

## EVALUATION OF INDUSTRY PRACTICES FOR WHEEL/RAIL FRICTION CONTROL

by Richard P. Reiff, Scott E. Gage, and Corey T. Pasta

### Summary

To supplement test and field performance data gathered for wheel-rail lubrication control, Transportation Technology Center, Inc. researchers have used the Association of American Railroad's NUCARS software to model the effects of track-lubrication condition on steady-state curving performance of freight cars. While proper application of lubrication has been proven to reduce both lateral loads and the amount of energy needed to move a train, both NUCARS predictions and field tests have indicated that curving resistance was minimized when friction was minimized on both gage-face and top-of-rail locations. In addition, these tests have shown that excessive lubrication of the high rail, combined with a dry low rail, can lead to large lateral gage widening forces on sharper curves. This could be a contributing factor in derailments caused by gage widening.

Industry practices in rail/wheel lubrication are provided in the form of target friction values for top and gage face locations. Data collected from NUCARS modeling was supplemented by full-scale tests conducted under a wide range of conditions at the Federal Railroad Administration's Transportation Technology Center near Pueblo, Colorado. The parameters investigated included lubrication condition (coefficient of friction,  $\mu$ ), track curvature, wheel/rail profiles, and truck condition (warp stiffness). Combinations of these parameters were analyzed to determine their effect on energy consumption, lateral forces and L/V ratios. Full-scale testing also monitored angle of attack, noise level, and resulting rail friction under a variety of application conditions. Test conditions utilized a 75-car freight train of 6,800 total tons traveling at an average speed of 30 mph over a 3.5-mile loop of varying curvature.

Major conclusions include suggested friction levels:

- The optimum top-of-rail friction coefficient was found to be 0.35 or greater with a maximum low-rail versus high-rail friction differential of 0.1.
- On the top of the low rail, a coefficient of friction greater than 0.45 can cause high lateral curving forces if the high rail gage force is lubricated.
- The optimum gage-face coefficient of friction is suggested to be no greater than 0.25. Values of friction have been measured as low as 0.05 on the gage face.
- From this limited simulation matrix, NUCARS results predict that the top-of-rail and wayside application methods offered the highest potential in energy reduction.

### Suggested Distribution:

- Maintenance of Way
- Planning & Analysis
- Track Maintenance
- Safety



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## INTRODUCTION AND CONCLUSIONS

Over the years, several lubrication studies have been conducted at the Federal Railroad Administration's (FRA) Transportation Technology Center (TTC) to determine the effectiveness of various lubrication methods. Results showed significant energy savings could be realized from improved curving performance with various lubrication practices. A goal of the Association of American Railroads (AAR)-sponsored research was to suggest target friction levels that could be used by field personnel for adjusting lubrication. In 1998, the AAR's NUCARS model was used to evaluate lubrication methods and their effectiveness as influenced by variations in track curvature, wheel/rail profile pairing, truck conditions, and train speed. Modeling results were supplemented with data collected on TTC tracks. Modeling and testing data were analyzed to develop industry practices for lubrication (rail-friction guidelines), and to evaluate top-of-rail (TOR) lubrication effectiveness.

An effective, consistent wheel/rail lubrication application method reduces many of the negative effects of wheel/rail forces. Historically, lubrication has been shown to increase wheel and rail life, reduce energy consumption of trains, reduce lateral curving loads, and control noise emissions. However, it has also been shown that too much or improperly applied lubrication may be as detrimental as no lubrication, and may adversely affect truck curving, train handling, and rail fatigue life.

Clearly, an optimum level of friction exists for each wheel/rail interface location (top-of-rail and flange face for both high and low rails). Although such optimal conditions may not be achieved everywhere, target friction values are the key to reduced fuel usage and wear. The purpose of this study is to analyze data (primarily from NUCARS computer modeling) that is representative of a wide range of performances. From this data, optimum levels of friction can be suggested. Through the use of automated high-speed tribometers (or other means of friction-coefficient measurement), the effectiveness of lubrication systems can be measured and managed.

NUCARS modeling indicated that wheel/rail pairing can overpower the effects of energy and

lateral load performance. Modeling also showed that the reduction in curving resistance was maximized when friction was minimized on both gage face and top-of-rail locations, and that high lateral forces and/or large L/V ratios can be induced by large friction differentials. Using these results, optimum friction coefficients for the top-of-rail and gage-face locations were specified.

