
Baseline versus TOR Average L/V

<table>
<thead>
<tr>
<th>Baseline #1</th>
<th>Baseline #2</th>
<th>Baseline #3</th>
<th>Baseline #4*</th>
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<tr>
<td>TOR Phase A</td>
<td>TOR Phase B</td>
<td>TOR Phase C</td>
<td>TOR Phase D</td>
</tr>
<tr>
<td>2.8 L/trip/day</td>
<td>4.8 L/trip/day</td>
<td>5.7 L/trip/day</td>
<td>9.5 L/trip/2 days</td>
</tr>
<tr>
<td>LR only</td>
<td>LR only</td>
<td>LR and HR</td>
<td>LR and HR</td>
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</table>

L/V

[-4% to -8%]  [-35% to -44%]  [-33% to -42%]  [+7% to +31%]

Figure 5. High Rail Average L/V for Uphill Trains

Trains to San Luis Potosí (Westbound, Uphill), Low Rail, Leading Axle, Cars Only
Baseline versus TOR Average L/V

<table>
<thead>
<tr>
<th>Baseline #1</th>
<th>Baseline #2</th>
<th>Baseline #3</th>
<th>Baseline #4*</th>
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<tbody>
<tr>
<td>TOR Phase A</td>
<td>TOR Phase B</td>
<td>TOR Phase C</td>
<td>TOR Phase D</td>
</tr>
<tr>
<td>2.8 L/trip/day</td>
<td>4.8 L/trip/day</td>
<td>5.7 L/trip/day</td>
<td>9.5 L/trip/2 days</td>
</tr>
<tr>
<td>LR only</td>
<td>LR only</td>
<td>LR and HR</td>
<td>LR and HR</td>
</tr>
</tbody>
</table>

L/V

[-7% to -11%]  [-21% to -26%]  [-19% to -25%]  [+2% to +13%]

Figure 6. Low Rail Average L/V for Uphill Trains

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Figure 7. High Rail L/V Distribution for Downhill Trains – Cars Only

Figure 8. Low Rail L/V Distribution for Downhill Trains – Cars Only

Figure 9. High Rail L/V Distribution for Uphill Trains – Cars Only
Trains to San Luis Potosí (Westbound, Uphill), Low Rail, Leading Axle, Cars Only

Figure 10. Low Rail L/V Distribution for Uphill Trains – Cars Only

Trains to Tampico (Eastbound, Downhill), High Rail, Leading Axle, Locomotives Only

Figure 11. High Rail L/V Distribution for Downhill Trains – Locomotives Only

Trains to Tampico (Eastbound, Downhill), Low Rail, Leading Axle, Locomotives Only

Figure 12. Low Rail L/V Distribution for Downhill Trains – Locomotives Only

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Figure 16. TOR Phase B3 Retentivity for High Rail, Uphill Trains

Figure 17. TOR Phase B3 Retentivity for Low Rail, Downhill Trains
Trains to San Luis Potosí (Westbound, Uphill), High Rail, Leading Axle, Cars Only
TOR Phase C Retentivity = ~1,400 axles

Baseline #3 NB HR Average L/V: 0.32

Figure 18. TOR Phase C Retentivity for High Rail, Uphill Trains

Trains to Tampico (Eastbound, Downhill), Low Rail, Leading Axle, Cars Only
TOR Phase D Retentivity = ~500 axles

Baseline #3 SB LR Average L/V: 0.28

Figure 19. TOR Phase D Retentivity for Low Rail, Downhill Trains
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