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# Simulations of Buff Force on Cars in a Curve

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The work described was performed by Transportation Technology Center, Inc.. a wholly owned subsidiary of the Association of American Railroads.

## Key Findings:

- Parametric simulations predict derailment at buff loads only in excess of 350 kips when considering curves as sharp as 10 degrees with typical superelevation and coupled cars varying by up to 40 feet in length.
- The typical derailment mechanism predicted is carbody roll toward the outside of the curve after the development of large truck side L/V values.
- A combination of short and long cars had derailment under 100 - 300 kips lower buff force when compared to the combination of the same 53-foot-long cars.
- Rail rollover is predicted in a case study simulation involving no curve superelevation and weak rail restraint intended to represent yard track conditions. For simulations with stronger rail restraint intended to represent mainline conditions, rail roll is predicted only as a result of the derailment, not as a cause.

Transportation Technology Center, Inc. (TTCI) is investigating the extent to which large longitudinal coupler forces produced by trains may develop lateral wheel/rail forces large enough to potentially result in track panel shift and/or rail rollover. TTCI studied factors that influence in-train forces and wheel-rail forces, as well as the factors that affect track stability and rail roll phenomena. This *Technology Digest* focuses on in-train forces and wheel-rail forces.

### INTRODUCTION

TTCI developed a research program to conduct simulations and tests to record dynamic load data to estimate effects of in-train forces on track. Preliminary modeling involving a simplified coupler arrangement represented by a solid drawbar showed that large wheel/rail lateral forces could be generated from large in-train buff forces.

Results and observations from the on-track tests at the Transportation Technology Center (TTC), Pueblo, CO, showed that the cars did not take up a jackknife orientation as a result of steady state buff forces approaching 300 kips, thus no large wheel/rail lateral forces were generated. It was determined that the simplistic representation of the cars coupling arrangement was the primary reason for the discrepancy. The post-test coupler models were updated to a more sophisticated and detailed representation, and the updated model produced results more closely matching the test data results. The new modeling effort focused on expanding the simulation matrix to evaluate higher buff loads, more accurate coupler representation, updated two-layer NUCARS®* track model, different car combinations, and a range of track curvatures.

### NUCARS® TRACK MODEL

The previous NUCARS® modeling effort consisted of three empty standard hopper (53 feet, 9 inches long) cars negotiating measured track geometry of the 4-degree curve of the Wheel Rail Mechanism loop (WRM) track at TTC.

The initial runs were completed at 7 mph with buff forces from 50 to 300 kips to replicate the track tests conducted at TTC in 2018. Later, the simulation matrix was extended to analyze higher buff forces up to 1,000 kips. Note that the maximum train action related buff force measured by TTCI in a revenue service train over 20,000 miles was only 320,400 pounds.[1] Peak buff forces greater than ~225,000 pounds were rare.

*NUCARS® is a registered trademark of Transportation Technology Center, Inc.

NUCARS® track models allow the user to simulate different levels of detail in the track characteristics. Track simulations may include hypothetical track geometries or measured track geometry supplied by the user. The simplest model is a rigid track model where the rail-to-ground relationship is defined through a single vertical stiffness and damping value and a single lateral stiffness and damping value. The rigid track model does not allow the rail to roll. The next type of track model is the one-layer track model, which adds individual connections between the rail and the ground at certain locations — this allows for more accurate rail movement and roll mechanics. The most advanced option is a two-layer model where each tie is represented as a body that can move; the rail is connected first to the ties and the ties are then connected to the ground. This model allows the movement of each tie to influence the adjacent ties and for tie displacement to be evaluated.

A three-car model was used and expanded by adding a two-layer NUCARS® track model beneath all runs. The track stiffness characteristics were validated against data taken by a Track Loading Vehicle (TLV) on site at TTC.[2] TLV data was taken for spiral, curve, and tangent track of the same 4-degree curve of the on-track test program by applying various lateral loads to the rail and measuring the rail head and tie lateral deflection. Static NUCARS® models were then simulated to match the rail and tie stiffnesses. The TLV and NUCARS® data for lateral rail head deflection per applied lateral force matched closely.