## RAILROAD LUBRICATION OPTIONS

Track lubrication is one of the most variable practices in the railway industry. Track lubrication was first applied by stationary wayside lubricators that apply a set amount of lubricant when triggered by wheel passage.

As the industry came to realize that lubrication could significantly improve fuel consumption, a means of lubricating the entire track (not just the curves) was sought. This led to the use of mobile applicators (using hi-rail equipment) and locomotive flange applicators. Recent experience with locomotive flange lubrication has shown difficulty in adjustment and less-than-acceptable reliability, thus a "behind-the-locomotive" TOR lubrication method has been proposed. A specially aligned locomotive-mounted system applies lubricant behind the last locomotive. The effectiveness of the TOR methods hinges on sufficient lubricant to reach the last car of the train, but not so much as to create a build-up resulting in driver slippage on the next locomotive pass.

## NUCARS MODEL AND ASSUMPTIONS

Five parameters were included in the NUCARS simulations:

- Lubrication condition
- Track curvature
- Wheel/rail profile pairing
- Truck condition (warp stiffness)
- Speed

The primary variable in this study is track lubrication, or the state of friction at various wheel/rail interfaces. Exhibit 1 lists the lubrication conditions and their associated friction coefficients.

The base-case (dry) condition used as the baseline for this study has a high friction coefficient of 0.5; steady-state friction coefficients of this



Exhibit 1. Rail Friction by Applicator Type

Condition	High-Rail Crown	High-Rail Gage Face	Low-Rail Crown
Base Case (Dry)	0.5	0.5	0.5
Base Case with Contamination	0.4	0.35	0.4
Locomotive Flange Lubricator	0.5	0.35	0.5
Locomotive System with Malfunction	0.25	0.25	0.3
Top-of-Rail System: Head of Train	0.25	0.2	0.2
Top-of-Rail System: End of Train	0.4	0.45	0.4
Wayside System at Lubricator	0.25	0.2	0.4
Wayside System at Distance	0.35	0.25	0.35
Hi-Rail after Application	0.25	0.15	0.3
Hi-Rail before Application	0.5	0.3	0.5

magnitude are typically found only in arid climates. The base case with contamination is typical of non-lubricated track in average-humidity environments.

The locomotive flange lubricator is designed to lubricate only the gage face of the high rail. A locomotive flange lubricator with a malfunction was modeled in which the rail crown and gage face of both rails were lubricated.

The top-of-rail lubrication study modeled a condition in which lubricant was applied to both the rail crown and gage face. This model also accounted for the reduced amount (and effect) of lubrication after each successive car passing. Thus, the friction levels gradually become higher toward the end of the train.

The friction levels for the wayside lubrication model were adjusted to account for the diminishing effect of lubrication at a distance from the lubrication site.

The final friction study simulates a lubricant schedule as applied by a hi-rail vehicle for two scenarios: one just prior to lubrication and the second just after hi-rail lubricant application.

Modeling included 14 unique wheel/rail profile pairings, and four cases were modeled in

which track gage was widened by 0.5- and 1-inch values from standard.

**RESULTS**

Exhibit 2 shows calculated train resistance for a 100-ton coal car as compared to the base-case (dry) lubrication condition.

The top-of-rail system for the head-of-train position had the greatest reduction in rolling resistance, followed closely by the wayside system at the applicator site.

