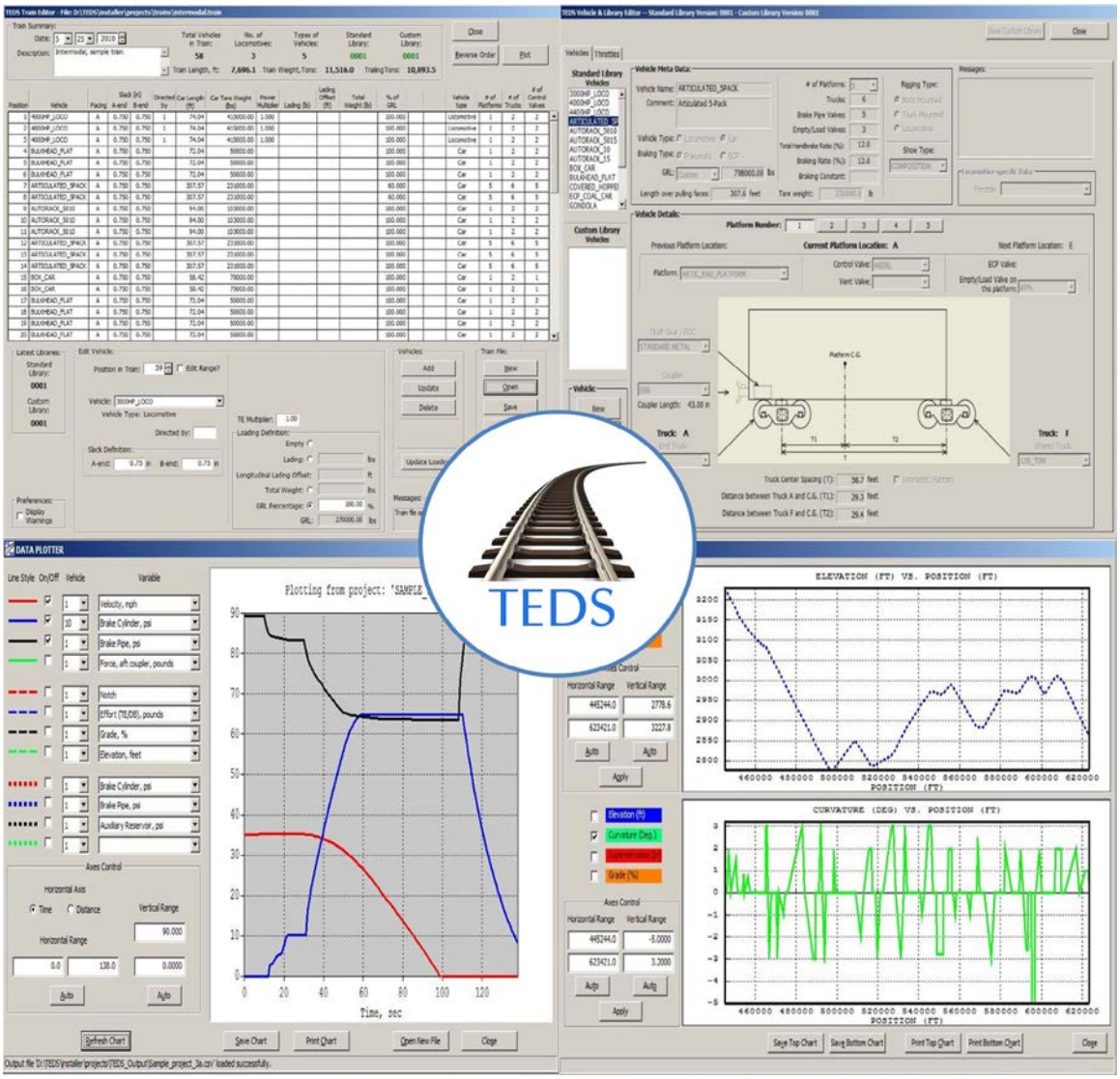
VALIDATION OF THE TRAIN ENERGY AND DYNAMICS SIMULATOR (TEDS)

U.S. Department of Transportation

Federal Railroad Administration

Office of Railroad Policy and Development
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words)

FRA has developed Train Energy and Dynamics Simulator (TEDS) based upon a longitudinal train dynamics and operations simulation model which allows users to conduct safety and risk evaluations, incident investigations, studies of train operations, ride quality evaluations, and evaluations of current equipment and new equipment designs.

This document describes how TEDS modelling software predictions were validated with publicly available data in order to establish a sufficiently high level of confidence for users, which will enable them to conduct studies and investigations with TEDS. This report describes the approach to validating TEDS and the associated criteria that were adopted for this purpose, and it discusses validating the model at the train level as well as validating simulations of the braking systems (both pneumatic and electronically controlled pneumatic (ECP)) and the coupling systems (both draft gears and cushioning units). Train level validation was accomplished using available velocity profiles, coupler forces, brake pipe and brake cylinder pressures and stopping distance data from for well documented published and publicly available sources.

After the validation process concluded, it was evident that TEDS is a high fidelity model that realistically predicts longitudinal train behavior under a variety of operating conditions, including acceleration, braking, steady state running, hilly terrain operation, and certain emergency conditions. Further, it demonstrated that TEDS' predictions are realistic for both gross train dynamics, which is measured by parameters such as position, velocity, and stopping distance, as well as inter-car dynamics, which is measured by parameters such as coupler forces.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

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1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

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[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

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1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

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[(9/5) y + 32] °C = x °F

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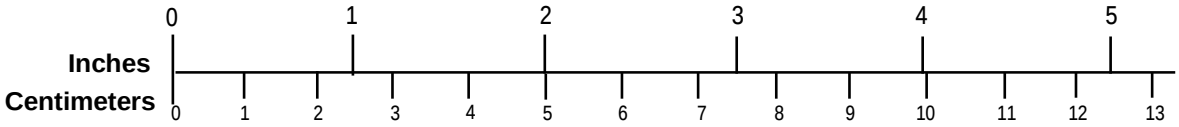

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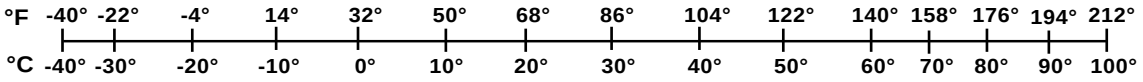

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Executive Summary

To support the development and evaluation of existing and proposed safety regulations and guidelines, improve railroad operational safety, and conduct analyses and investigations of railroad incidents, the Federal Railroad Administration (FRA) funded the development of a longitudinal train dynamics simulator named the Train Energy and Dynamics Simulator (TEDS). This validation report demonstrates that TEDS is a high fidelity model that realistically predicts longitudinal train and component behavior under a variety of operating conditions, including acceleration, braking, steady state running, over hilly terrain, and certain emergency conditions.

TEDS has the capability to conduct safety and risk evaluations, incident investigations, train operation and energy consumption studies, ride quality evaluations, and evaluations of current equipment and new equipment design. It takes user-specified details about train consist, track characteristics and train handling in order to simulate the longitudinal dynamics and energy consumption resulting from the operation of a train over a section of track.

Because intended users are going to apply this simulation to a wide range of uses, they need to be confident that TEDS delivers reliable results. This confidence is typically established through model validation.

In this document, the validation process is described at both the component and system level. Coupler forces and air brake system response are validated at the component level using a variety of publicly available source data.

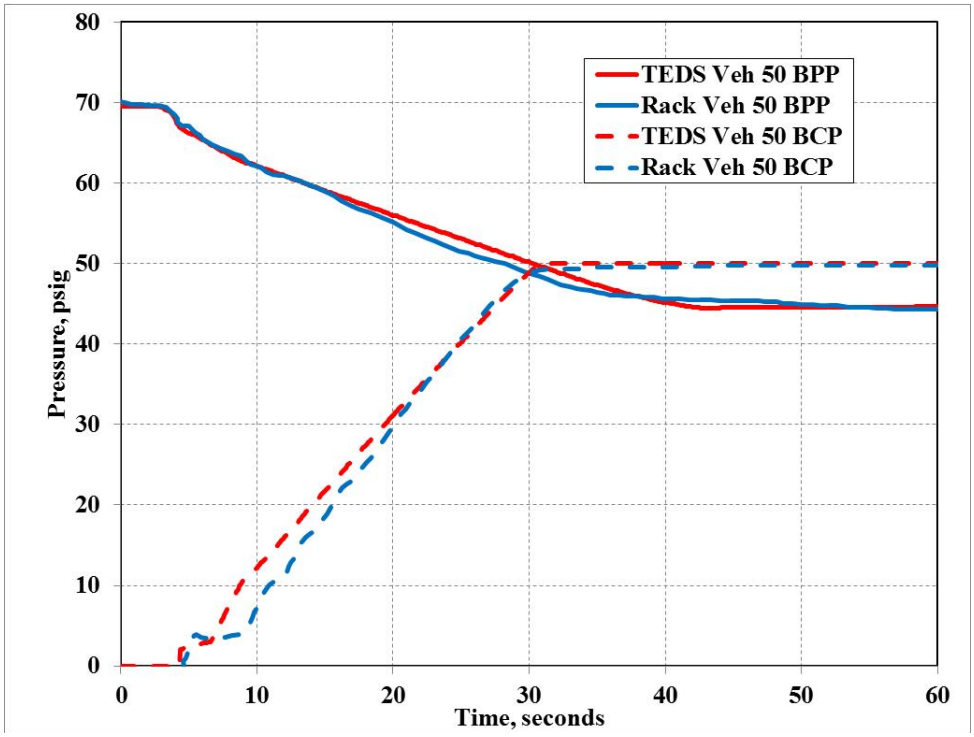
Air brake model predictions are verified by comparing TEDS simulations of braking behavior to data from published sources including air brake test rack data from the the American Society of Mechanical Engineers (ASME) and Air Brake Association proceedings (referenced in the report), specifications from the Association of American Railroads (AAR) Standards and Recommended Practices, and descriptions from air brake manufacturers' instructional brochures. During the development phase, the published and collected data were used to check the model's formulation and the integrity of results it yielded. These comparisons show that TEDS accurately represents both conventional pneumatic and electronically controlled pneumatic (ECP) brake system characteristics, such as brake cylinder pressure build-up and release rates, supply reservoir and brake pipe response.

For system level validation, several train accidents investigated by the National Transportation Safety Board (NTSB) were used to compare train behavior before the accidents. These allowed establishing the predictive capability of TEDS over significantly long track segments. Additional system level validation was supplied by a complete set of train test data from the AAR publication R-799. This volume was prepared in the early 1990s by the AAR to serve as a validation document for those using the Train Operation and Energy Simulator (TOES), which is the AAR's own proprietary longitudinal train dynamics and operation simulation model. This report contains test data collected from a revenue service unit coal train.

When TEDS-predicted forces were compared with this measured data, the predictions were reasonable and well within the validation criteria; i.e. they capture the event, its trends, and predict a magnitude of the associated variable in reasonable agreement with the measured test

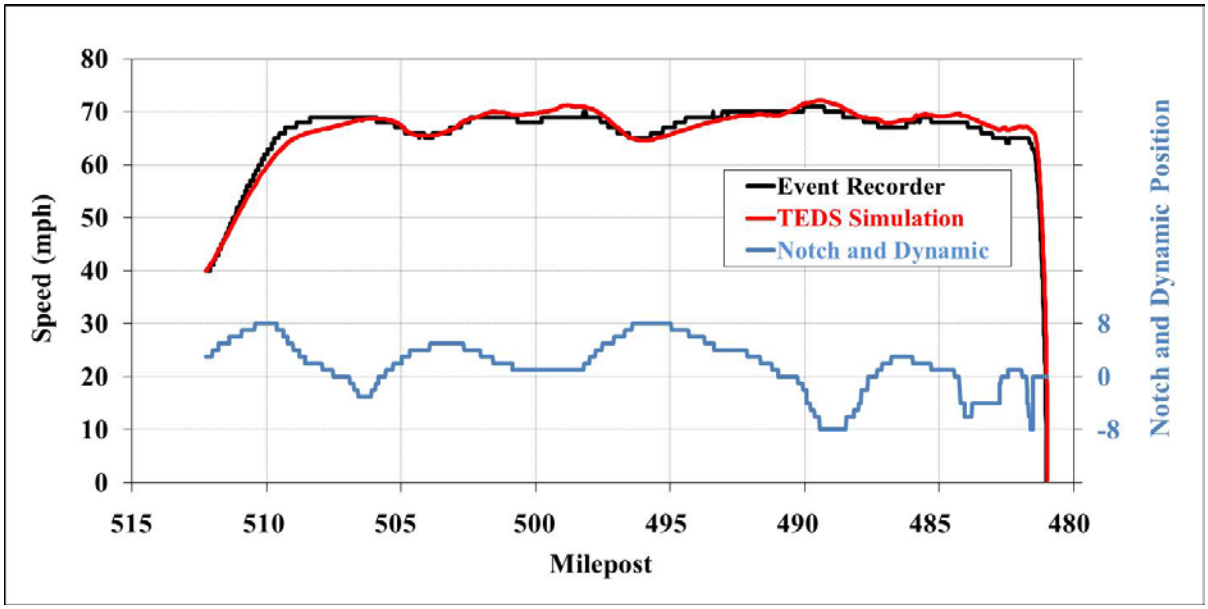
data. Similarly, TEDS predictions of train speed and air brake system pressures correlate closely with the measured data as shown in the following charts.

The chart below shows a sample comparison of TEDS air brake system predictions with test rack data for a full service application on a 50 car train. The brake pipe and brake cylinder pressures predicted by TEDS match the measured data very well.



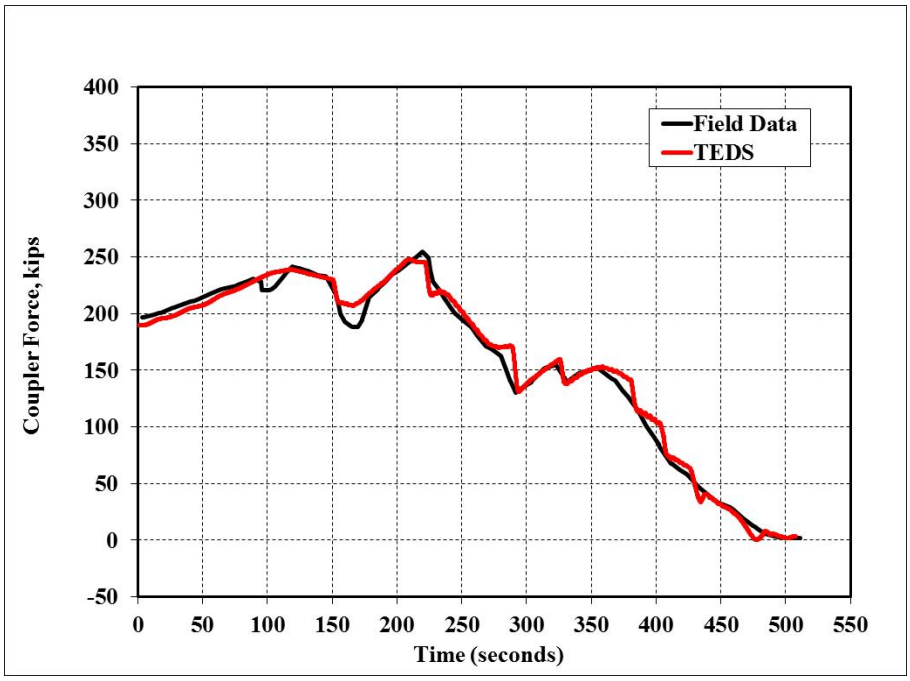
Comparison of test rack data and TEDS simulation for full service application, vehicle 50

The second chart shows the train speed predicted by TEDS compared to event recorder data for approximately 30 miles of simulation. The predictions closely match the event recorder speed.



Westbound Goodwell, OK train handling and speed comparison

The third chart shows the coupler force predicted by TEDS compared to measured test data for a cresting event on a unit coal train. The coupler force predicted by TEDS matches the measured test data very well.



Comparison of predicted to measured coupler force on selected car for the cresting operation

1. Introduction

To support development and evaluation of safety regulations and guidelines, develop and assess proposed standards to improve railroad operational safety, and conduct analyses and investigations of railroad incidents, the Federal Railroad Administration (FRA) funded the development of Train Energy and Dynamics Simulator (TEDS) software to perform longitudinal train dynamics simulations. After users specify the train consist, track characteristics, and train handling data, TEDS simulates the longitudinal train dynamics and energy consumption resulting from the operation of a train over a section of track.