Next the updated two-layer track model was added to an existing three-hopper car model created by TTCI.[3] Because the lateral track properties were different for tangent, spiral, and curved track, three separate track models were developed and applied within the appropriate section of the modeled WRM curve.

When compared with the original statistics of the three-car model simulated without the track model, the general trends remained the same with slight variations at some buff forces. The largest change was the buff force at which the model first derailed. The three-car model with the two-layer track generally derailed at a buff force ~50 kips larger than the first derailment of the three-car model without a track model — most likely because the track model provides more compliance for displacement, both in rail roll and track lateral displacement.

The main outputs analyzed were truck side L/V ratio, single-wheel L/V ratio, and maximum axle load ratio. The truck side L/V values were compared to a truck side L/V limit of 0.6,[4] the single-wheel L/V compared to a limit of 1.0, and the maximum axle load ratio compared both to the Prud'homme limit of 0.4[5] and to the TLV limit of 0.88.[6] Figure 1 shows the maximum axle load ratio within the 4-degree curve for the two models. Both models have steadily increasing axle load ratio with increasing buff force. The model without the track modeled first derailed at 900 kips while the model with the track first derailed at 950 kips.

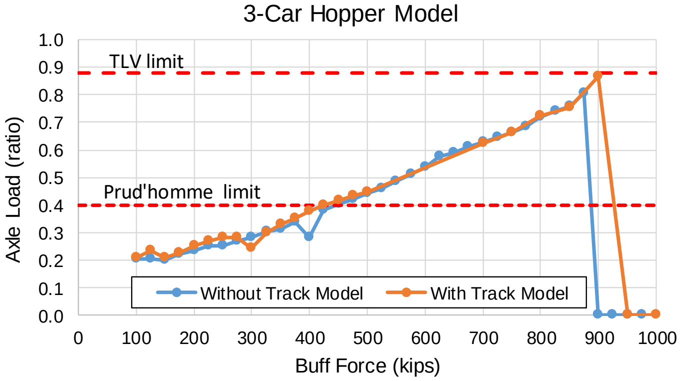

**Figure 1.** **Maximum axle load ratio versus buff force for three-car models with and without a two-layer track model on 4-degree curve**

The derailment mechanism for the runs that derailed was the middle car of the three-car model lifting off the rail due to the vertical component of the buff force through the train consist. As the middle car was lifted, the wheels lifted off the low rail and the car rolled over the high rail. The resultant lateral forces were high enough to roll the rail if the fastening system is modeled with characteristics representing degraded timber ties, lifted spikes, or yard conditions. In these simulations, a model representing well maintained track at TTC was used, and the rail did not roll.

## MULTIPLE-LENGTH THREE-CAR MODELS

Next, three-car model combinations with differences in car length were evaluated. It was expected that long car-to-short car combinations in curves would lead to greater angularity in the coupler connection, which would further lead to higher lateral forces resulting from the buff forces through the train consist. The following coupled three-car models of varying car length combinations were simulated:

- Empty Hopper/Empty Hopper/Empty Hopper (EH_EH_EH)
- Empty Hopper/Empty Well/Empty Hopper (EH_EW_EH)
- Empty Sand/Empty Well/Empty Sand (ES_EW_ES)
- Empty Hopper/Empty Flatcar/Empty Hopper (EH_EF_EH)

Table 1 shows the truck center spacing and total length for each car. Note that these combinations comply with the generally accepted guideline for train make-up that cars shorter than 45 feet should not be coupled to cars 80 feet and longer regardless of weight.

