

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

# Simulation of Longitudinal Forces in Trains with End-of-Car Cushioning

Scott Cummings, Kevin Koch, Adam Klopp, and Ron Lang

## Summary

Longitudinal coupler forces can be difficult to control in trains containing blocks of cars equipped with hydraulic end-of-car cushioning devices (EOC units). Transportation Technology Center, Inc. used Train Operation and Energy Simulator (TOES™) to model the draft (tensile) and buff (compressive) coupler forces in trains operated on track with undulating elevation profiles. A total of 42 simulations comprising a variety of conditions showed the following:

- Generally applicable operating guidelines based on train makeup for trains with many EOC unit equipped cars may be cumbersome because:
  - The relationship between coupler forces and train makeup is not easily predictable when other variables are included such as track elevation profile and load distribution in the train.
  - Coupler forces are highly dependent on train handling.
- Buff loads are generally higher when a block of EOC unit cars is at the head end of the train. Draft loads are generally higher when a block of EOC unit cars is at the middle or rear of the train. The largest coupler forces in the modeling cases were buff forces, indicating that the preferred location for a block of EOC unit cars is toward the rear of the train despite the expected increase in draft forces.
- In several cases, a block of 20 EOC unit cars showed significantly higher buff or draft forces than a block of 10 EOC unit cars, indicating that a block size of 20 EOC unit cars in a non-unit train may be larger than optimal.
- Draft forces increased 6 to 26 percent and buff forces increased 13 to 47 percent when the trailing tonnage behind a block of 20 EOC unit cars was increased from 5,000 tons to 7,000 tons.
- A loaded unit boxcar train with 50 cars equipped with 15-inch travel EOC units produced a maximum draft force 30 percent larger and a maximum buff force just 14 percent smaller compared to a loaded unit autorack train with 100 cars equipped with 10-inch travel EOC units.
- Limited cases of synchronously operated distributed power at the rear of the train showed a reduction in the maximum buff and draft forces between 0 percent and 57 percent.

The modeling effort described in this document is a first step toward providing the data needed for operating guidelines. Additional TOES™ modeling is planned to further evaluate the effects of train makeup and distributed power, both synchronously and asynchronously controlled. Train brake applications and releases in trains with blocks of cars equipped with EOC units will also be evaluated.



**INTRODUCTION**

Large longitudinal coupler forces are generated when a speed differential exists between adjacent cars in a train. This dynamic train action can cause damage to mechanical components and lading and, in extreme cases, can result in derailment. Transportation Technology Center, Inc. (TTCI) is measuring and modeling in-train coupler forces as part of the Strategic Research Initiatives Program. This *Technology Digest* focuses on simulations designed to explore the coupler forces associated with different train make-up scenarios.

**BACKGROUND**

End-of-car cushioning devices (EOC units) use hydraulic cylinders in place of standard draft gear for their improved performance in absorbing yard impacts. Although these devices protect the lading while the cars are in yards, they have long been known to create train handling issues,<sup>1</sup> particularly in undulating terrain, due to their long travel. When many EOC units are in the same train, they allow large speed differences between cars in the train that result in buff (compression) or draft (tension) impacts between cars. Most EOC units are designed with 10 or 15 inches of nominal travel and take a fully extended position when not exposed to external forces. Modern EOC units have a “preload” value (nominally 50 kips for a 10-inch travel unit and 100 kips for a 15-inch travel unit) that limits their travel until the preload force is attained. The preload feature was added in an attempt to reduce train action.

Simulations were conducted using TTCI’s Train Operation and Energy Simulator (TOEST™). The TOEST™ model is a state-of-the-art train action model capable of calculating in-train forces generated under given environmental and train-handling conditions. The TOEST™ program includes non-linear models of draft gears, EOC units, and a computational fluid dynamics model of the air brake system. The TOEST™ model has been validated in North American freight service and has been used by the railway industry for over 20 years.<sup>2,3</sup>

**REVENUE SERVICE TESTING AND MODEL COMPARISON**

TTCI recently completed revenue service testing of a boxcar with 15-inch EOC units and a bi-level autorack with 10-inch EOC units. Each car was outfitted with a GPS receiver and an unmanned data collection device that recorded coupler force, coupler displacement, carbody acceleration, and carbody strains. Each car traveled more than 20,000 miles in service during the testing. Locomotive event recorder data and train consist information was gathered for test data with pertinent longitudinal train action. The GPS inputs allowed TTCI engineers to match the recorded data with a location which then enabled the use of track charts for elevation and curvature profiles.