These simulations offer invaluable opportunities for conducting safety and risk evaluations, incident investigations, studies of energy consumption and train operations, ride quality evaluations, and evaluations of both new and current equipment. They also have wide range of potential uses for the following:

- Evaluating the effectiveness of operating rules (current and proposed)
- National Transportation Safety Board (NTSB) accident investigations and evaluations of potential impact of proposed rules
- Examining the impact of speed limits on rail line capacity
- Evaluating of mixed equipment consists and related operating practices on safety and efficiency
- Studying the effect of new equipment design on train operation
- Train handling parametric studies
- Developing Positive Train Control (PTC) braking routines for speed and stop enforcement algorithms
- Optimizing motive power trains and routes
- Safety evaluations for electronically controlled pneumatic (ECP) braking

TEDS is a complex and comprehensive simulation tool that can be used to study how train dynamics is affected by the type of equipment in the train, the track profile, train handling, train make-up, etc. The usefulness of TEDS is highly dependent on its ability to produce simulation results that are realistic and reasonable so they can be used to draw conclusions and make decisions. To develop a level of confidence in the predictions produced by any simulation model, validating the model is generally required. If a model is validated, it can be used to conduct studies and investigations with a certain level of confidence in the results obtained.

This report discusses TEDS validation by splitting the process into two major areas:

- *Component-level validation*: The air brake system and the coupling force system were separately validated to ensure that these elements predicted behavior that was consistent with the expected behavior. The results of simulated air brake system performance were compared with measured data from an air brake test rack and results of simulations of ramp impact coupler forces with measured data.
- *System-level validation*: After the individual components were validated, simulations of the air brake system (brake pipe propagation, brake cylinder pressure for application and release) predictions of train speed, stopping distance, and coupler forces in the train were compared with previously measured train performances.

Overall, the validation process demonstrated that TEDS is a high fidelity model that realistically predicts longitudinal train behavior under a variety of operating conditions, including acceleration, braking, steady state running, hilly terrain operation, and emergency conditions. Further, this process revealed that TEDS' predictions are realistic for both gross train dynamics, which is measured by parameters such as position, velocity, and stopping distance, as well as inter-car dynamics, which is measured by parameters such as coupler forces.

2. Approach to Validation

To validate a complex simulator such TEDS at the system level, three elements are necessary:

a. Validation criteria that are defined from an engineering perspective, since it is not possible to exactly match point-for-point measured data in any simulation model.
b. Data for subsystem validation that was generated in a controlled environment, such as test rack data from air brakes and impact ramp data from draft gears and cushioning units.
c. Data from a revenue service train test for system level validation.

The following three criteria were used to validate TEDS:

1. TEDS should predict the occurrence of an event that was observed in the test.
2. TEDS should predict the trend of each parameter (coupler force, brake pipe and brake cylinder pressure, vehicle speed, etc.) that was involved in the event.
3. TEDS should be able to predict the amplitude of the parameter of the event reasonably well. What constitutes "reasonably well" is discussed below in a context specific to the parameters of interest.

For validation of coupler force predictions, a peak coupler force value within ±20 percent of the significant peaks (i.e. greater than 100,000 lbs) constitutes a good validation.

For the brake system, it is expected that TEDS should faithfully follow the brake application and release events in terms of timing and trend. If TEDS predicts that steady state (equalized) brake cylinder and brake pipe pressures are within 5 psi of the measured test values, that constitutes good validation. This variance is comparable to the Association of American Railroads (AAR)'s certification requirements where equalized cylinder pressure is allowed a ±3 psi variation from the target. However, during transient phases (i.e. when the brakes are being applied or released the difference between the TEDS predictions and measured data might have a larger variation for brief periods as opposed to the 5 psi defined for the steady-state values.

One of the basic validation criteria is that the predicted and measured train speeds should correlate. It is expected that a well thought-out and formulated simulation model, with valid input data, would show a good correlation between the predicted and measured speed. TEDS has been carefully and methodically developed to meet these expectations. For validation purposes, it is expected that the TEDS predicted speed should be within 2 mph of the measured speed.

To understand how the criteria were applied, consider a run-in or run-out event that was due to throttle manipulation or undulating terrain. Such an event <u>occurs</u> (criterion 1) with significant variation in force. It would also include a <u>trend</u> (criterion 2) in coupler force, represented either by an increase in magnitude or change in algebraic sign such as changing coupler force from draft to buff or vice-versa. TEDS should be able to predict that the event occurs at a time that corresponds to the handling change or a location that corresponds to the terrain change,

depending on which feature resulted in the event. TEDS should predict that the trend of the event occurs in the same direction as in the measured data.

Predicting the magnitude of the event's parameter of interest (criterion 3) is the most difficult criterion to satisfy, due to the assumptions that are required to develop the model and linearizing (or piecewise linearization) of the input data and characteristics, which are often nonlinear. Also, comparing magnitudes of predictions to measured test data is difficult due to the variability and inaccuracies inherent in measurements.

Table 1 summarizes the criteria for TEDS' validation.

Table 1. Validation criteria for TEDS coupling, air brake, and vehicle dynamics systems.

Regime	Parameter	Criterion
Coupler Forces	Occurrence	Predict synchronization in timing and location
	Trend	Show correct trend
	Magnitude	Predict peaks (>100,000 lbs) within ±20 percent
Air Brake	Occurrence	Predict synchronization in timing and location
	Trend	Show correct trend
	Magnitude	Predict steady state pressure within ±5 psi
Speed	Occurrence	Predict synchronization in timing and location
	Trend	Show correct trend
	Magnitude	Predict speed within ±2mph

3. Component Level Validation

The TEDS model contains the following components (or modules):

- air brake system
- coupler force system
- vehicle and train dynamics system

Initially, the first two components were validated separately from the other components before the overall results of the TEDS model were validated to decouple the validation effort and simplify the process of validation. The air brake system was decoupled from the vehicle and train dynamics because vehicle dynamics are independent from changes in air brake system pressure. Therefore the air brake system can be separately validated from the train and vehicle dynamics components. Since the coupler force system is decoupled from the air brake system when no air braking is occurring, the coupler force system can be separately validated from the other components.

3.1 Air Brake System

The air brake model in TEDS is a fluid mechanics-based mathematical model of air flow through the brake system of a train. The model represents the brake pipe, auxiliary and emergency reservoirs, control valve volumes and interconnecting passages, brake cylinders, and venting devices present on each rail car. The key quantities modeled include system pressures and air flows. The calculation procedure considers the brake pipe as discrete control volumes (of varying length) centered about each valve and venting device.

In this model, differential equations that govern mass and momentum conservation are solved simultaneously for the set of control volumes representing the brake pipe. Frictional effects such the resistance of the flow of air within the pipe and leakage from the pipe are also considered.

The control valve model includes the high-level modes that the valve operates in:

- Release and recharge
- Lap
- Application

The interconnection of reservoirs within a control valve is governed by pressure differences between reservoirs, the rate of brake pipe pressure reduction, and the previous state of the control valve. Modeled control valve states and functions include:

- Release and recharge
- Retarded recharge
- Preliminary quick service
- Quick service limiting

- Service
- Lap
- Emergency
- Accelerated emergency release
- Accelerated service release (ABD and later valves)
- Accelerated application (ABDW and later valves)

The air brake model can represent the interconnection of two or three reservoirs or volumes to calculate flows and pressure changes. Isothermal flow is assumed because the mass of air in the system is small compared to the mass of the reservoirs, cylinders, and the brake pipe itself and the small, transient fluctuations in air temperature are not significant to the train's braking performance.

Air brake test racks are used by the industry to evaluate and quantify the performance of control valves. In each rack, there is 50 feet of brake pipe, a 2,500 cubic inch auxiliary reservoir, and a 3,500 cubic inch emergency reservoir connected to each control valve. While any brake cylinder can be connected to the valves, typically a standard freight car brake cylinder with a 10-inch diameter and 8-inch stroke is utilized.

Published air brake test rack data, which is included in a paper from the 1986 Winter Meeting of the American Society of Mechanical Engineers (ASME) [1], shows data for a 50-car train equipped with ABDW valves during a full service application and a release from the full service application. An emergency application for a 150-car train is also presented. The air brake system component validation includes comparisons of model predictions with this data.

3.1.1 Full Service Application

A full-service application, using a 25 psig reduction, was made from a brake pipe pressure of 70 psig. Cars 1, 25, and 50 were reported in the test rack data. The test rack data was compared with the predictions of pipe pressure and brake cylinder pressure, as shown in Figure 3.1-1, Figure 3.1-2, and Figure 3.1-3. When TEDS predicted the final steady-state pressure for both the brake cylinder and the brake pipe, it matched the test rack data; the time at which full brake cylinder pressure is achieved for each car is matched very closely, along with the pressures in the upper half of the cylinder buildup. The cylinder pressure starts to increase at nearly the same time as the test rack data for all three cars.

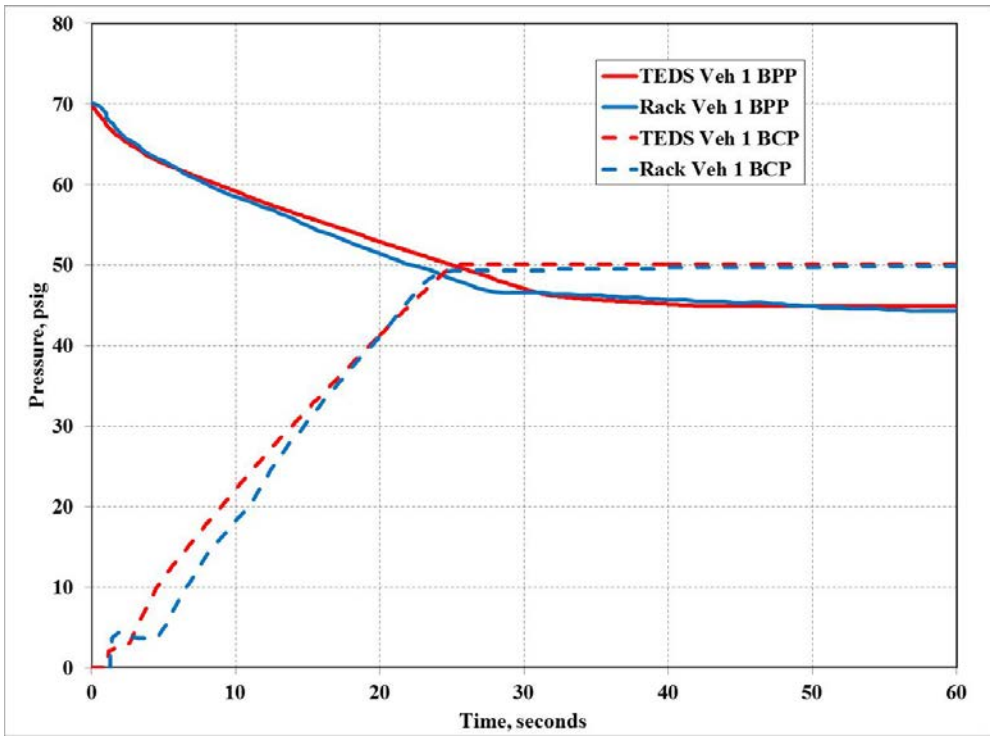


Figure 3.1-1. Comparison of test rack data and TEDS simulation for full service application, vehicle 1.

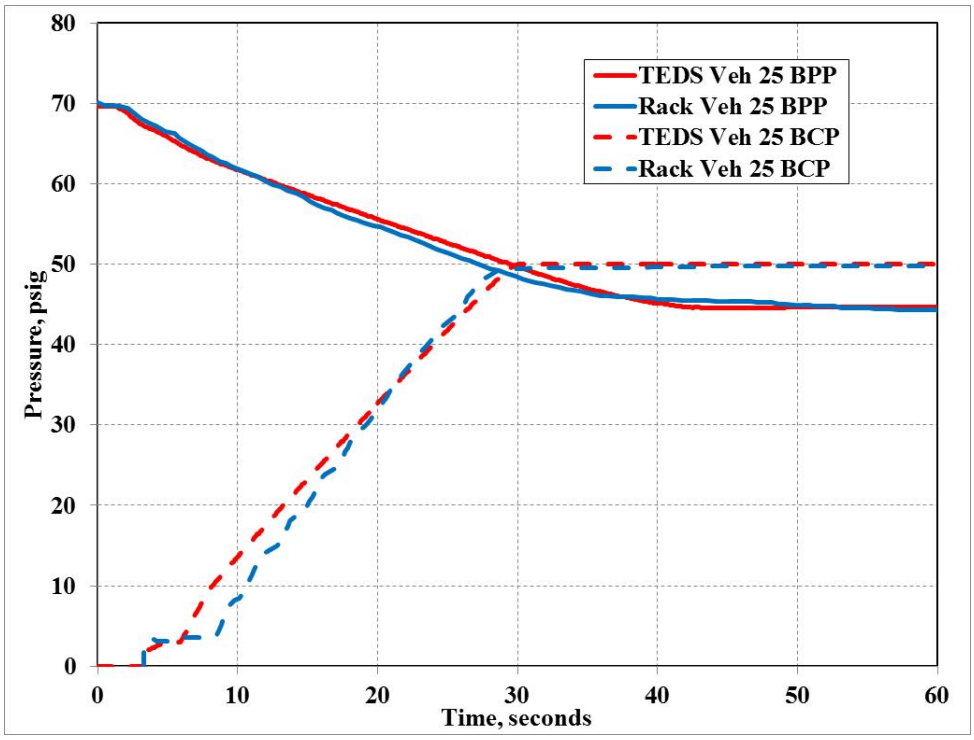


Figure 3.1-2. Comparison of test rack data and TEDS simulation for full service application, vehicle 25.

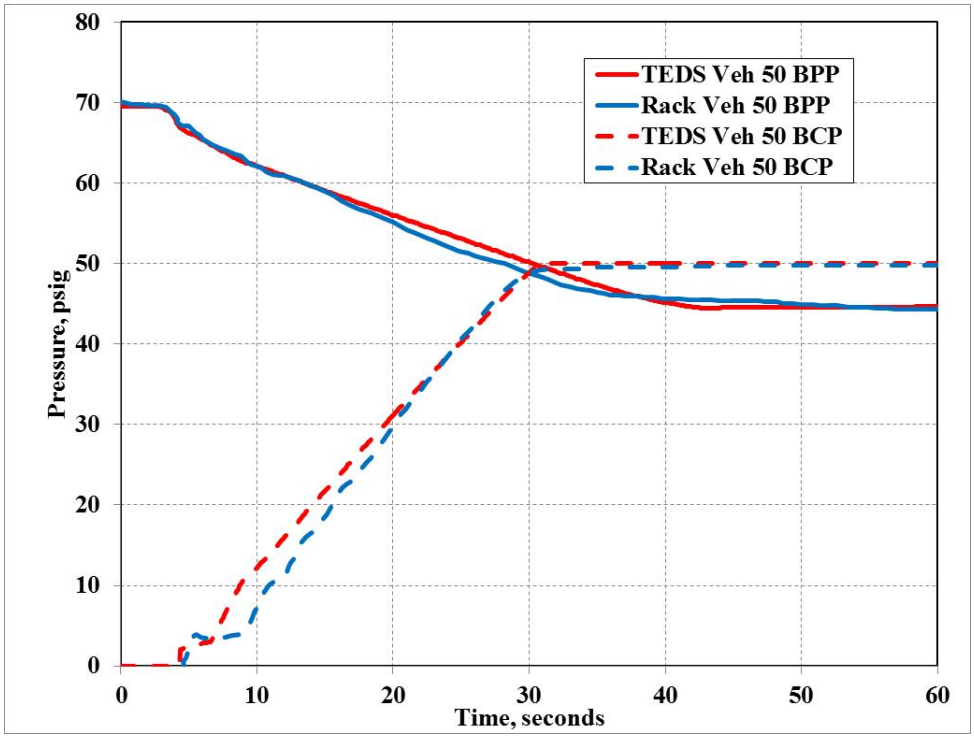


Figure 3.1-3. Comparison of test rack data and TEDS simulation for full service application, vehicle 50.

3.1.2 Release from Full Service Application

Data for a release from a full service application was taken from the 1986 ASME paper [1] (50-car test rack having 50 feet of brake pipe per car and all cars are equipped with ABDW valves). A TEDS simulation and the test rack data are compared for car 1 (Figure 3.1-4), for car 25 (Figure 3.1-5), and for car 50 (Figure 3.1-6). The brake pipe and brake cylinder pressures predicted by TEDS follow the trends in the test rack data very well, including the slight overshoot of pipe pressure at car 50, which is due to the reflection of the accelerated service release pressure wave at the closed end of the pipe.

