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Analysis of Coupler Forces in Trains with End-of-Car Cushioning using the TOES™ Model

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Summary

Transportation Technology Center, Inc. (TTCI) conducted simulations using the Train Operation and Energy Simulator (TOES™) model to investigate the effects of train handling and train make-up on longitudinal coupler forces and to produce generalized guidelines for trains with end-of-car cushioning (EOCC).

The simulations were divided into two parts: flat track simulations and real-world hill and sag simulations. The flat track simulation set consisted of 9,624 different simulations and showed that consist make-up and distributed power (DP) configuration had a significant effect on the magnitude of the maximum coupler forces. Consists with DP had lower in-train forces than head-end only power for almost every condition modeled. The study shows that remote units helped to control slack in the train. The DP configurations with two remote locomotives (in the middle and at the rear of the train) provided the best overall control of coupler forces through a wide variety of handling scenarios

Size and location of the EOCC block within the train also had considerable effects on the magnitude of the maximum coupler forces, which were generally lower when the block of EOCC equipped cars were placed at the rear of the train because there was no trailing tonnage behind the EOCC car block. The size of the EOCC car block also had a significant effect on the maximum coupler forces when the EOCC car block exceeded about 40 cars.

The real-world hill and sag set, consisting of 66 different simulations, showed that asynchronous control of remote units generally limited the amount of slack action in the train and reduced the likelihood of run-in and run-out events, but it also resulted in higher steady state buff forces because the remote units were constantly pushing the train into a compressed state. Undesired emergency brake (UDE) simulations showed that if a UDE occurred while a train was cresting a hill or negotiating a sag, the resulting coupler forces could exceed 300 kips.

The modeling effort described provides some of the data needed to develop operating guidelines. Additional details and insights from the TOES™ modeling will be provided in a future report. This effort is part of the Association of American Railroads' Strategic Research Initiative on dynamic load environment of train equipment.

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INTRODUCTION

Longitudinal coupler forces are generated when a speed differential exists between adjacent cars in a train. This dynamic train action can cause damage to cars and lading and, in extreme cases, can result in derailment. As part of the AAR's Strategic Research Initiatives Program, TTCI conducted an analysis of coupler forces in trains that contain cars equipped with end-of-car cushioning (EOCC) units. This *Technology Digest* focuses on simulations designed to explore the coupler forces associated with different train make-up and train handling scenarios.

BACKGROUND

EOCC units use hydraulic cylinders in place of standard friction draft gears to absorb energy and to improve the performance of cars in yard impacts. Although these devices protect the cars and lading during coupling impact events, they can create challenges during normal train operations. Around 15 percent of the cars in the fleet are equipped with EOCC units. This can include autoracks, boxcars, flatcars, and gondolas.

Most EOCC units are capable of 10 or 15 inches of longitudinal slack action and take a fully extended position in the absence of applied external forces. A block of 20 cars equipped with 10-inch EOCC units allows up to 33 feet of longitudinal slack action in the train. A block of 20 cars equipped with 15-inch EOCC units allows up to 50 feet of longitudinal slack action in the train. The 10 to 15 inches of travel per EOCC unit is large compared to typical friction draft gears. When many EOCC units are in the same train, they create the potential for large speed differences between cars that can result in buff (compression) or draft (tension) impacts between cars. Modern EOCC units have a preload feature that attempts to reduce train action.

Because cars equipped with EOCC units allow for large displacements and large speed differentials between cars, blocks of these types of cars must be carefully placed within the train to minimize adverse effects from train handling and normal operations. TTCI previously performed simulations to evaluate the effects of different variables on longitudinal coupler forces in trains containing blocks of cars equipped with EOCC units.[1] The study found that coupler force magnitudes were affected considerably by train handling and train make-up; including EOCC car block size, EOCC car block position, and train load profile. The study also found that the effects of train make-up and train handling can be difficult to separate and are dependent on one another.