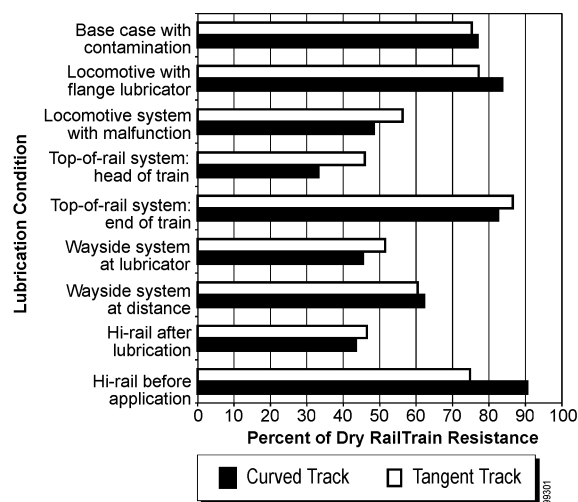
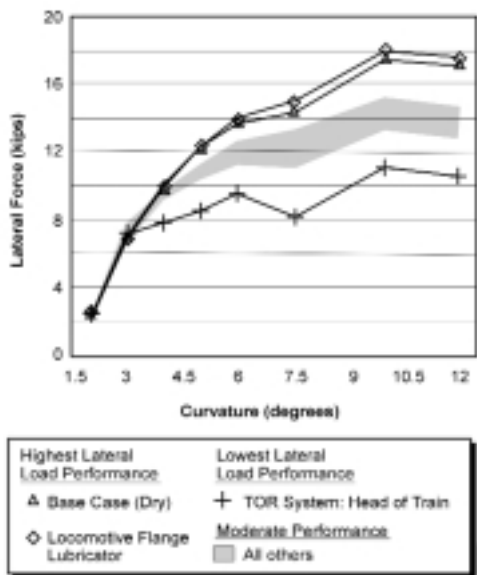


Exhibit 2. Rolling Resistance as Compared to Base Case (Dry)

Exhibit 3 is a plot of maximum lateral forces calculated in NUCARS for various curvatures and lubrication methods. The TOR head-of-train friction resulted in the lowest lateral forces. Aside from the base case (dry), the locomotive flange lubricator and hi-rail before application conditions produced the highest lateral forces. These results indicate that both rail crown and flange faces should be lubricated (to the proper friction coefficient) to best avoid high lateral forces.

From the NUCARS analysis, an initial set of lubrication guidelines was created. The optimum top-of-rail friction coefficient was found to be 0.3 or greater, with a friction differential between high and low rail of 0.1 or less. A top-of-low-rail coefficient of friction greater than 0.45 can cause high lateral curving forces if the high rail is lubricated. The optimum gage-face coefficient of friction is suggested to be no greater than 0.25.

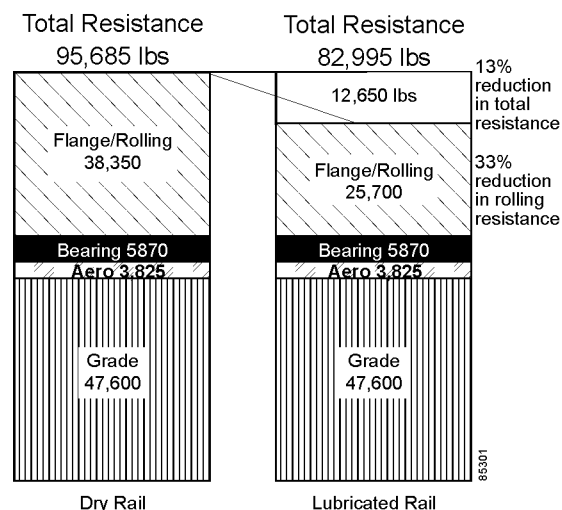
It was found that curving resistance values were relatively sensitive to parameter changes, while lateral force values proved less sensitive. Increasing gage by 0.5 and 1 inch did not significantly affect curving performance.



**Exhibit 3. Maximum Lateral Force as a Function of Lubrication and Curvature**

A number of parameters that make up total train resistance, including grade, gearing, aerodynamic, and rolling resistance were used. Wheel and rail lubrication can only reduce the rolling resistance; other parameters are not affected. The amount of fuel savings that can be attributed to a reduction in rolling resistance will depend on the route, train speed, train handling, and other factors. Exhibit 4 shows the major categories of resistance for a typical hilly route with high curvature. A 33 percent reduction in rolling resistance has a net effect of reducing the overall energy by about 13 percent, as other parameters remain the same. A similar train operating over tangent track at low gradient may see less than 5 percent total energy reduction under the same percentage of rolling resistance.

Future work in the area of industry practices for wheel/rail lubrication will monitor field performance (energy, curving, and friction) as alternative methods are demonstrated under various implementation schemes. This will also include further on-track investigation of top-of-rail lubrication systems.



**Exhibit 4. Major Categories of Resistance for a Hilly Route with High Curvature**

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**Note: Contact Richard Reiff at (719) 584-0581 with questions or comments about this document.**  
**E-mail: richard\_reiff@ttci.aar.com**  
**Web site: www.ttci.aar.com**

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