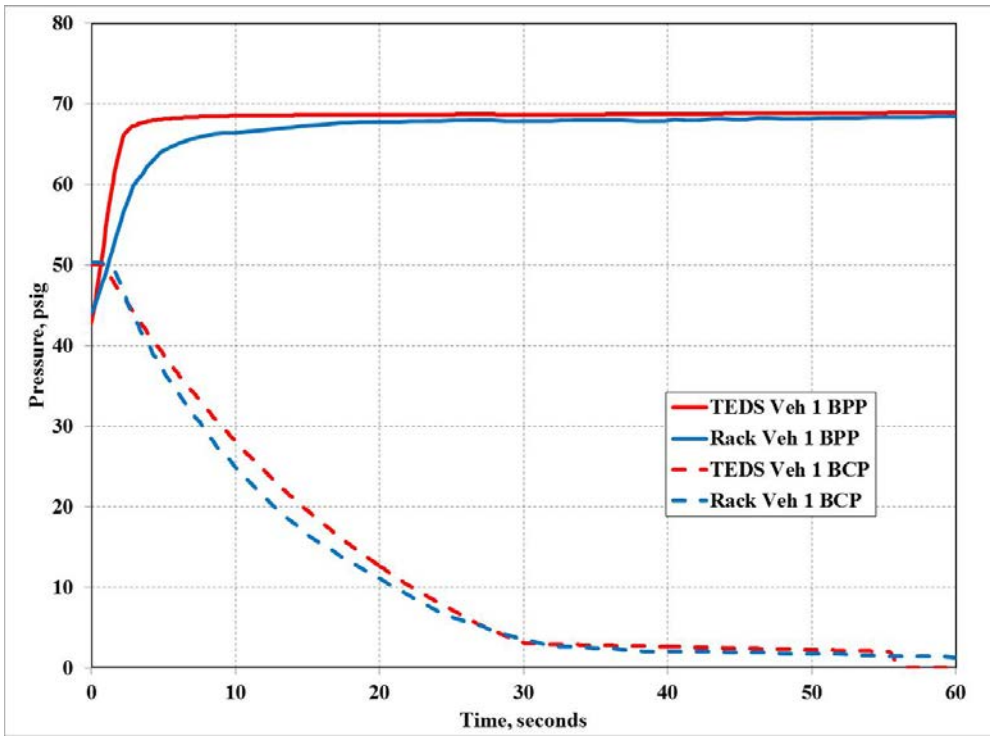


Figure 3.1-4. Comparison of test rack data and TEDS simulation for release from full service application, car 1.

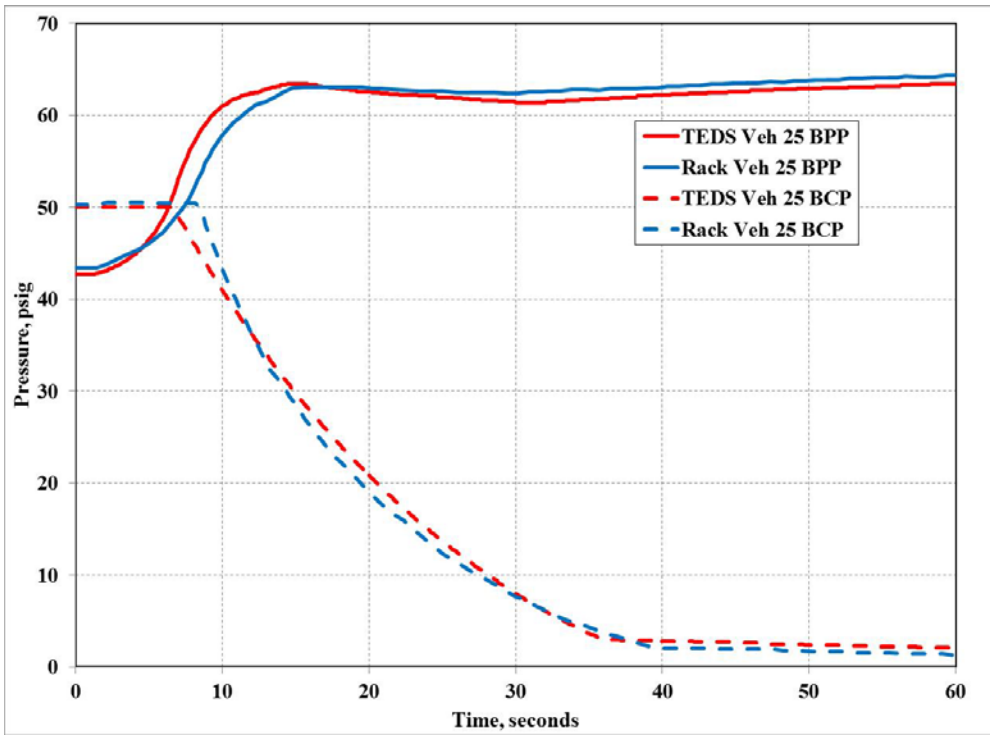


Figure 3.1-5. Comparison of test rack data and TEDS simulation for release from full service application, car 25.

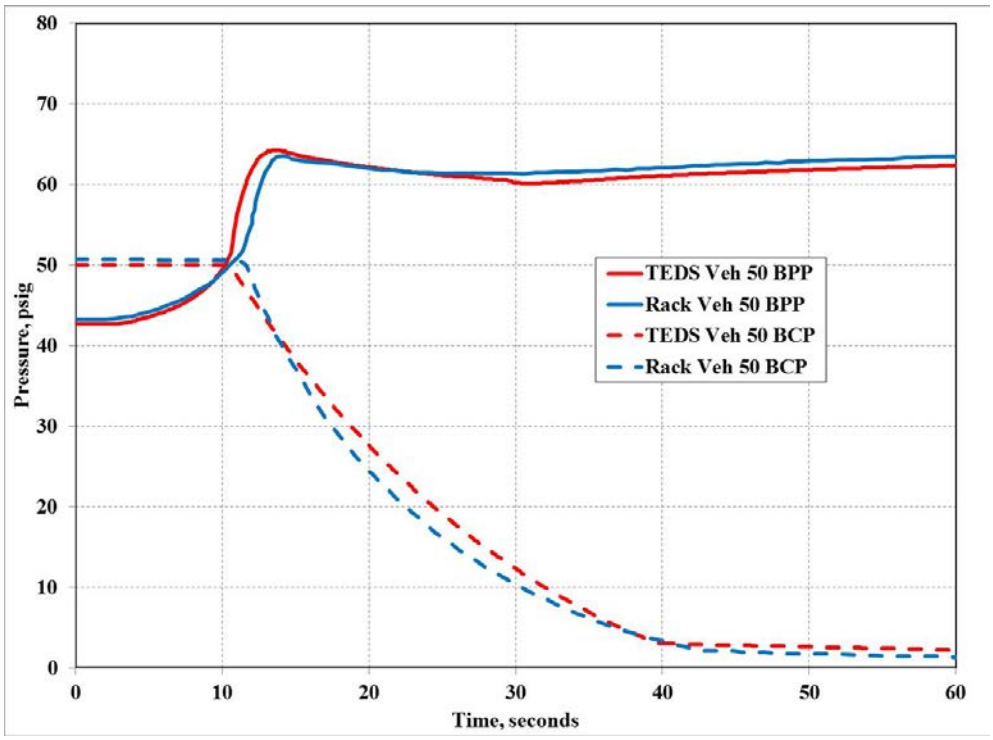


Figure 3.1. Comparison of test rack data and TEDS simulation for release from full service application, car 50.

3.1.3 Full Service Application with DB60L Valves

A second full service application was conducted on a test rack that was configured to simulate 25 cars (with 300 feet of brake pipe each) as a representation of 5-platform doublestack cars [2]. Each simulated car included two DB60L valves, one ABDW valve, and the regulating valve pressure setting was 90 psig. Figure 3.1-7 compares the TEDS simulation results with the test data for car 12 in the test rack. The predictions of the brake pipe pressure and cylinder pressure follow the test data very well. Also, Figure 3.1-8 compares simulation results for car 25 in the test rack, and again the predictions of brake pipe and brake cylinder pressure match the test data well.

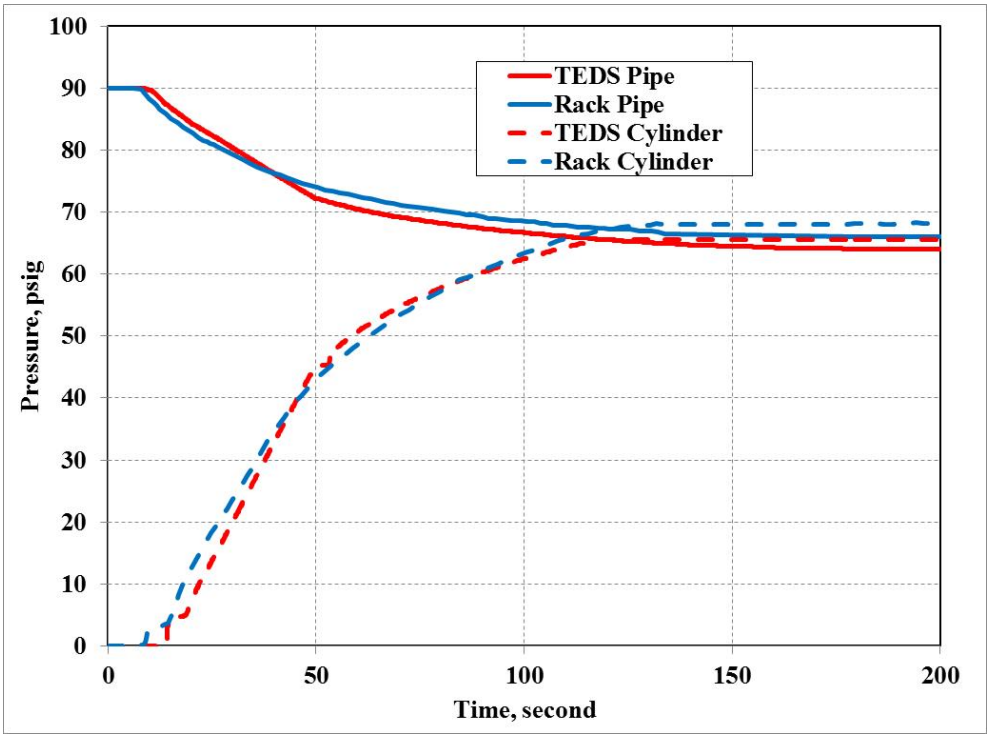


Figure 3.1-6. Comparison of test rack data and TEDS simulation of full service application on simulated 5-pack doublestack car 12.

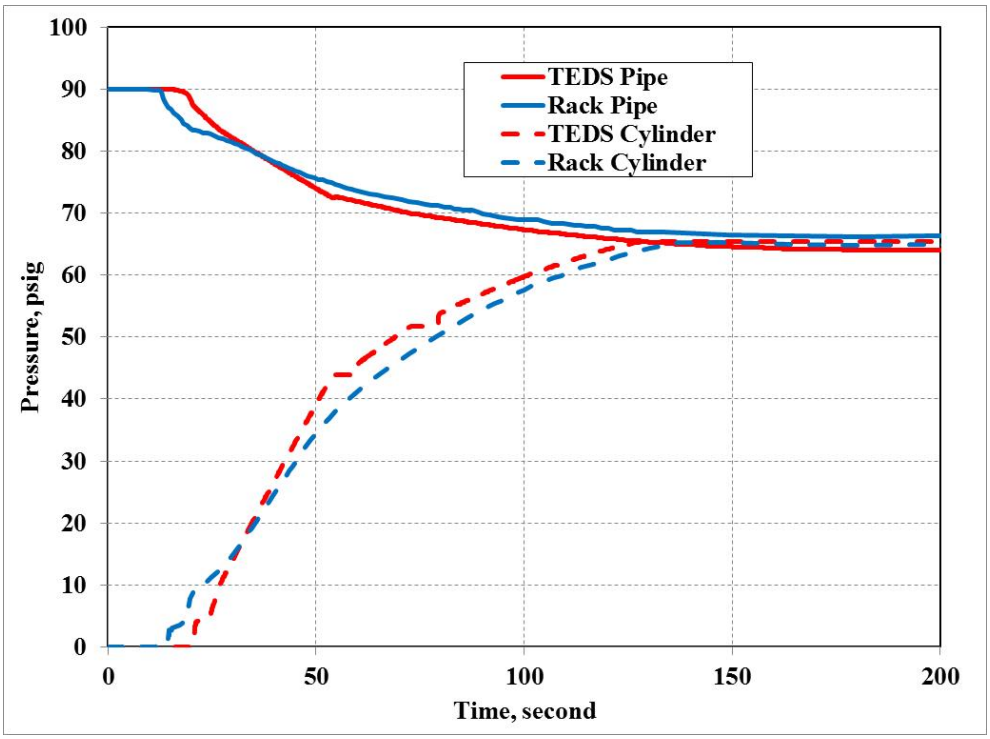


Figure 3.1-7. Comparison of test rack data and TEDS simulation of full service application on simulated 5-pack doublestack car 25.

3.1.4 Emergency Application

An engineer-initiated emergency was simulated on a 150-car train equipped with ABD valves with the regulating valve pressure setting at 80 psig. Figure 3.1-9 displays a comparison of the simulation with the test rack data. The TEDS simulation results match the slopes of the test rack data's brake pipe pressure drop and the brake cylinder pressure buildup well.

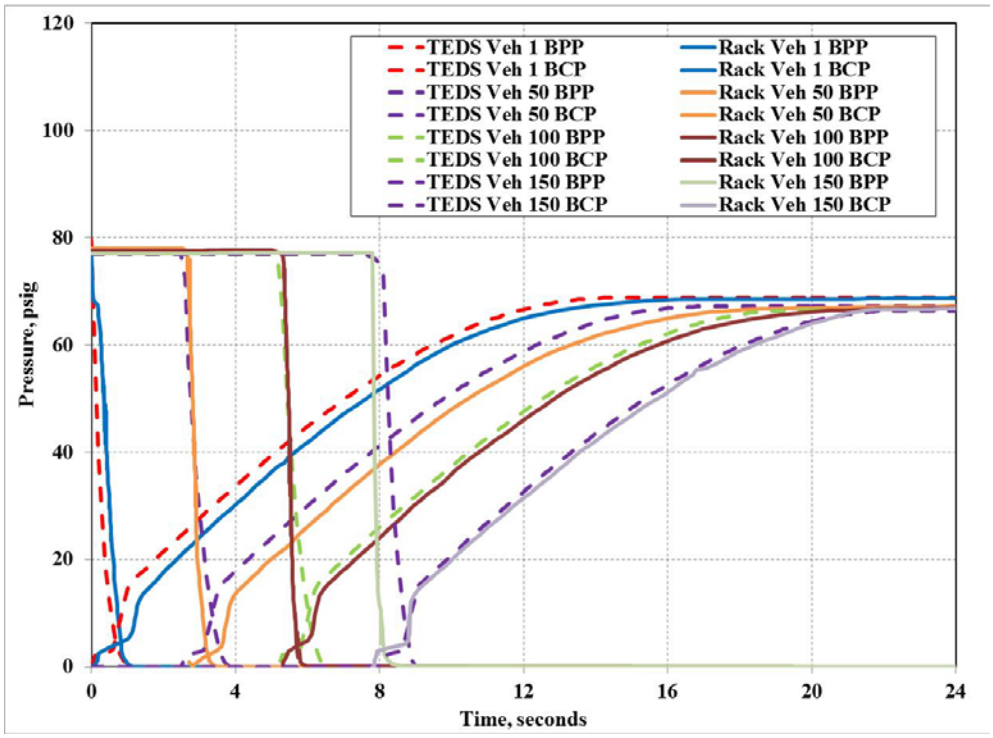


Figure 3.1-8. Comparison of test rack data and TEDS simulation of emergency application on 150-car train equipped with ABD valves.

3.1.5 ECP Brake Full Service and Release

Figure 3.1-10 and Figure 3.1-11 show comparisons of TEDS simulation results with measured test data from braking tests of a train made up of 156 ore cars retrofitted with ECP brakes [3] for a full service brake application and release on car 1 and car 156, respectively. The trends and magnitudes are matched closely by TEDS. The reservoir pressure does not drop nearly as much in an ECP train as in a conventional pneumatic train because the entire air supply in the ECP train is provided by a single reservoir with a volume of 6,000 cubic inches. The brake cylinder air for service applications in a conventional pneumatic train is provided by the auxiliary reservoir, which has a volume of 2,500 cubic inches. Thus, the pressure drops much less in the ECP train. When the reservoir pressure drops below a specified target in the ECP train, charging of the reservoirs by the brake pipe begins which causes the drop in brake pipe pressure.