Building upon this work, TTCI conducted longitudinal train dynamics simulations to further investigate the effects of train handling and train make-up and to produce generalized guidelines for trains with EOCC units. Simulations were conducted using TTCI's Train Operation and Energy Simulator (TOES™), a computer program that models longitudinal train dynamics such as run-in and run-out events occurring from train handling. The TOES™ program includes non-linear models of draft gears, EOCC devices, and a computational fluid dynamics model of the air brake system.

SIMULATION MATRIX

The simulation matrix consisted of two distinct modeling efforts:

1. **Flat track simulations:** trains on flat, tangent track with train handling designed to create buff and draft impacts, and
2. **Real-world hill and sag simulations**: trains cresting hills and negotiating sags in the track.

The simulation matrix was split into two sections to allow the analysis to address many different parameter variations and scenarios at a general level and still account for realistic conditions that can be encountered in a revenue service environment. The flat track simulations were an attempt to isolate the effects of train make-up and train handling by removing track and terrain features that necessitate a particular type of train handling. The train handling used in the flat track simulations was designed to create run-in and run-out slack action events. Dynamic brake, full-service brake, and emergency brake applications were applied in the model to rapidly decelerate the train and create run-in events. The train was rapidly accelerated using a throttle application to initiate run-out events. The parameters that were varied in the flat track simulation set included:

- Train handling scenario: Dynamic brake, throttle, full-service brake, emergency brake.
- Initial train speed: 0 (throttle only), 10, 20, 30, 40, 50, and 60 (braking only) mph.
- Train size: 50, 100, 150, and 200 cars.
- EOCC car block size: 0, 10, 20, 30, 40, 50, 75, 100, 150, and 200 cars.
- EOCC car block position: Front, middle, and rear of the consist.
- Distributed power (DP) configuration: Head-end, head-middle, head-2/3, head-rear, and head-middle-rear.

The real-world simulations were conducted to show how realistic operating scenarios that may be encountered in revenue service — cresting a hill or negotiating a sag — may affect the magnitude of longitudinal coupler forces. The parameters that were varied in this real-world simulation set included:

- Track layout: Cresting a hill or negotiating a sag at 20 mph
- Consist make-up and DP configuration:
  - 100 cars with 2 locomotives in the lead, none in the middle and 1 at the rear of the train (2-0-1 locomotive configuration).
  - 100 cars with 3-0-0 locomotive configuration.
  - 200 cars with 2-2-2 locomotive configuration.
  - 200 cars with 3-3-0 locomotive configuration.
- Position of the 20-car EOCC block: Front, middle, and rear of the consist.
- Distributed power control: Synchronous and asynchronous control of the tractive and dynamic braking effort between the lead and remote units.

Figure 1 provides the track layout used for this simulation set. To simplify the data analysis process, the simulations were split up to consider the hill (0.75 to -0.75 percent grade) and sag (-0.75 to 0.75 percent grade) track sections separately.

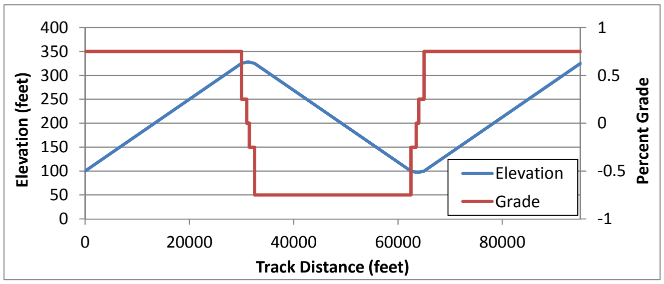

Figure 1. Track Elevation and Grade Data

Simulations were also conducted to investigate the potential effects of an undesired emergency brake occurring while a train was cresting a hill or negotiating a sag. The UDE simulations used the same train, track, and operating commands as the real-world hill and sag simulations, but a UDE was initiated at the point where the maximum buff (for hill cresting) or draft (for sag negotiation) force occurred. The UDE applications were initiated at car 50 in each train because the air signal would take the longest time to propagate to the nearest locomotives from this location.