TOEST™ models were developed using event recorder, consist, and track chart information to compare the model outputs with the recorded data. Once the speeds were matched between the real train and the simulated train, a comparison of

the coupler displacements and coupler forces provided confidence in the model. Figure 1 shows the recorded locomotive speed and the simulated speed. Figure 2 shows the recorded coupler force and the simulated coupler force.

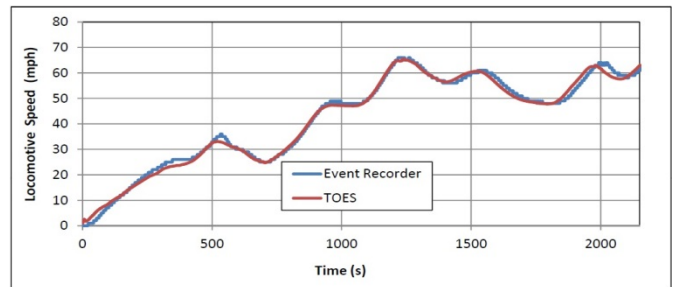


Figure 1. Measured Speed and TOEST™ Speed

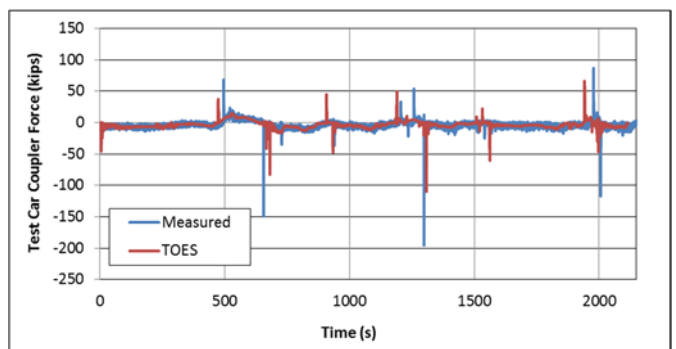


Figure 2. Measured Coupler Force and TOEST™ Coupler Force

**SIMULATION RESULTS**

A total of 42 simulations were run for the effort described herein. Train speed was controlled only with throttle and dynamic brake; train brake was not used. The preload feature was used on all EOC units modeled. Two general categories of TOEST™ simulations were conducted in order to maintain realism while also exploring more generalized conditions. These categories can be defined as follows:

1. Real World Simulations: variations of an actual test train operating over real undulating territory using the same handling commands as the engineer
2. Generalized Simulations: variations of idealized trains operating over idealized track with customized handling commands

The Real World Simulations focused on the effects of train length, train tonnage, block size of EOC unit cars, and placement in train of EOC unit cars. Distributed power was also investigated in two simulations. These simulations were operated over the same piece of undulating track that was used for the model validation. The engineer’s train handling commands were converted from a time-based format as provided in the event recorder data to a distance-based format for use in TOES. The locomotives changed throttle and dynamic brake settings at the same location on the track regardless of how long it took the train to reach that location. This way, the actual consist was able to be re-ordered and have tonnage added or subtracted without creating a speed profile

that diverged more than +/- 6 mph from the actual test train. Simulated speed profiles were plotted next to the actual speed profile to ensure that the magnitude and location of head end run-ins and run-outs (as shown by abrupt speed changes) were similar for the Real World Simulations. The consists used in the Real World Simulations typically included covered hoppers, tank cars, flatcars, boxcars, and a block of EOC unit equipped cars comprised primarily of autoracks and also two boxcars. The cars were a mix of loads and empties that happened to be in the actual test train.