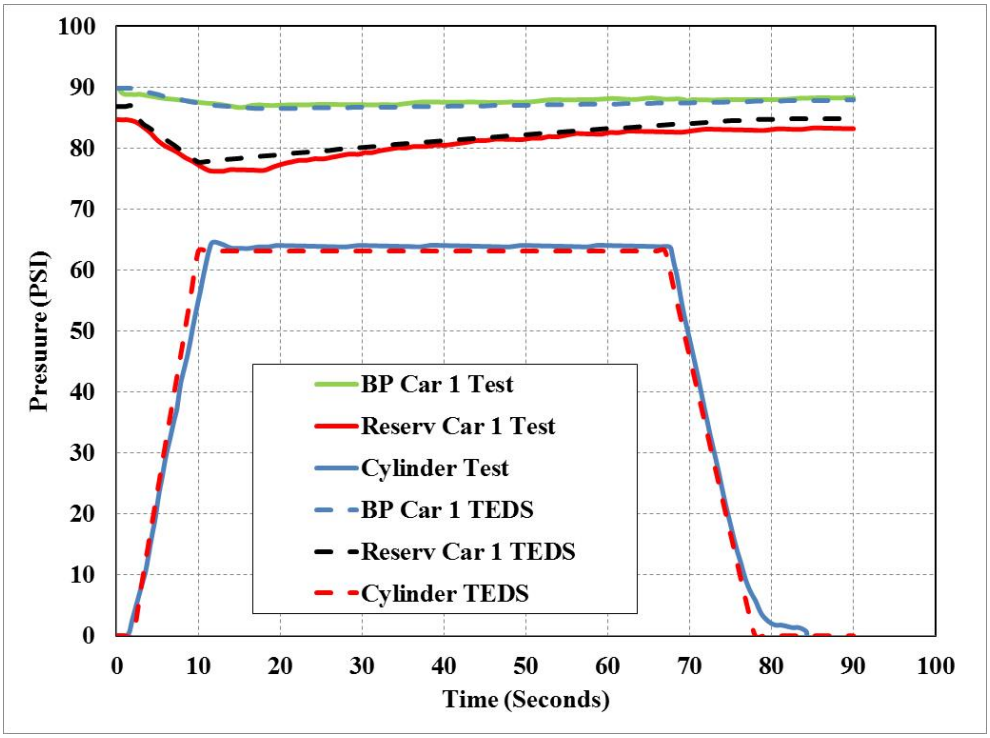


Figure 3.1-9. Comparison of TEDS simulation and measured test data for ECP brake reduction and release on car 1.

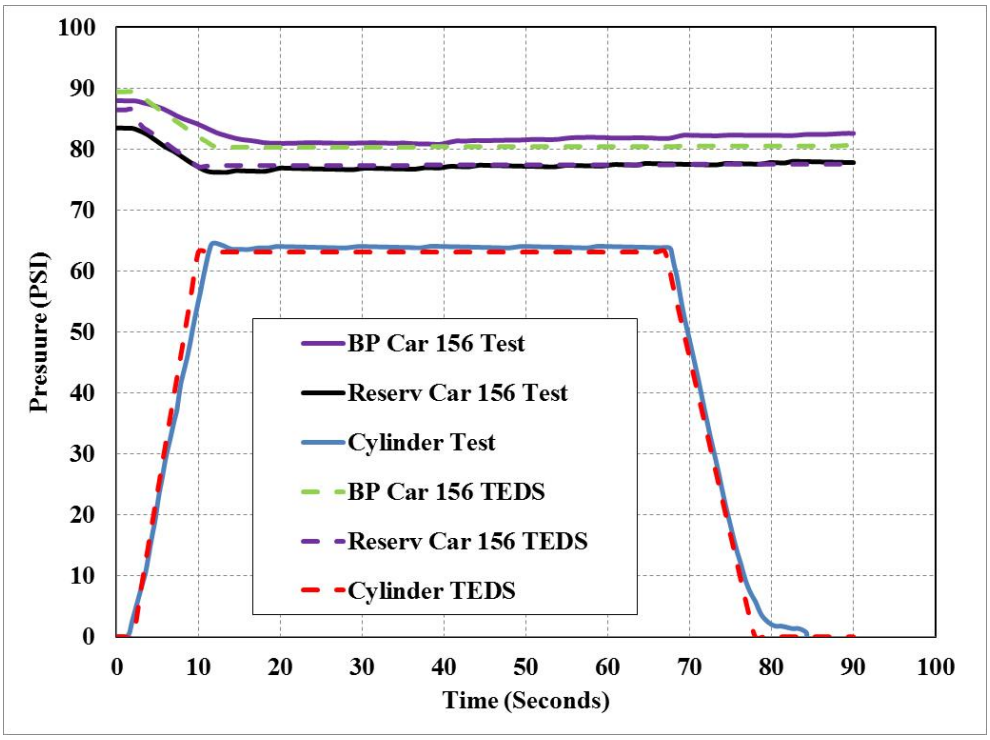
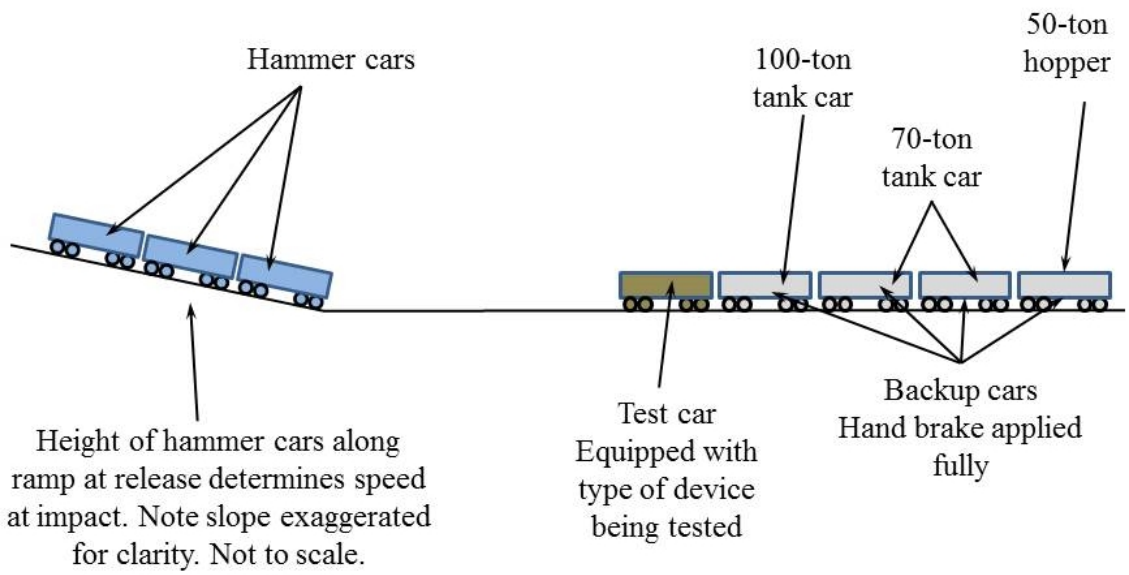


Figure 3.1-10. Comparison of TEDS simulation and measured test data for ECP brake reduction and release on car 156.

3.2 Coupler Force System

Coupler force model elements (such as draft gears and end-of-car cushioning units) are often tested, typically on an impact track. In such tests, several cars are placed at the bottom of the ramp. The first car in the string is called the anvil car (test car) and is struck by the moving (or hammer) cars. The string of cars behind the anvil car are called the "backup cars." The anvil car is equipped with the element being tested. The testing conducted by the AAR [4] included three hammer cars in the moving string. All of the hand brakes on the backup cars were fully applied. The target speed for this particular test governs the location along the ramp from which the car is released. A higher release location results in a greater speed. The impact test setup is shown in Figure 3.2-1. Coupler force and travel were recorded and cross-plotted to show the force-stroke characteristics.



Draft gear and end-of-car cushioning unit impact test setup.

3.2.1 Friction Draft Gear

Metal friction draft gears were testing the impact test arrangement shown (Figure 3.2-1). Figure 3.2-2) shows the results at several test speeds. The figure shows some of the variability in the test data and the difficulty in precisely matching the measured characteristics at all speeds.

Figure 3.2-3 compares the measured test data of coupler force and stroke for a 2.05 mph impact with the TEDS predictions, and Figure 3.2-4 shows the comparison for a 3.90 mph impact. The predictions follow the test data very well in both cases.

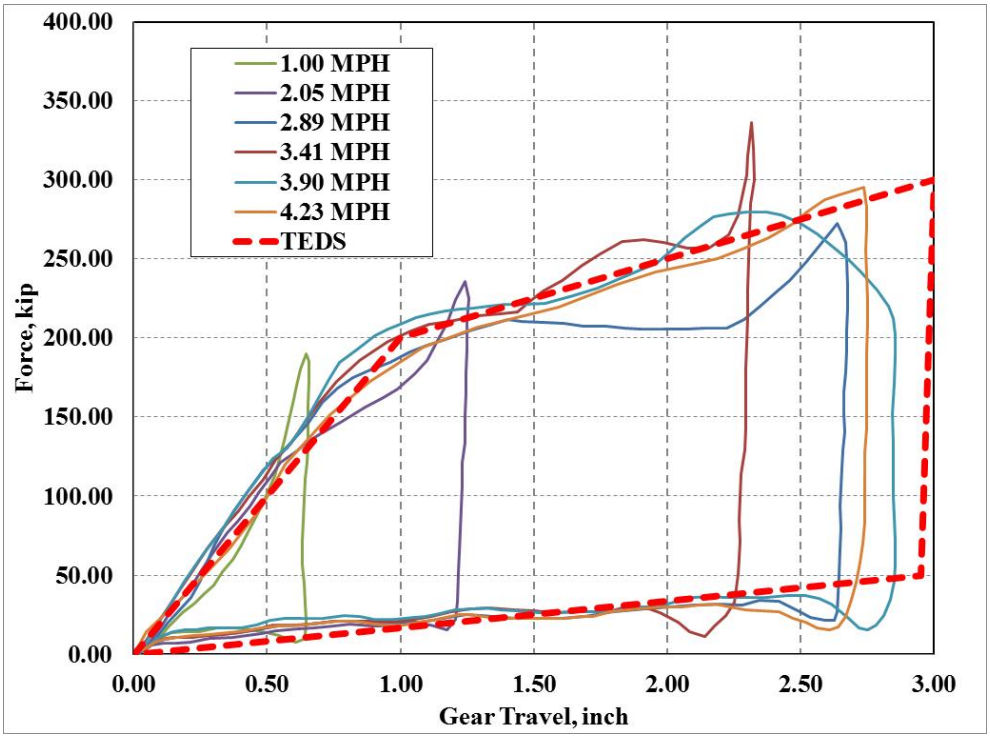


Figure 3.2-1. Overlay of multiple speeds tested for metal friction draft gear.

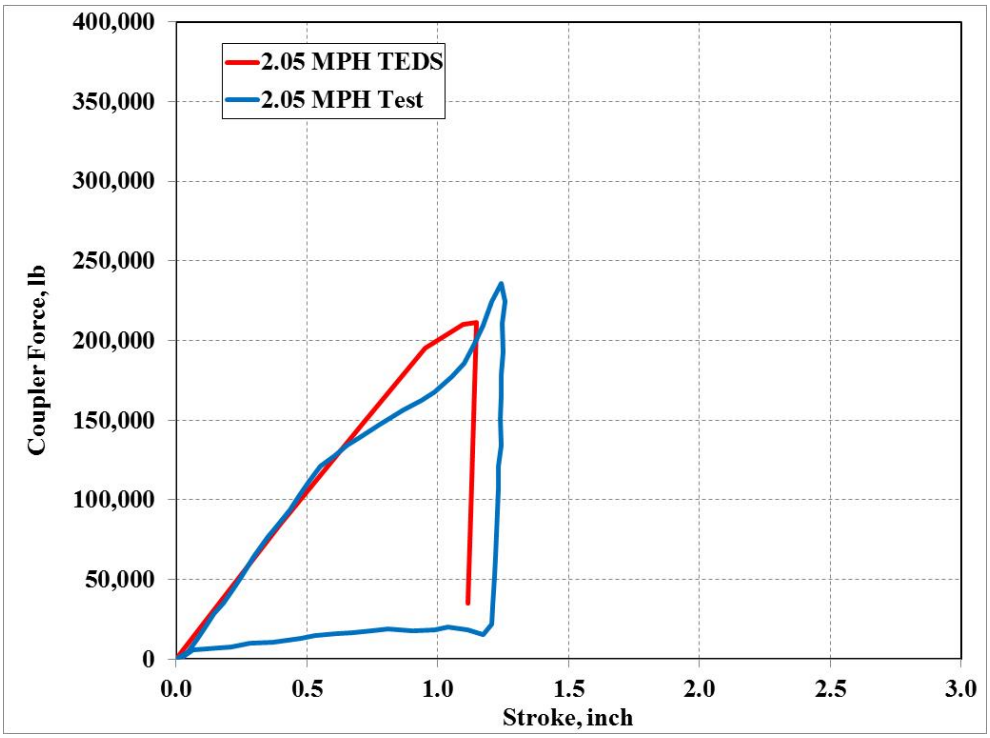


Figure 3.2-2. Metal friction draft gear force-stroke comparison at 2.05 MPH impact.

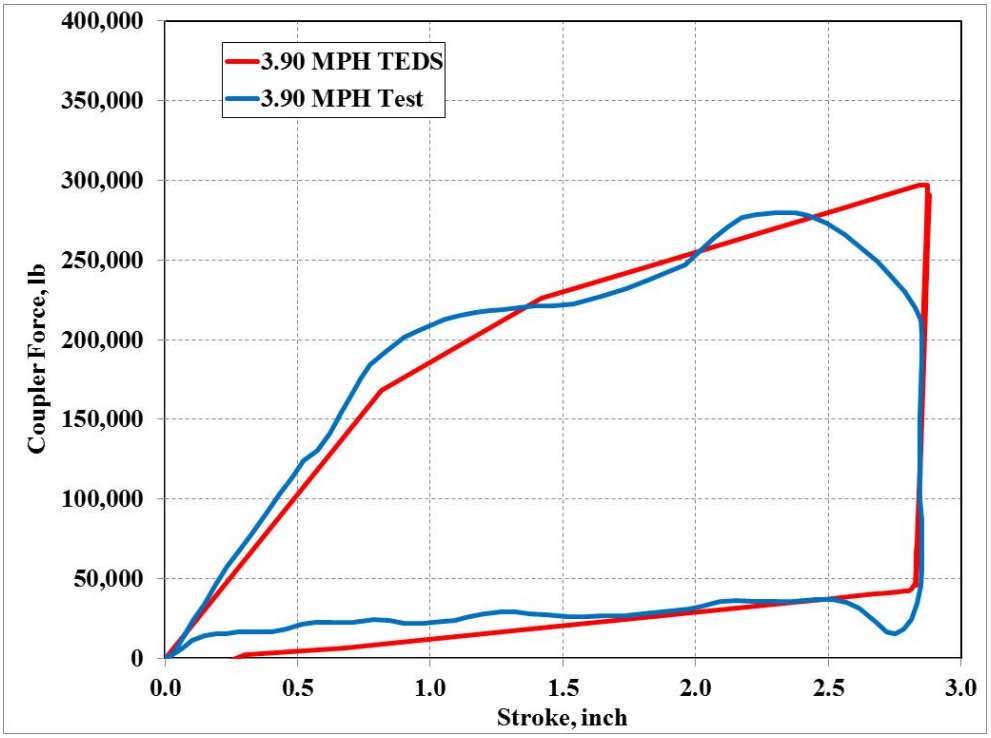


Figure 3.2-3. Metal friction draft gear force-stroke comparison at 3.90 MPH impact.

3.2.2 Rubber Friction Draft Gear

Rubber draft gears were also characterized at several speeds using the impact test setup shown in Figure 3.2-1. Figure 3.2-5 shows the force-stroke characteristics for several speeds tested for the rubber draft gear.

Figure 3.2-6 compares the measured test data for a 1.18 mph impact with the TEDS predictions and Figure 3.2-7 shows the comparison for a 3.94 mph impact. The TEDS predictions match the measured test data well in both cases.