SIMULATION RESULTS

A total of 9,624 simulations were performed for the flat track simulation set. Figure 2 shows the average and range of the maximum coupler forces in the simulations for the different train handling scenarios, train sizes, and DP configurations. Due to the unusual handling commands, the values in Figure 2 should be considered from a relative standpoint to evaluate the benefits of alternative train configurations rather than actual coupler forces expected from typical operations. Results from the simulations showed that consist make-up and DP configuration had a significant effect on the magnitude of the maximum coupler forces. Consists with DP had lower in-train forces than head-end only power for almost every condition modeled. The remote units in the train reduced the number of cars that were being pushed or pulled by a single locomotive consist, and they helped to control slack in the train. The magnitude of the maximum coupler forces in the simulations tended to be lowest when the remote units were distributed evenly throughout the train. Even when remote units are placed in a train, buff and draft forces can still reach high magnitudes depending on the handling of the train. Size and location of the EOCC car block within the train also had considerable effects on the magnitude of the maximum coupler forces. Coupler forces were generally lowest when the block of EOCC equipped cars were placed at the rear of the train because there was no trailing tonnage behind the EOCC car block. The size of the EOCC car block had a significant effect on the maximum coupler forces when the EOCC car block exceeded about 40 cars.

The real-world hill and sag simulations were conducted to examine the effects of train handling, distributed power control, EOCC car block position, distributed power configuration, and UDE applications on the coupler force magnitudes of trains negotiating undulating territory. A total of 66 simulations were performed for the real world hill and sag simulation set. The simulations showed that for both hill and sag negotiations, asynchronous control of remote units generally limited the amount of slack action in the train and reduced the likelihood of run-in and run-out events. However, it also resulted in higher steady state buff forces because the remote units were constantly pushing the train into a compressed state. Results from the UDE simulations showed that maximum buff and draft forces increased significantly when a UDE application occurred while traversing a hill or sag in the track. The maximum coupler forces in the UDE simulations were 307 kips in buff and 259 kips in draft for the hill cresting simulations, and 282 kips in buff and 219 kips in draft for the sag negotiation simulations.

Figure 3 compares the maximum buff and draft forces from the real-world hill and sag simulations.