Table 1 contains details and results for each Real World Simulation. The maximum draft and buff coupler forces are used to summarize the results. Draft forces remained below 300 kips except for case R11 with 40 EOC unit cars located in the middle of the train. Although these draft forces could be contributing significantly to fatigue damage of the knuckles, they are not large enough to result in the fast fracture of a knuckle that is in good condition. Buff forces remained below 200 kips for all Real World Simulations, indicating that derailment from a large buff run-in event would not be expected in this terrain for the simulated consists given proper train handling.

Table 1. Real World Simulation Details and Results

Label	Total Cars	EOC Unit Car Block Size	EOC Unit Block Location	Primary EOC Unit Car type	EOC Unit travel (inch)	Distributed Power (Head/Mid/Rear)	Max Draft Force (kips)	Max Buff Force (kips)
R1	100	5	Head	Autorack	10	3/0/0	166	118
R2	100	5	Middle	Autorack	10	3/0/0	168	120
R3	100	5	Rear	Autorack	10	3/0/0	169	105
R4	100	10	Head	Autorack	10	3/0/0	189	137
R5	100	10	Middle	Autorack	10	3/0/0	181	122
R6	100	10	Rear	Autorack	10	3/0/0	168	103
R7	100	20	Head	Autorack	10	3/0/0	204	133
R8	100	20	Middle	Autorack	10	3/0/0	297	136
R9	100	20	Rear	Autorack	10	3/0/0	276	100
R10	100	40	Head	Autorack	10	3/0/0	206	194
R11	100	40	Middle	Autorack	10	3/0/0	307	123
R12	100	40	Rear	Autorack	10	3/0/0	294	103
R13	90	20	Head	Autorack	10	3/0/0	165	152
R14	90	20	Middle	Autorack	10	3/0/0	178	148
R15	90	20	Rear	Autorack	10	3/0/0	166	93
R16	110	30	Head	Autorack	10	3/0/0	201	174
R17	110	30	Middle	Autorack	10	3/0/0	253	152
R18	110	30	Rear	Autorack	10	3/0/0	294	105
R19	120	20	Head	Autorack	10	3/0/0	177	143
R20	120	20	Middle	Autorack	10	3/0/0	232	154
R21	120	20	Rear	Autorack	10	3/0/0	174	109
R22	100	20	Head	Autorack	*D	3/0/0	191	108
R23	100	20	Middle	Autorack	*D	3/0/0	196	104
R24	100	20	Rear	Autorack	*D	3/0/0	185	100
R25	100	20	Rear	Boxcar	15	3/0/0	239	135
R26	100	20	Rear	Boxcar	15	2/0/1 <sup>S</sup>	122	106

\*D = EOC units replaced with standard draft gear

<sup>S</sup> Distributed power unit operated synchronously with head end power

Figure 3 shows the effects of different size blocks of EOC unit cars at different locations in the train. As expected, the largest buff load occurs when the EOC unit cars are at the head end of the train and buff and draft loads are higher when more EOC unit cars are coupled together in a block. Surprisingly, the largest draft loads occurred when the EOC unit block was placed in the middle of the train. The train consists used for the Real World Simulations were based on the actual test consist and thus, blocks of loaded and empty cars were located throughout the train. When the block of 20 EOC unit cars was moved from the rear of the train (as reported in the actual test consist) to the head or middle of the train, the distribution of tonnage changed, and this affected the results. Similarly, when the total number of cars in the train was altered for these simulations, the distribution of tonnage changed, and this also influenced the results. For example, all other variables being equal, the maximum draft force would be expected to increase as more cars were added to the train. However, the difference in consists between simulations R8 and R20 was the insertion of 20 fully loaded covered hoppers immediately in front of the block of EOC unit cars. This large mass served to dampen the abrupt speed change, and consequently the large draft coupler force. So, the nature of the Real World Simulations limits the ability to compare the effects of changes to a single variable in isolation.