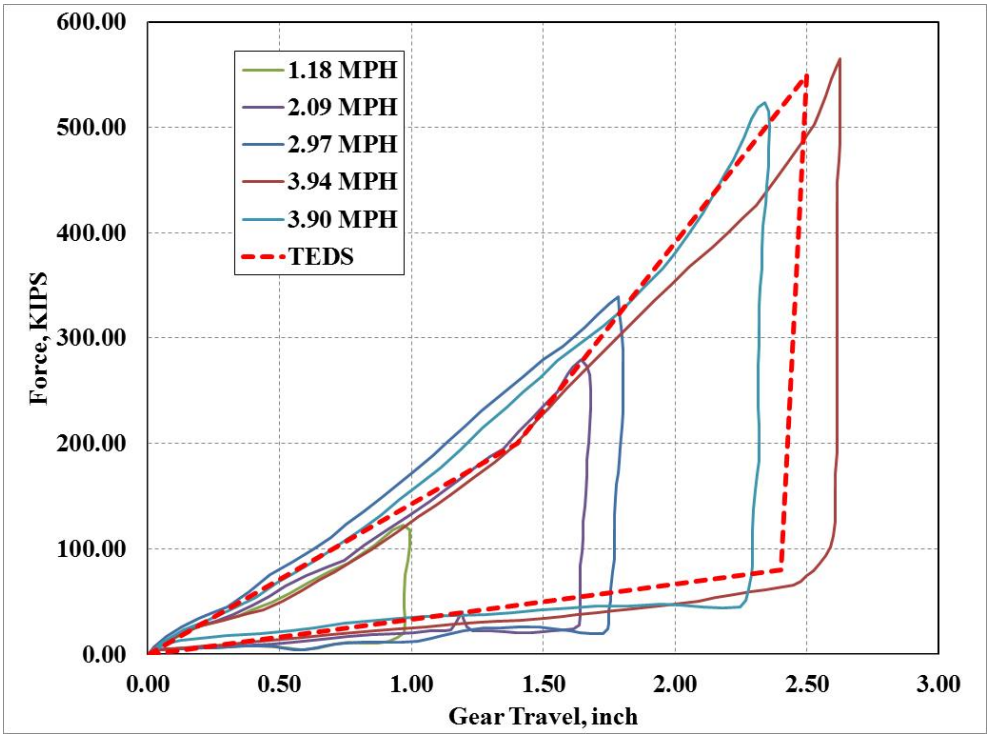


Figure 3.2-4. Overlay of multiple speeds tested for rubber draft gear.

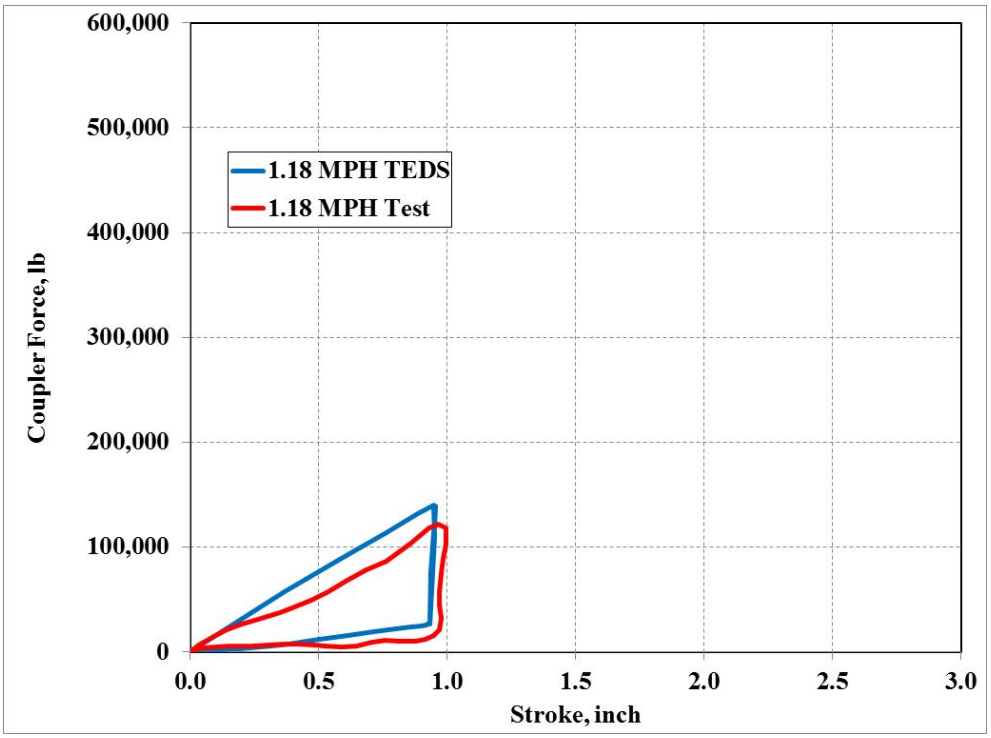


Figure 3.2-5. Rubber draft gear force-stroke comparison at 1.18 MPH impact.

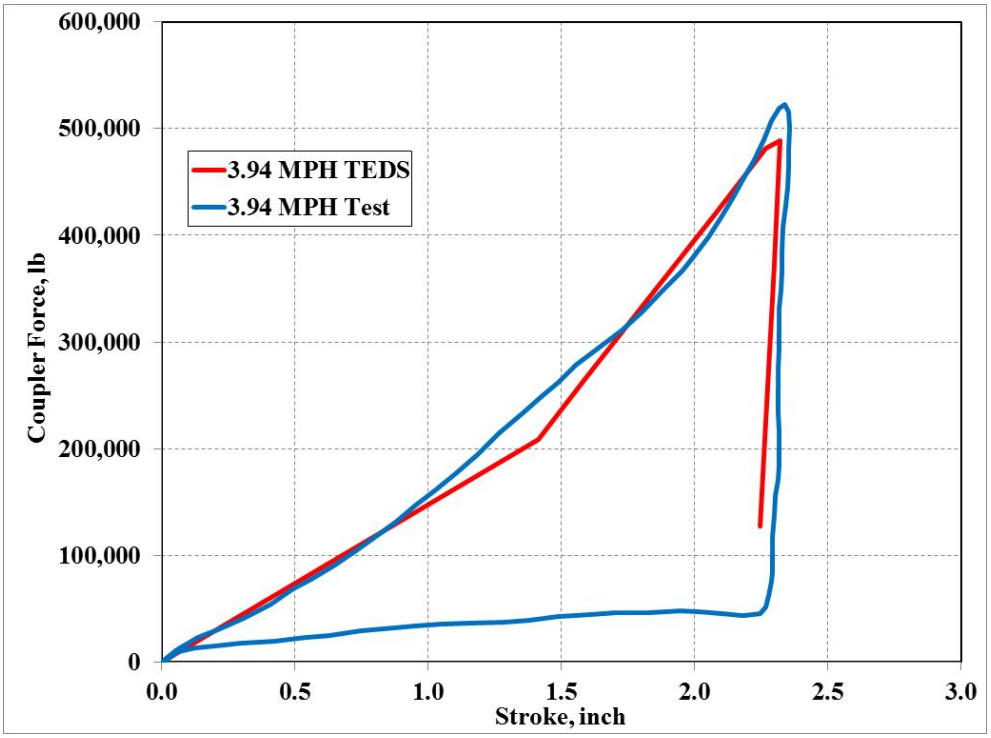


Figure 3.2-6. Rubber draft gear force-stroke comparison at 3.94 MPH impact.

4. System Level Validation

4.1 Air Brake System

A unit coal train's air brake data from a full service reduction was presented at an American Society of Mechanical Engineers – Rail Technology Division meeting in October 1992 [5]. The train included 99 cars and six locomotives, with four locomotives located at the head end and the remaining two locomotives placed near the middle of the train. The remote units were not charging the brake pipe, although the application was initiated from both the lead and remote sets of locomotives. The regulating valve setting was 100 psig. The application was not typical because shortly after the initial partial application, a release was made. This was followed by a full service reduction.

The following figures compare the TEDS predictions of brake pipe and brake cylinder pressure with the four cars that were instrumented for data collection: Figure 4.1-1 for car 1, Figure 4.1-2 for car 17, Figure 4.1-3 for car 57, and Figure 4.1-4 for car 77. For all four cars, the trend and magnitude of the predicted brake pipe pressure follows the measured data very well.

The brake cylinder pressure trends generated by the data are followed very well by TEDS for all four cars. The predicted brake cylinder pressure magnitudes are also fairly close to the measured data. Minor differences in the final cylinder pressure may be due to slight cylinder volume differences. Cylinder pressures that change significantly after the pipe pressure has stabilized, such as in Figure 4.1-2 and Figure 4.1-3, are not completely understood and could be due to measurement drift, or leakage in the valve through an incompletely closed port between the auxiliary reservoir and the brake cylinder. Overall, the match between the TEDS predictions and the measured test data was very good.

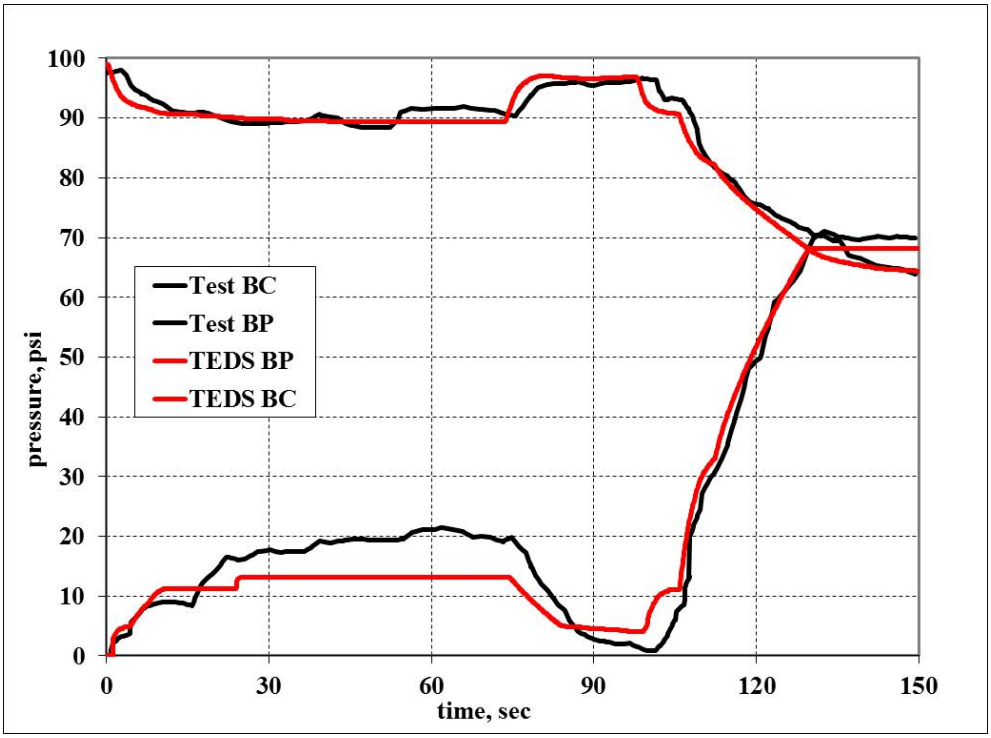


Figure 4.1-1. Comparison of brake pipe and brake cylinder pressures on car 1 on the unit coal train.

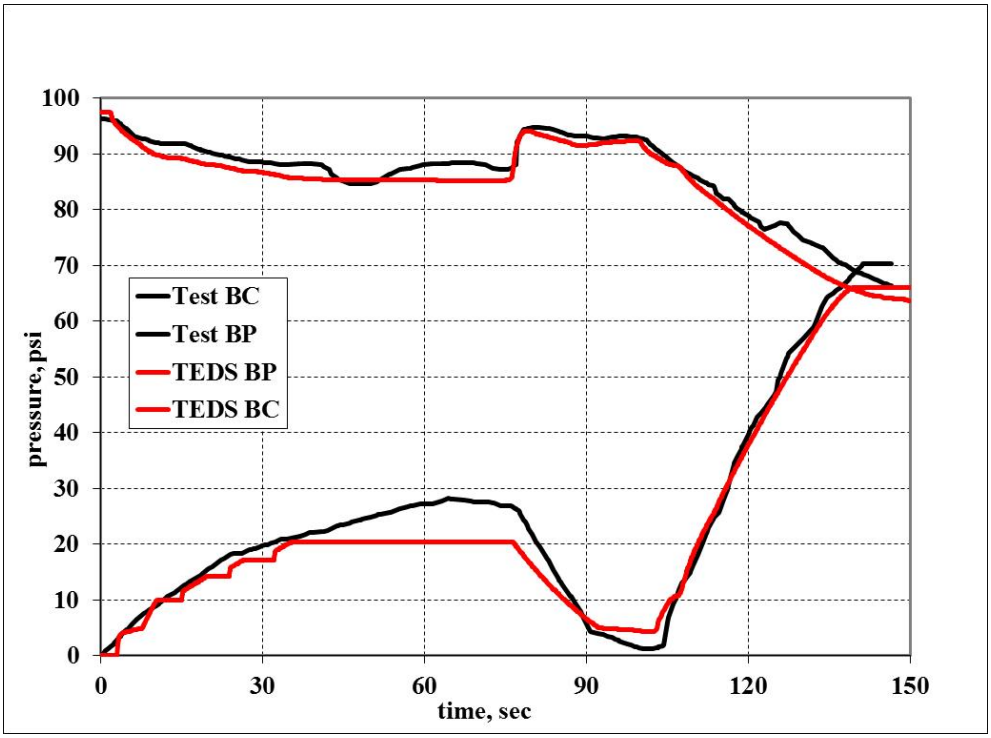


Figure 4.1-2. Comparison of brake pipe and brake cylinder pressures on car 17 on the unit coal train.

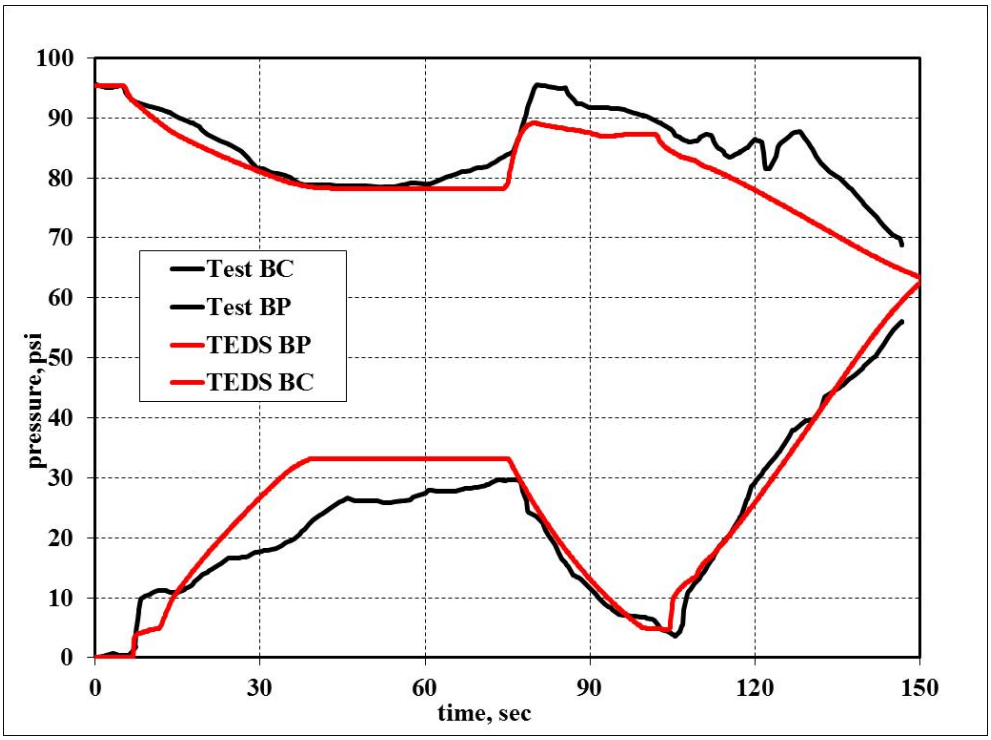


Figure 4.1-3. Comparison of brake pipe and brake cylinder pressures on car 57 on the unit coal train.