All cars were modeled with E60 type couplers except for the empty flatcar, which was modeled with E69 couplers. The basic track geometry of the WRM was used in terms of curvature and superelevation, but with ideal track (no irregularities in gage, surface, or alignment) and with the simpler rigid NUCARS® track to isolate the effects of the buff forces translating into lateral wheel/rail forces.

Table 1. Truck center spacing and length of cars used in NUCARS® models

| Car | Truck Center Spacing | Total Length |
|---|---|---|
| Sand | 28′ 11″ | 41′ 11″ |
| Hopper | 40′ 6″ | 53′ 9″ |
| Well | 62′ 9″ | 75′ 10″ |
| Flat | 66′ | 93′ 11″ |

Higher degrees of curvature increase the lateral forces transferred to the rail from buff forces in the train consist, so the simulation matrix was expanded to included higher degree curvatures. The simulations were run at balance speed using the following degrees of curvature and superelevation of the test curves of the WRM loop at TTC:

- Four-degree curve with 3-inch superelevation at 33 mph
- Seven-degree curve with 3-inch superelevation at 25 mph
- Ten-degree curves with 4-inch superelevation at 24 mph

The main simulation outputs were the truckside L/V, single-wheel L/V, and maximum axle load ratio. These outputs were compared to the same limits described previously. Figure 2 shows the truck side L/V for the EH_EW_EH model on 4-, 7-, and 10-degree curves.

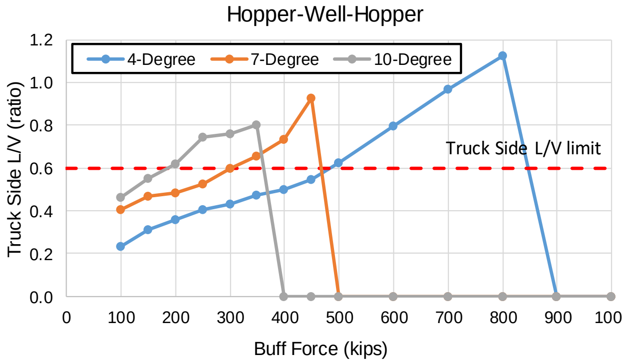

Figure 2. EH_EW_EH model truck side L/V over a variety of curvatures

Simulations that derailed had all results set to zero. The results for the EH_EH_EH and ES_EW_ES followed a similar trend to the EH_EW_EH for all outputs. All three models derailed in the same way, with the middle car rolling toward the outside of the curve.

The EH_EF_EH model results followed a slightly different trend than the other models: rather than a steady rise in outputs such as truck side L/V with increasing buff force, a large increase in the outputs occurred suddenly. Figure 3 shows the truck side L/V increased drastically between 200 kips and 250 kips buff force on 4-degree and 7-degree curves, because the flatcar was modeled with the longer E69 coupler, and at a certain buff force the couplers "popped" to their lateral limit toward the outside of the curve. The couplers popping out to the lateral limit led to much higher lateral forces in the trucks nearest the couplers. Once the couplers popped out, large lateral forces were transferred to the trucks in the empty hopper cars closest to the flatcar. This led to a high truck side L/V in these trucks and eventual unloading of the low rail wheel and derailment where one of the hoppers rolled to the outside of the curve. For each model, as the buff force increased the single-wheel L/V, truck side L/V, and axle load ratio increased, exceeded the criteria limit, and then derailed. Figure 4 shows the first buff force at which each EH_EF_EH model derailed on each degree of curvature.