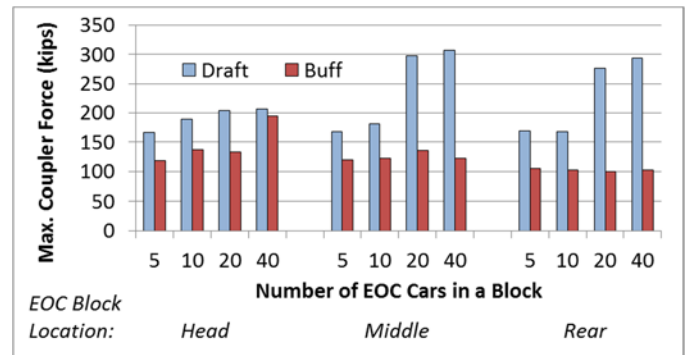


Figure 3. Effect of Size and Location of EOC Unit Car Block in a 100 Car Train

The train consists used in the Generalized Simulations were more uniform, containing just one or two car types per train. These simulations looked at the effects of unit boxcar trains of different lengths, unit autorack trains of different lengths, and trains with a mix of autoracks and hoppers having a variety of load distributions. Figure 4 shows the track profile used for the Generalized Simulations. This track was constructed to provide undulating terrain with ascending and descending 1.5-percent grades in decreasing wavelengths from 20,000 feet down to 1,000 feet. The intention of this track profile was to provide a challenging route regardless of train length and tonnage. The throttle and dynamic brake commands of each simulated train were customized to try to minimize train longitudinal forces while targeting a speed of 40 mph.

Table 2 contains details and results for each Generalized Simulation including the maximum draft and buff coupler forces. The more severe elevation profile of the Generalized Simulations is evident in the larger draft and buff forces compared to the Real World Simulations. Maximum draft forces ranged from 218 kips to 385 kips. Knuckle fracture starts to become a concern at draft forces larger than 300 kips. Maximum buff forces ranged from 146 kips to 649 kips. Buff forces larger than about 200 kips are considered a risk for derailment. Three simulations involving a block of 20 EOC unit cars followed by at least 5,000 trailing tons (G4, G7, G8) produced buff forces near or above 500 kips.

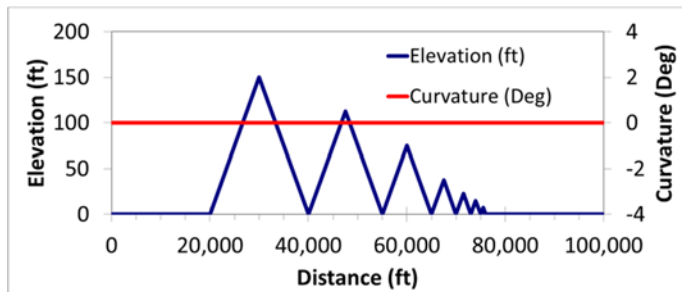


Figure 4. Track Elevation and Curvature Profile Used for the Generalized Simulations

Table 2. Generalized Simulation Details and Results

Label	Total Cars	EOC Unit Car Block Size	EOC Unit Block Location	EOC Unit Car type	EOC Unit travel (inch)	Trailing Tonnage Behind EOC Block	Trailing Tonnage Details	Distributed Power (Head/Mid/Rear)	Max Draft Force (kips)	Max Buff Force (kips)
G1	80	10	Head	Autorack	10	5000	U*	3/0/0	218	270
G2	80	10	Head	Autorack	10	7000	U*	3/0/0	263	305
G3	80	20	Head	Autorack	10	5000	U*	3/0/0	299	335
G4	80	20	Head	Autorack	10	7000	U*	3/0/0	376	494
G5	80	10	Head	Autorack	10	5000	EL*	3/0/0	275	312
G6	80	10	Head	Autorack	10	7000	EL*	3/0/0	323	311
G7	80	20	Head	Autorack	10	5000	EL*	3/0/0	363	555
G8	80	20	Head	Autorack	10	7000	EL*	3/0/0	385	629
G9	60	60	All	Autorack	10	0	N/A	3/0/0	231	165
G10	80	80	All	Autorack	10	0	N/A	3/0/0	228	215
G11	100	100	All	Autorack	10	0	N/A	3/0/0	263	257
G12	100	100	All	Autorack	10	0	N/A	2/0/1 <sup>S</sup>	264	197
G13	30	30	All	Boxcar	15	0	N/A	3/0/0	246	146
G14	40	40	All	Boxcar	15	0	N/A	3/0/0	332	215
G15	50	50	All	Boxcar	15	0	N/A	3/0/0	341	222
G16	50	50	All	Boxcar	15	0	N/A	2/0/1 <sup>S</sup>	314	191