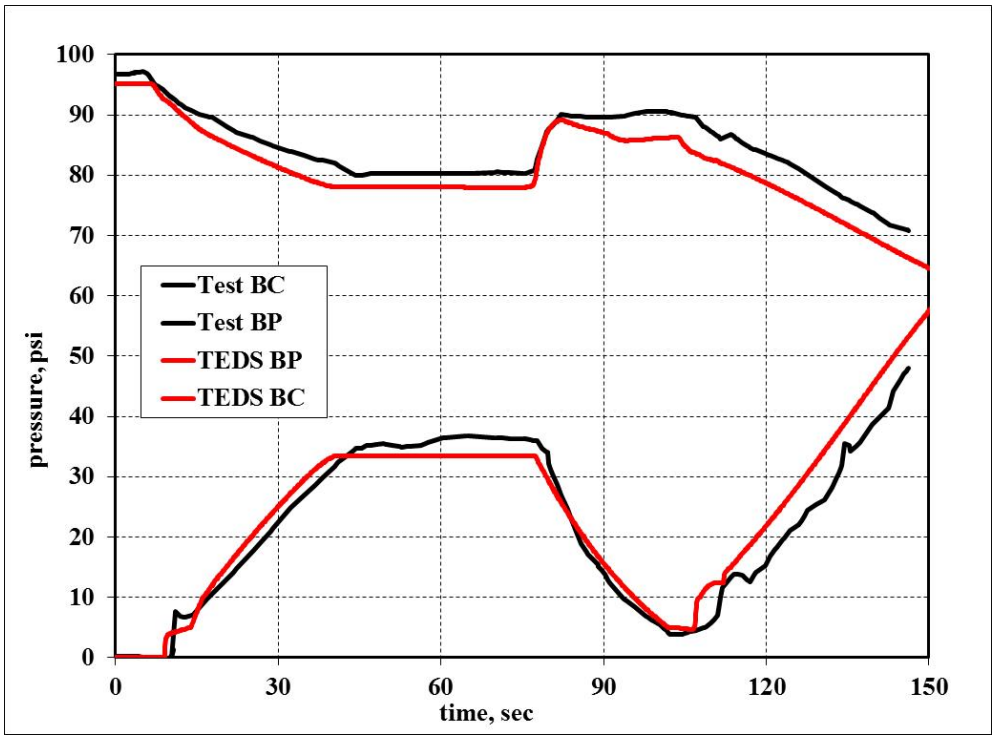


Figure 4.1-4. Comparison of brake pipe and brake cylinder pressures on car 77 on the unit coal train.

4.2 Train Speed

When the National Transportation Safety Board (NTSB) investigates a train incident, it gathers all pertinent data on the accident, which includes complete train information, track data around the incident site, and train handling data from the event recorders. Once NTSB publishes its final report, all this data is available to the public NTSB docket sites.

To validate TEDS' ability to predict train speeds, incidents from the NTSB docket where the track data includes several miles preceding the event were chosen. These cases were selected since they had been simulated at the behest of NTSB during its evaluation of TEDS as a potential investigative support tool. The trains involved in these events were simulated with TEDS and those results were compared to the event recorder speed.

4.2.1 Simulation of Train Approaching Tiskilwa, IL

The Tiskilwa, IL incident is documented in a NTSB docket [6]. Twenty six (26) cars were derailed in this incident, releasing some hazardous material and requiring evacuation of nearby residents.

A summary of the train in the Tiskilwa, IL incident is shown in Table 4.2-1. All locomotives are at the head end of the train. The weight and length distributions are shown in Figure 4.2-1 and Figure 4.2-2, respectively. The car lengths and weights are fairly uniform except for the three empty cars in vehicle positions 84-86. The track chart for this scenario is shown in Figure 4.2-3. The segment simulated is entirely descending grade. The train was simulated for approximately 9 miles.

The train handling and speed for this scenario is shown in Figure 4.2-4. The train handling varies between notch 2 and dynamic 5. The event recorder only stores the locomotive speed to the nearest integer value. Therefore, the reported speed from the event recorder (the black curve) shows jumps in value at several locations. The lead locomotive speed from the TEDS simulation shown in the red curve in Figure 4.2-4 matches the event recorder speed very well.

Table 4.2-1. Tiskilwa, IL train summary.

No. of Locomotives	Head-end	2
	Middle	0
	Remote/Rear	0
Total Horsepower		8,800
No. of Cars	Total	131
	Empty	3
	Loaded	128
Trailing Tons		16,350
Total Tons		16,780
Horsepower/Ton		0.538
Train Length (Including Locomotives) in feet		8,156

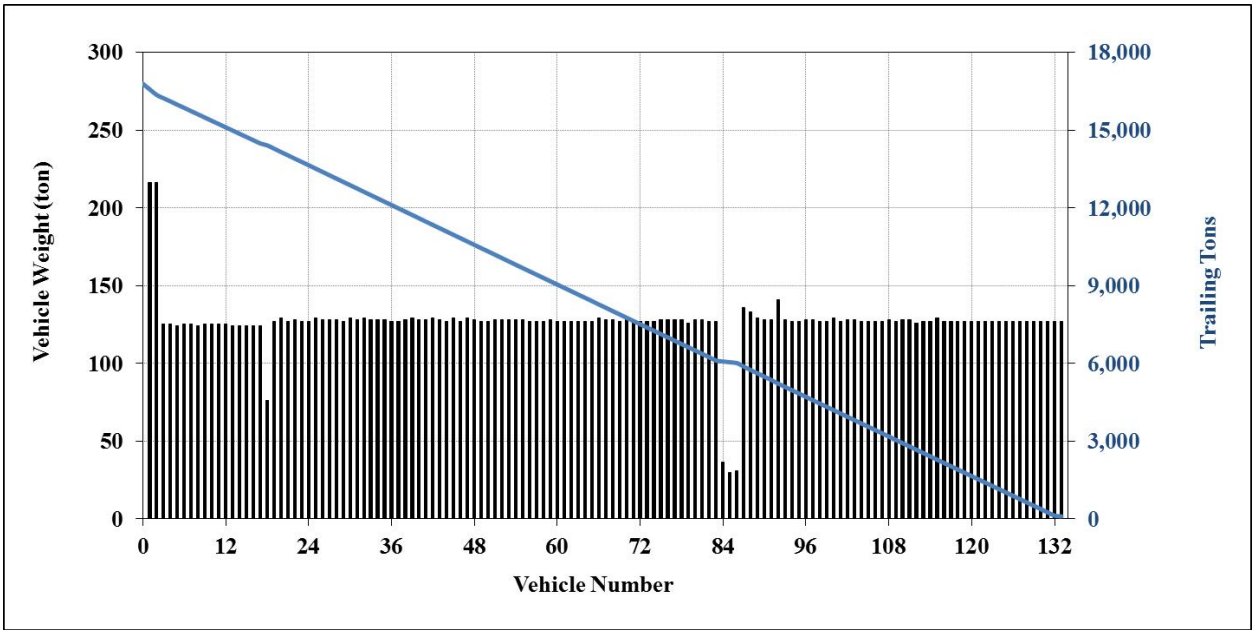


Figure 4.2-1. Tiskilwa, IL train weight distribution.

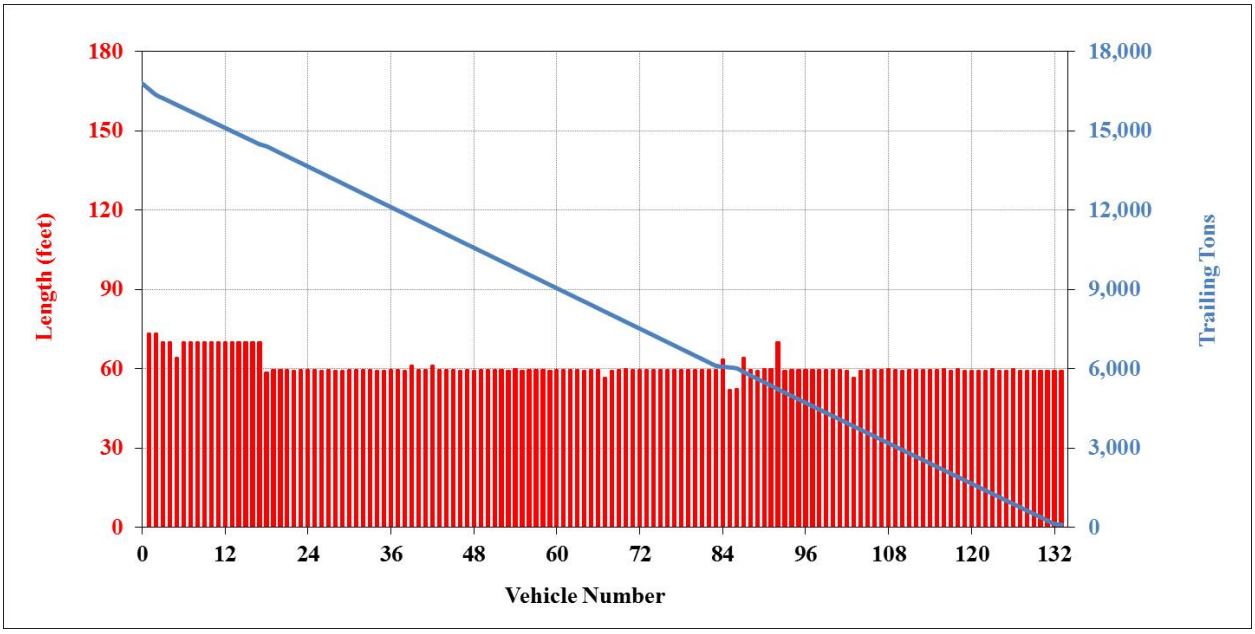


Figure 4.2-2. Tiskilwa, IL train length distribution.

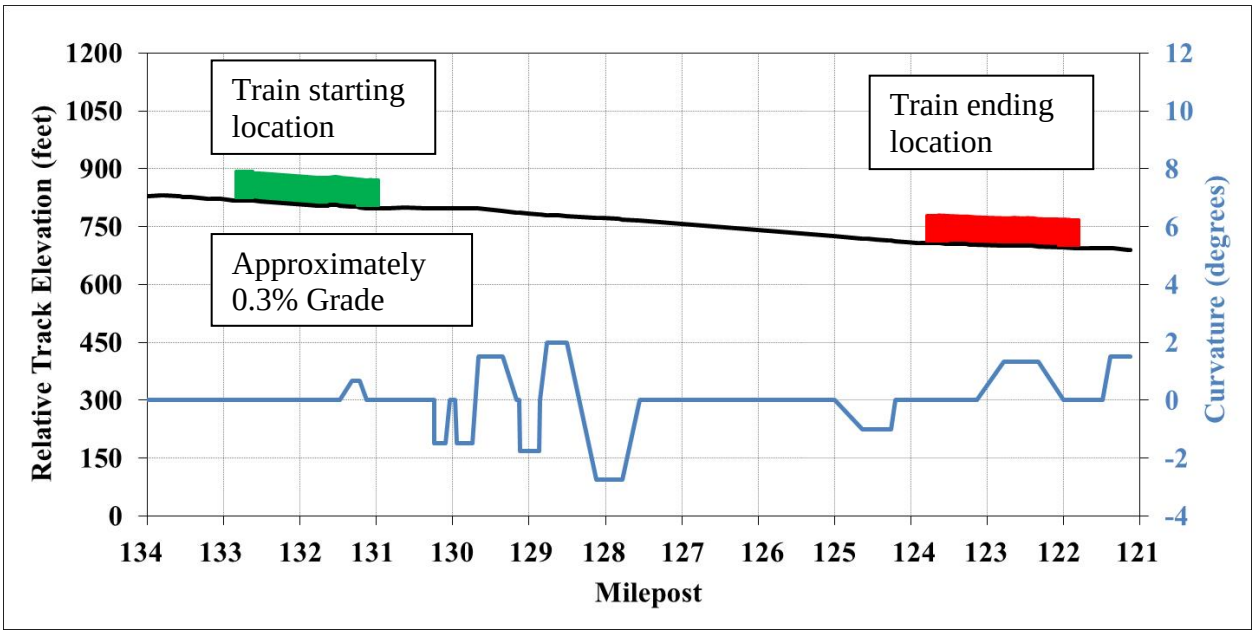


Figure 4.2-3. Tiskilwa, IL track chart. The train was simulated for approximately 9 miles.

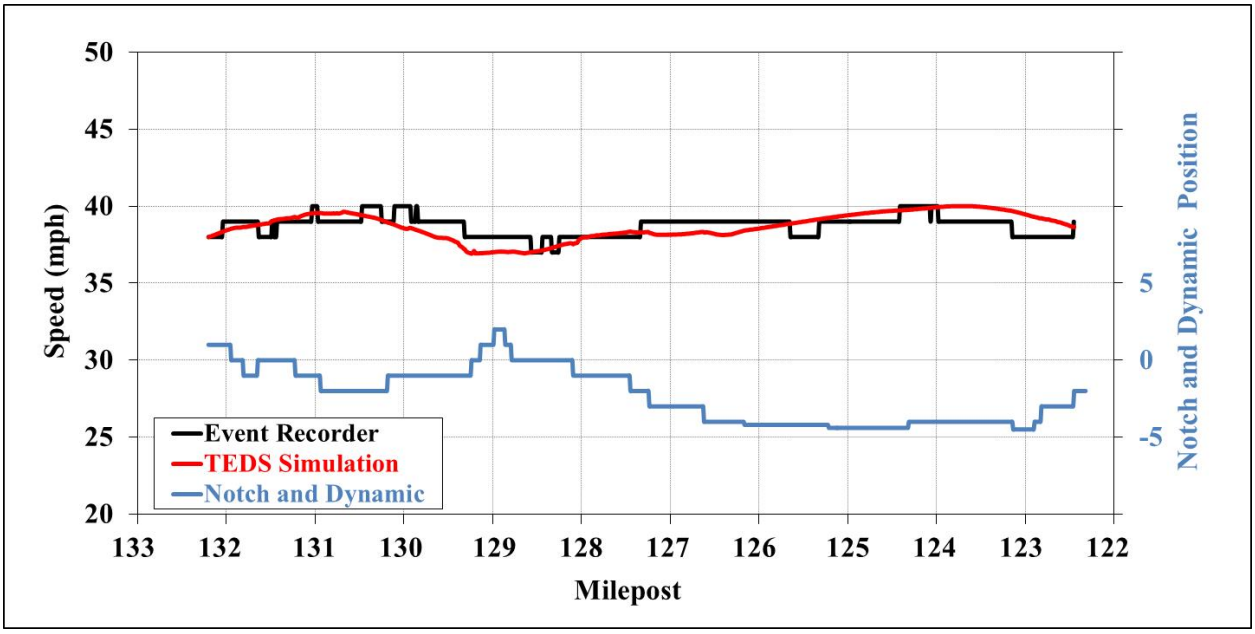


Figure 4.2-4. Train handling and comparison of simulated and event recorder speed.

4.2.2 Simulation of Train Approaching Red Oak, IA

In the Red Oak, IA incident, a loaded coal train collided with the rear end of a maintenance-of-way train, which caused the derailment of two locomotives and twelve cars [7].

A summary of the train in the Red Oak, IA incident is given in Table 4.2-2. One locomotive was located at the end of the train and was operated remotely while the remaining two locomotives were located at the head end. The weight and length distributions are shown in Figure 4.2-5 and Figure 4.2-6, respectively. The car lengths and weights are fairly uniform throughout the train. The track chart for this scenario is shown in Figure 4.2-7. The terrain here is entirely ascending grade. The train was simulated for approximately 9 miles.

The train handling and speed for this scenario is shown in Figure 4.2-8. The train handling varied between notch 8 and dynamic 8 for the entire ascending grade route. The event recorder only stored the locomotive speed to the nearest integer value. Therefore the reported speed from the event recorder (the black curve) shows stairstepping throughout the run. The lead locomotive speed from the TEDS simulation shown in the red curve in Figure 4.2-8 matches the event recorder speed very well.

Table 4.2-2. Red Oak, IA train summary.