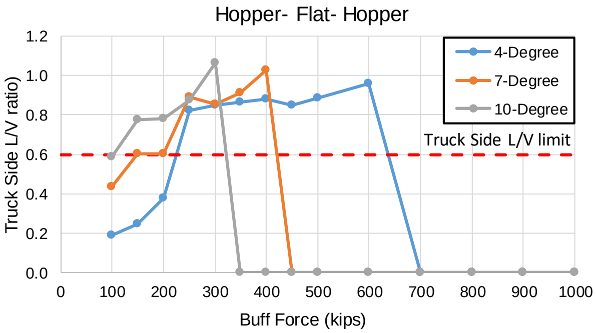

Figure 3. EH_EF_EH model truck side L/V over different curvatures

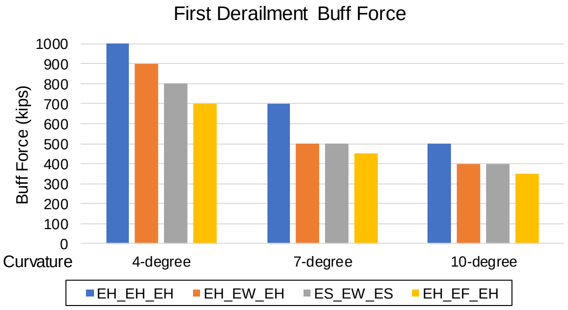

Figure 4. First derailment buff force for each model and curvature

## CASE STUDY

One example of a special case model under development is an EF_EF_EH model with a single-layer track model included. The flatcars modeled have a longer E69 coupler, which in addition to the large difference in carbody length will lead to large lateral forces in curves. The model was run over a 10-degree curve with no superelevation and low strength track representative of yard conditions. The goal of this model was to show how a lower buff force can lead to rail roll in certain situations. Figure 5 shows a NUCARS® simulation for a 300-kip buff force run, which exceeds the truck side L/V limit and rolls the right rail at Axle 7 (Axle 3 in middle flat) before derailing.

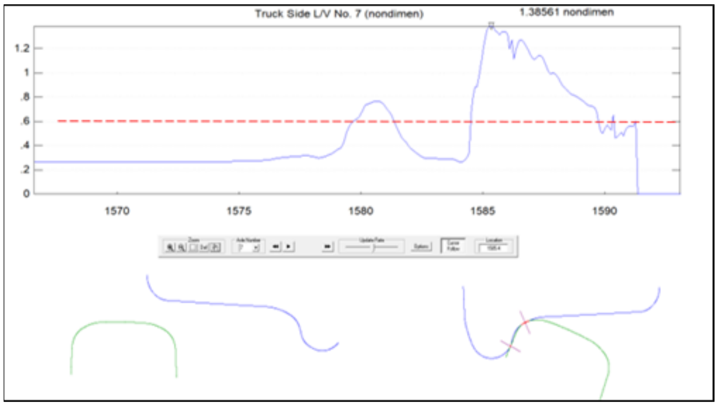

**Figure 5. NUCARS® case study model truck side L/V and Axle 7 wheel and rail animation**

## CONCLUSION AND NEXT STEPS

TTCI created NUCARS® models to investigate the effect of in-train forces on various car combinations and track structures. Simulations were run over a variety of scenarios. TLV data was used to validate a two-layer NUCARS® track model. Models run over both the rigid track model and the two-layer model showed similar trends; however, some two-layer models derailed at a slightly higher buff force, because the two-layer track allows for additional rail movement under higher lateral forces. Models with different car lengths were run over 4-, 7-, and 10-degree curves. As buff force was increased, single wheel L/V, truck side L/V, and axle load ratio all increased, eventually reached the respective limits, and derailed soon after exceeding that criteria. Different car combinations followed the same trends; however, combinations with larger differences in car length tended to exceed criteria limits and derail at lower buff forces. When the models derailed, one of the cars rolled toward the outside of the curve after developing large truck side L/V values. In the simulations, the strong track model was used, and the rail did not roll. However, the resultant truck side L/V values were high enough to roll the rail if a weaker fastening system is used. With the strong track, the rail roll is a result of the derailment rather than a cause of derailment.

The next steps in this effort will expand the number of variables modeled to replicate problematic in train forces. Additions to the effort include adding more car combinations (car length and coupler combinations), perturbations in the track, impulse buff forces due to slack action, initial offset of couplers, and introduction of cant deficiency and weaker track structure.

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