U\* = all trailing tonnage cars loaded to a uniform gross rail load

EL\* = a block of empty cars in the middle of the train and a block of fully loaded cars at the rear of the train

<sup>S</sup> Distributed power unit operated synchronously with head end power

When using the TOES model, small changes in train handling can produce large changes in the resulting coupler force. The degree to which optimal handling is necessary to move challenging trains over challenging terrain without

producing large coupler forces is an indication that train handling variation should be taken into consideration when developing operational recommendations.

Figure 5 shows the results of an 80-car train with either 10 or 20 EOC cars at the head end (G1–G8). Not only is the amount of trailing tonnage behind the EOC unit block important, but the load profile of the train consist is critical. When the trailing tonnage is all loaded uniformly, the buff loads are much lower compared to the cases when empty cars are placed directly behind the EOC unit block and fully loaded cars are located at the rear of the train.

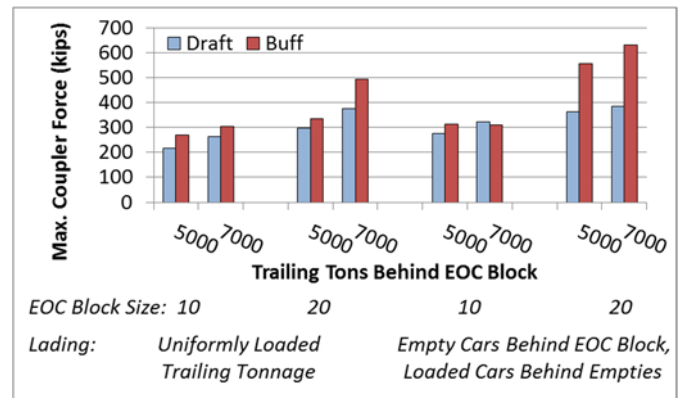


Figure 5. Effects of Trailing Tonnage, EOC Unit Car Block Size, and Load Profile in an 80-Car Train

## CONCLUSION AND FUTURE WORK

TOEST™ simulations have been used to evaluate the relative effects of multiple variables on longitudinal coupler forces in trains containing blocks of car equipped with EOC units. Train handling, trailing tonnage, number of EOC unit cars coupled together in a block, placement in the train of that block, and load profile of the train are all important considerations. Over idealized terrain with 1.5% undulating grades and careful train handling, buff and draft forces did not exceed 323 kips when a block of 10 cars with 10-inch travel EOC units were placed at the head of the train and the trailing tonnage behind the block of EOC unit cars did not exceed 7,000 tons. Additional cases will be simulated to further investigate the effects of train makeup and the use of distributed power to minimize coupler forces. The use of train brake will also be investigated in the simulations.

## REFERENCES

- Holl, R., 1971, "Handling a Unit Train with Cars Equipped with End-of-Car Cushioning Devices – a Case Study," *AAR Conference on Train/Train Dynamics Interaction*, Chicago.
- Andersen, D., D. Mattoon, S. Singh, 1991, "Validation of Train Operations and Energy Simulator (TOES) - Version 1.5 Part I: Conventional Unit Train (SD-036)," R-799, AAR/TTCI.
- Andersen, D., D. Mattoon, S. Singh, 1992, "Validation of Train Operations and Energy Simulator (TOES) - Version 2.0 Part II: Intermodal Train (SD-042)," R-822, AAR/TTCI.

Visit our website at <http://www.ttc.aar.com>

Disclaimer: Preliminary results in this document are disseminated by the AAR/TTCI for information purposes only and are given to, and are accepted by, the recipient at the recipient's sole risk. The AAR/TTCI makes no representations or warranties, either expressed or implied, with respect to this document or its contents. The AAR/TTCI assumes no liability to anyone for special, collateral, exemplary, indirect, incidental, consequential or any other kind of damage resulting from the use or application of this document or its content. Any attempt to apply the information contained in this document is done at the recipient's own risk.