No. of Locomotives	Head-end	2
	Middle	0
	Remote/Rear	1
Total Horsepower		17000
No. of Cars	Total	130
	Empty	0
	Loaded	130
Trailing Tons		18,529
Total Tons		19,159
Horsepower/Ton		0.89
Train Length (Including Locomotives), ft		7,122

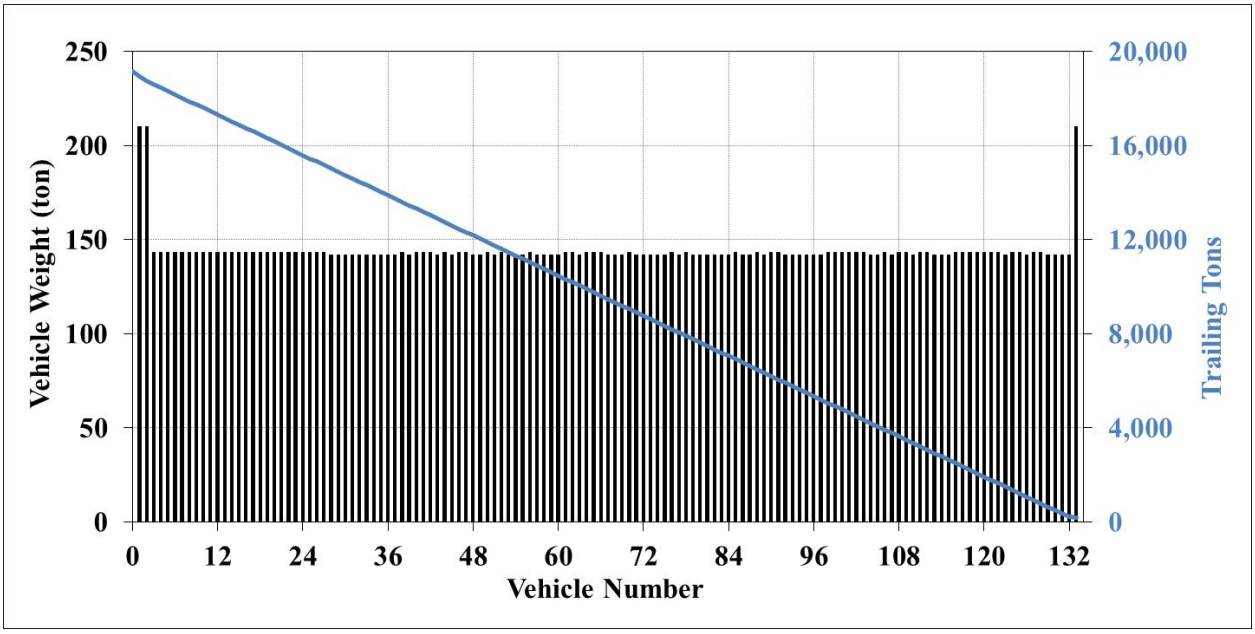


Figure 4.2-5. Red Oak, IA train weight distribution.

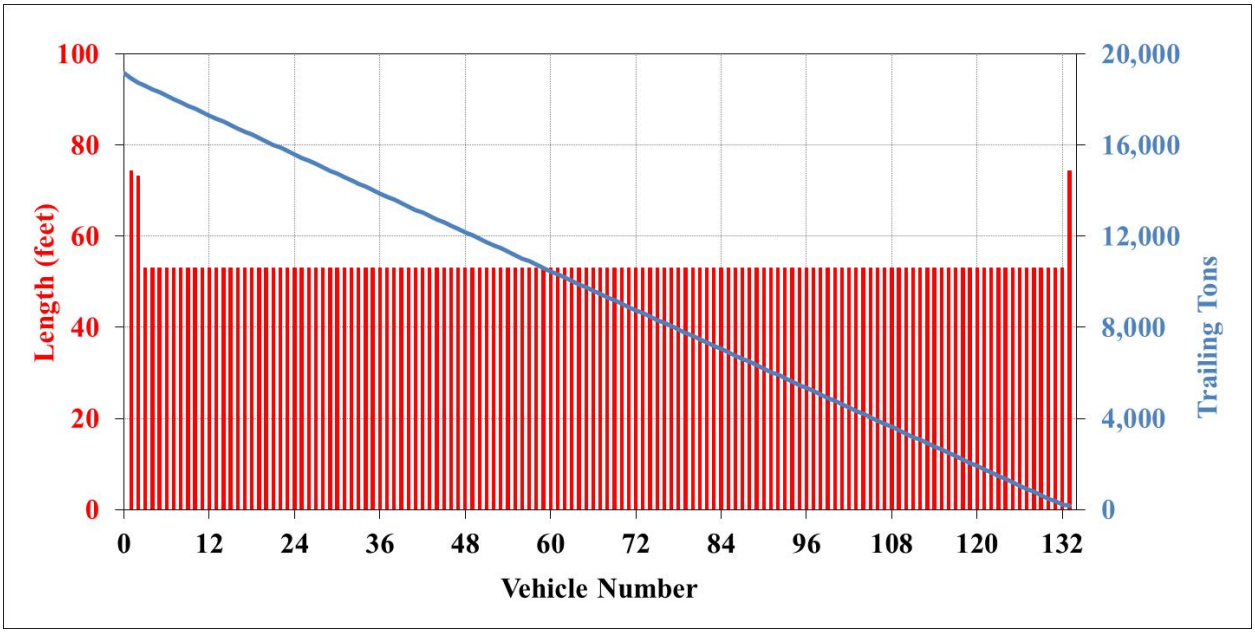


Figure 4.2-6. Red Oak, IA train length distribution.

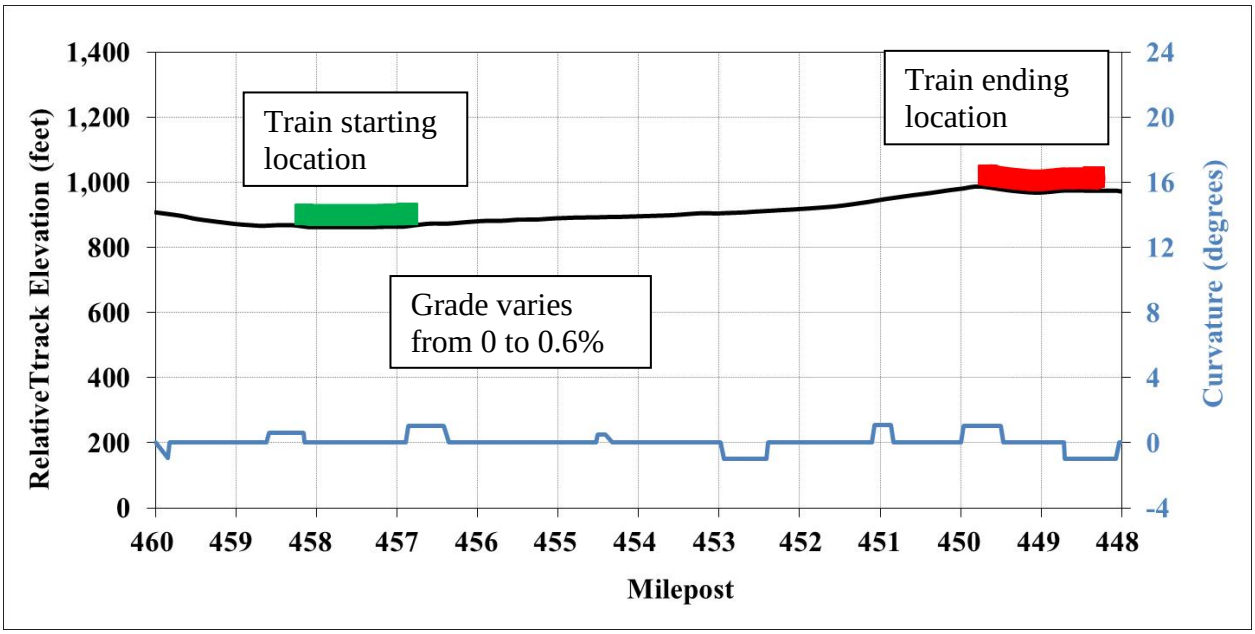


Figure 4.2-7. Red Oak, IA track chart.

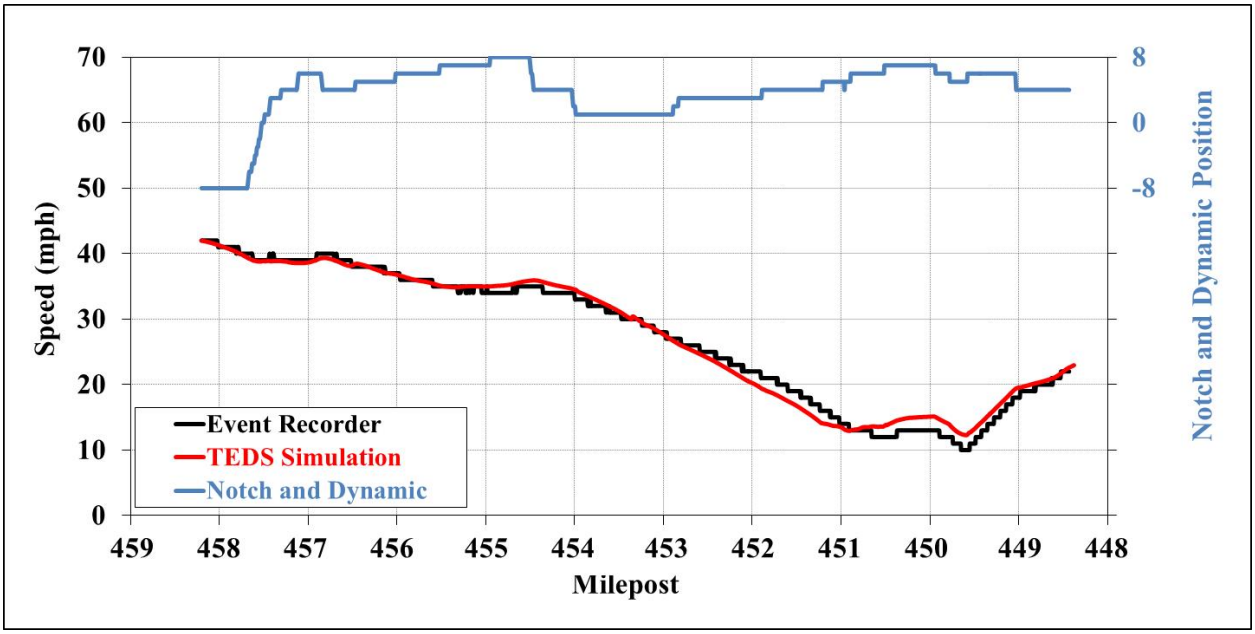


Figure 4.2-8. Red Oak, IA train handling and speed comparison.

4.2.3 Simulation of Westbound Train Approaching Goodwell, OK

In the Goodwell, OK incident, two mixed freight trains were in a head-on collision [8]. The summary of the westbound train in the Goodwell, OK event is shown in Table 4.2-3. One locomotive was located at the rear of the train and operated remotely. The remaining two locomotives were located at the head end of the train. The weight and length distributions are shown in Figure 4.2-9 and Figure 4.2-10, respectively. The car lengths and weights are fairly uniform throughout the train. The track chart for this scenario is shown in Figure 4.2-11. The terrain here is entirely ascending grade. The train was simulated for approximately 55 miles.

The train handling and speed for this scenario is shown in Figure 4.2-12. The train handling varied between notch 8 and idle for the entire ascending grade route. The event recorder only stored the locomotive speed to the nearest integer value. Therefore, the reported speed from the event recorder (the black curve) shows stairstepping throughout the run. The lead locomotive speed from the TEDS simulation shown in the red curve in Figure 4.2-12 matches the event recorder speed very well.

Table 4.2-3. Westbound Goodwell, OK train summary.

No. of Locomotives	Head-end	2
	Middle	0
	Remote/Rear	1
Total Horsepower		12,690
No. of Cars	Total	80
	Empty	0
	Loaded	80
Trailing Tons		5,759
Total Tons		6,389
Horsepower/Ton		1.98
Train Length (Including Locomotives) in feet		7,742

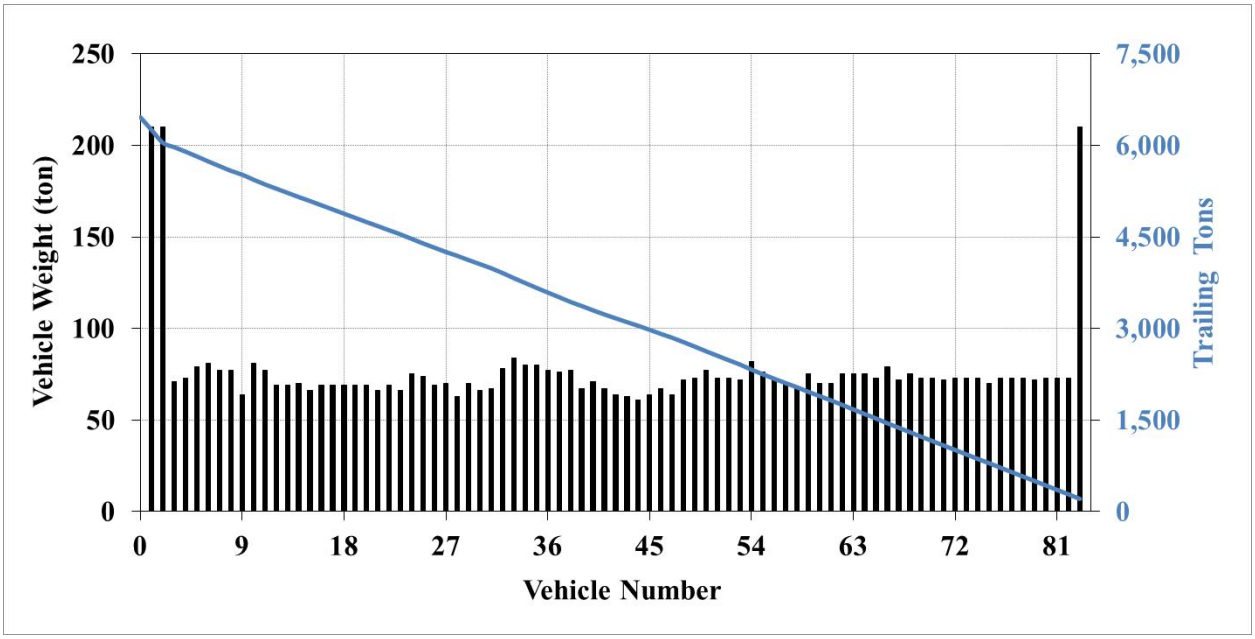


Figure 4.2-9. Westbound Goodwell, OK train weight distribution.

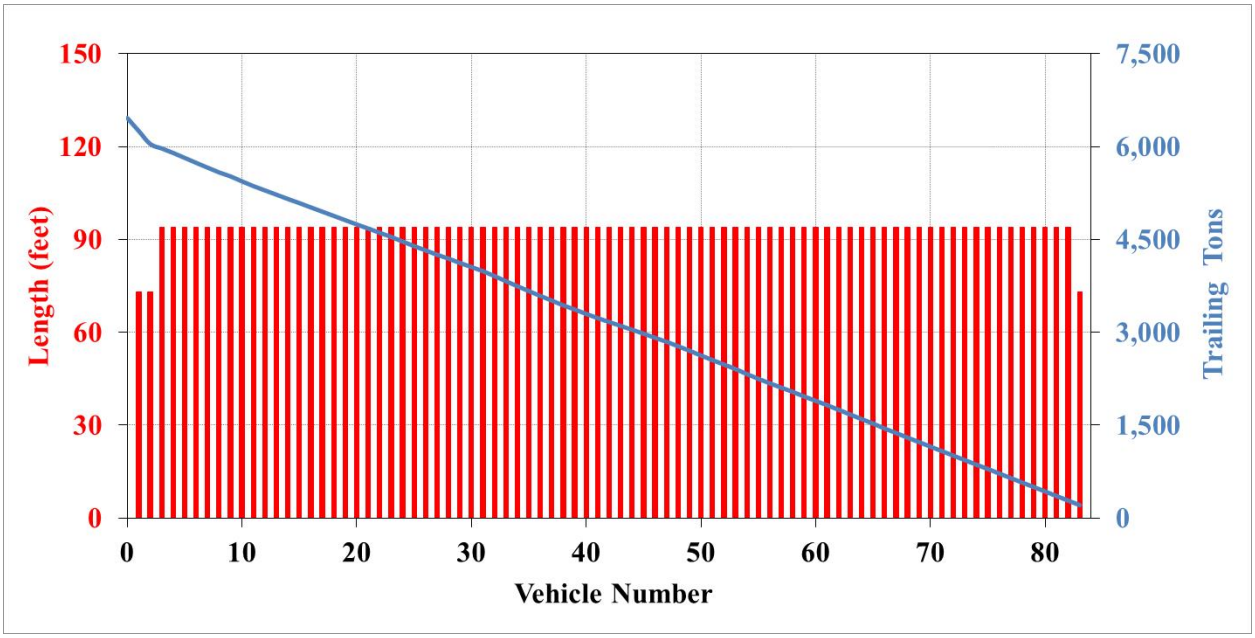


Figure 4.2-10. Westbound Goodwell, OK train length distribution.