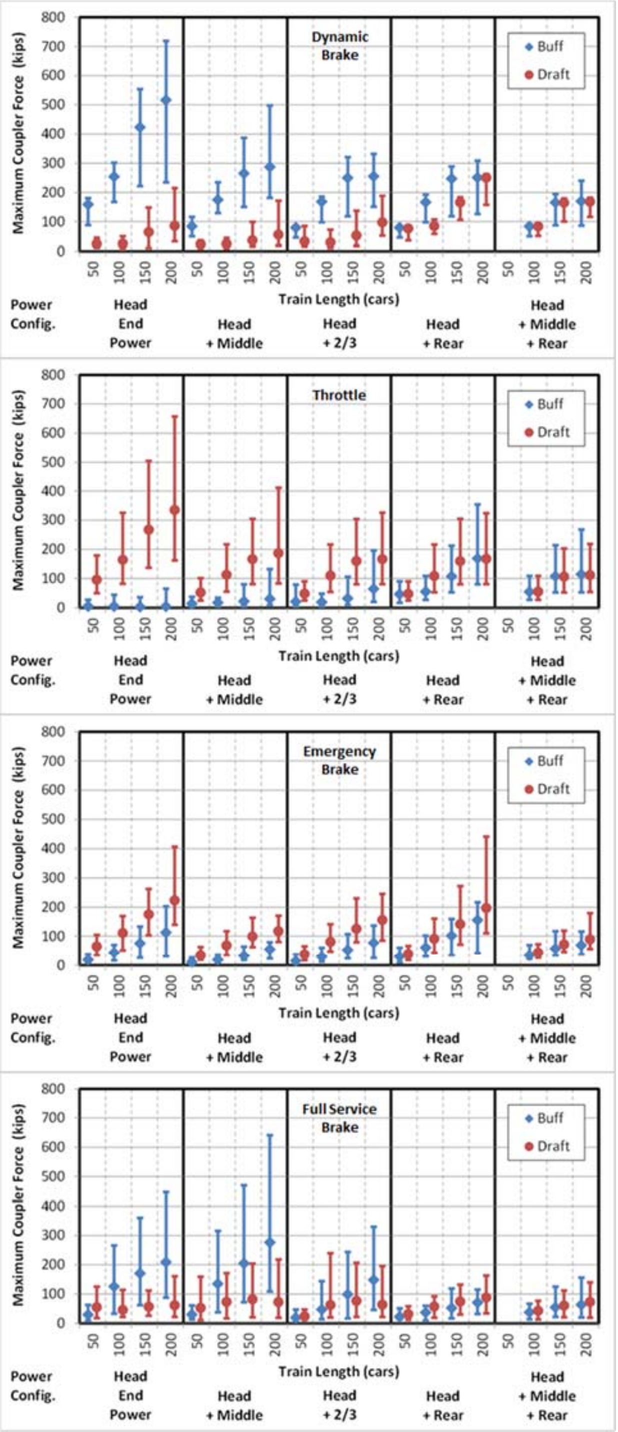

Figure 2. Average and Range of the Maximum Forces in the Flat Track Simulations

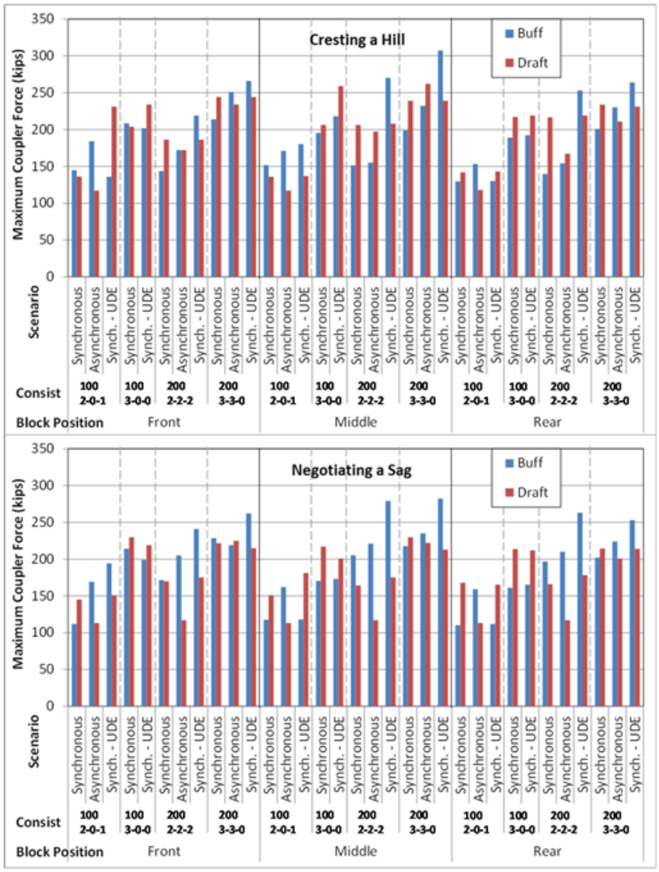

Figure 3. Maximum Forces, Real-world Simulations

CONCLUSION AND FUTURE WORK

The flat track simulations showed that consists with DP had significantly lower coupler forces for almost every case modeled. The simulations also showed that coupler forces tended to be lower when blocks of EOCC cars were confined to the rear of the train and were limited to about 40 cars. The real-world hill and sag Simulations showed that asynchronous power can limit slack action in the train, but may result in higher steady state buff forces. A future TTCI report will provide additional details and insights from this modeling effort.

References

1. Cummings, Scott, Kevin Koch, Adam Klopp, and Ron Lang. April 2015. “Simulation of Longitudinal Forces in Trains with End-of-Car Cushioning.” *Technology Digest* TD-15-010. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.