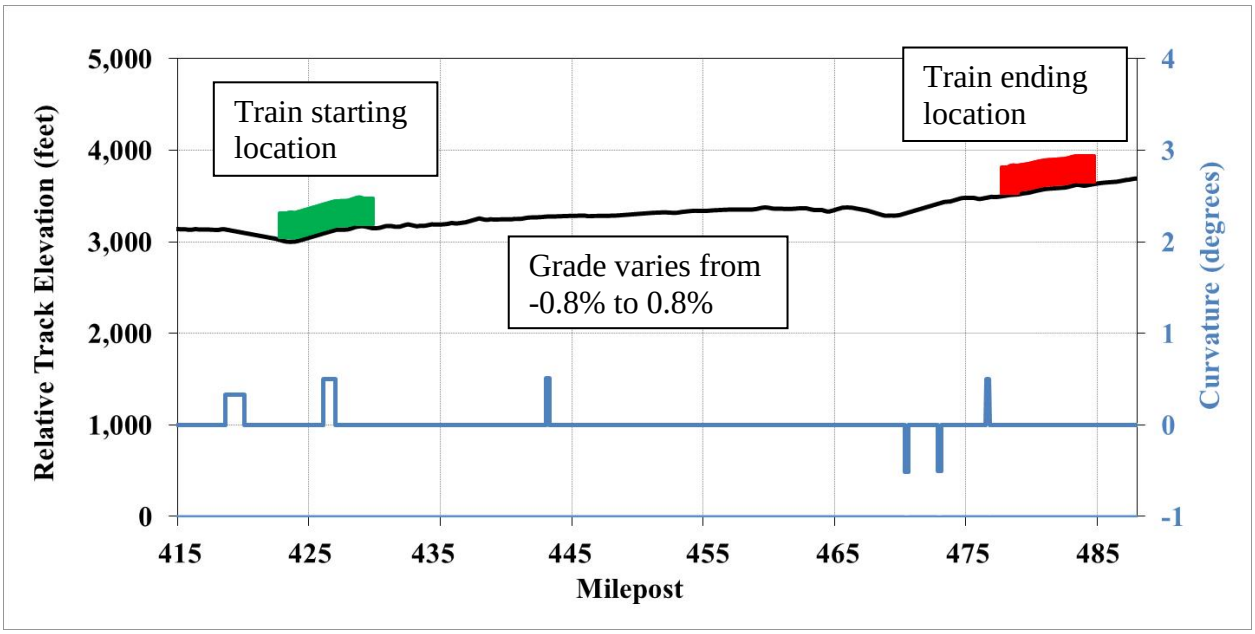


Figure 4.2-11. Westbound Goodwell, OK track chart.

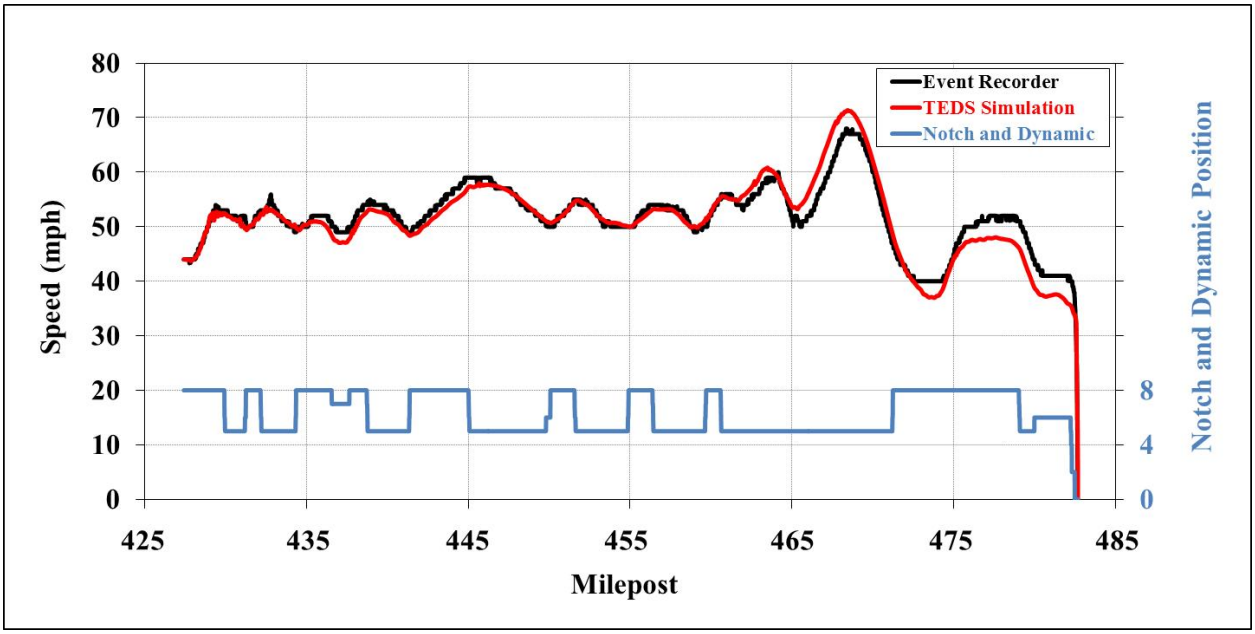


Figure 4.2-12. Westbound Goodwell, OK train handling and speed comparison.

4.2.4 Simulation of Eastbound Train Approaching Goodwell, OK

In the Goodwell, OK incident, two mixed freight trains were in a head-on collision [8]. The summary of the eastbound train in the Goodwell, OK event is shown in Table 4.2-4.

Two locomotives were at the head end of the train while the third locomotive was at the rear of the train and operated remotely. The weight and length distributions are shown in Figure 4.2-13 and Figure 4.2-14, respectively. The car lengths and weights are fairly uniform throughout the train. The track chart for this scenario is shown in Figure 4.2-15. The terrain here is entirely descending grade. The train was simulated for approximately 30 miles.

The train handling and speed for this scenario is shown in Figure 4.2-16. The train handling varied between notch 8 and dynamic 8 for the entire descending grade route. The event recorder only stored the locomotive speed to the nearest integer value. Therefore the reported speed from the event recorder (the black curve) shows stairstepping throughout the run. The lead locomotive speed from the TEDS simulation shown in the red curve in Figure 4.2-16 matches the event recorder speed very well.

Table 4.2-4. Eastbound Goodwell, OK train summary.

No. of Locomotives	Head-end	3
	Middle	0
	Remote/Rear	1
Total Horsepower		17,500
No. of Cars	Total	108
	Empty	0
	Loaded	108
Trailing Tons		6,330
Total Tons		7,188
Horsepower/Ton		2.43
Train Length (Including Locomotives) in feet		7919.5

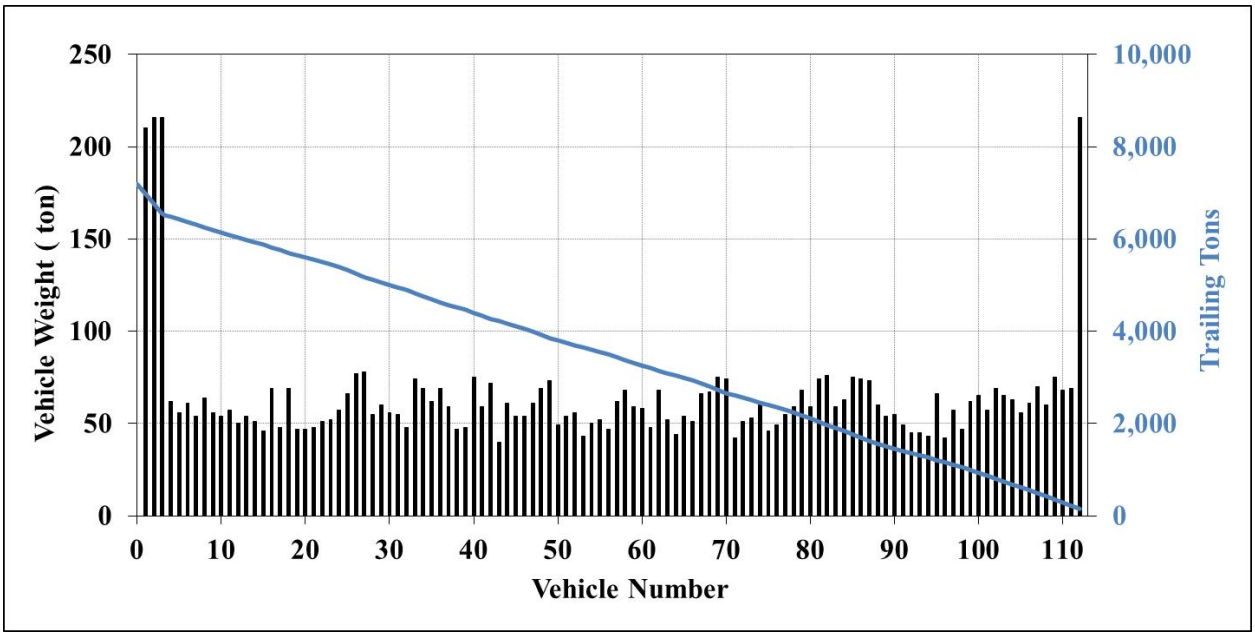


Figure 4.2-13. Eastbound Goodwell, OK train weight distribution.

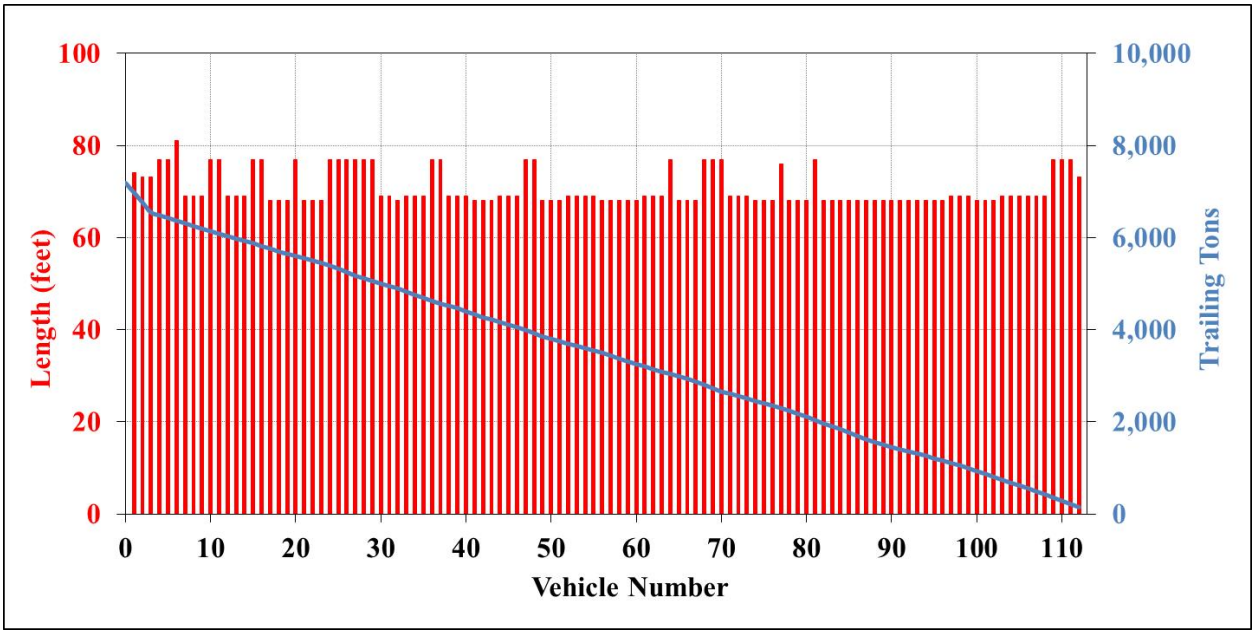


Figure 4.2-14. Eastbound Goodwell, OK train length distribution.

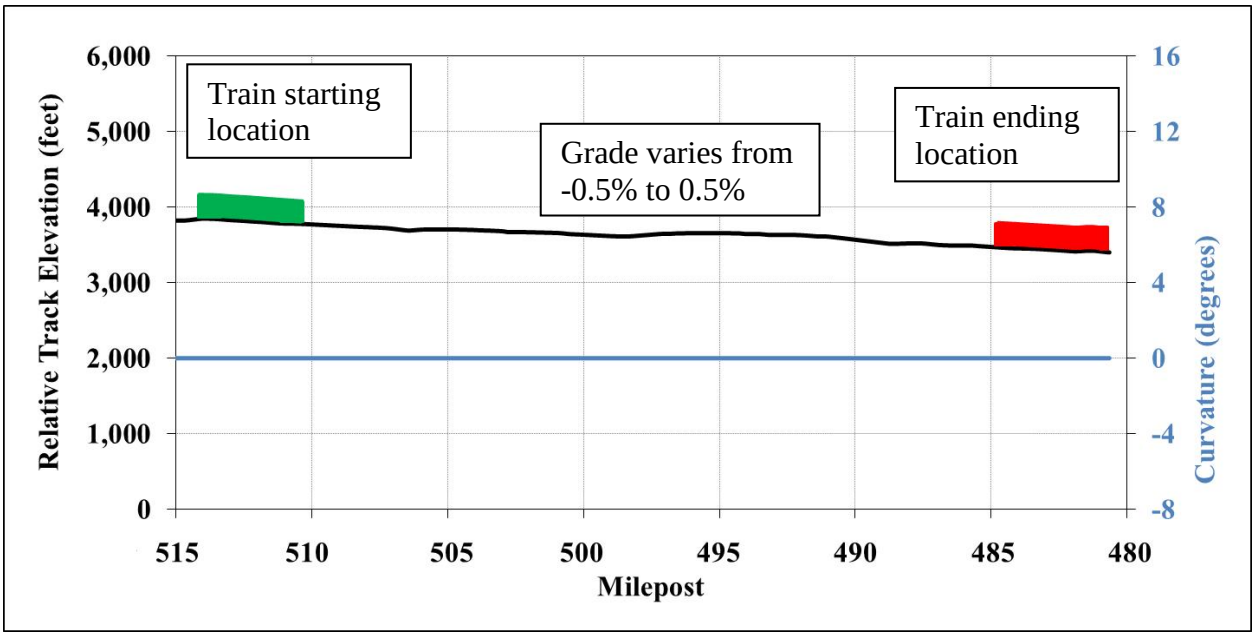


Figure 4.2-15. Eastbound Goodwell, OK track chart.

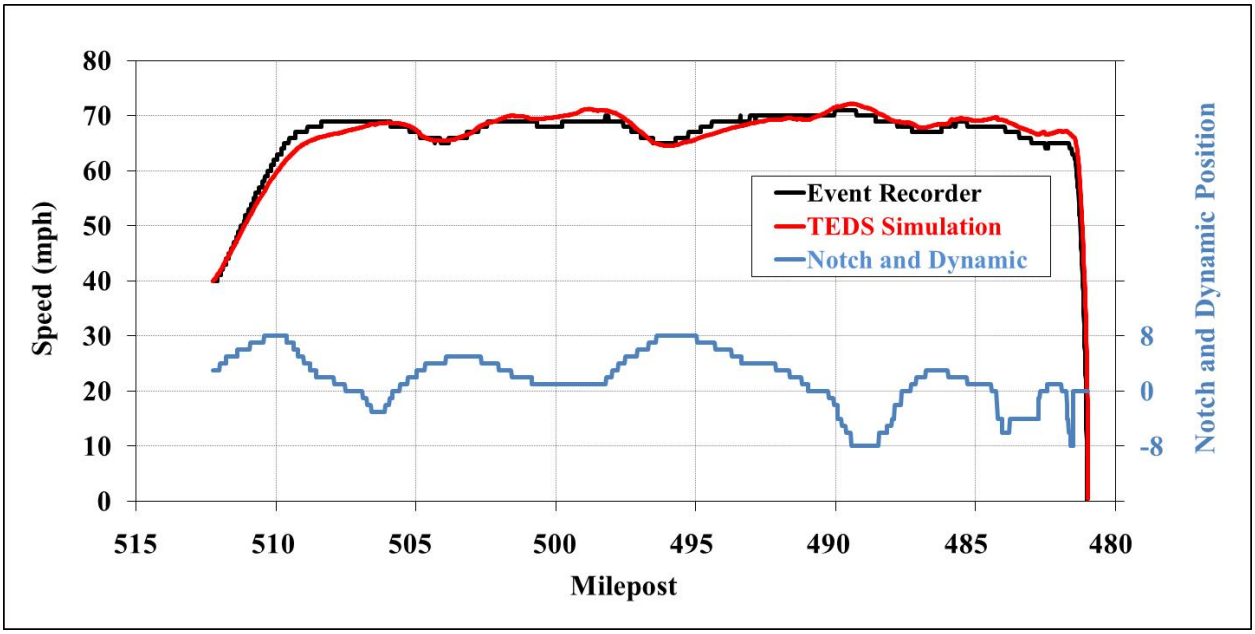


Figure 4.2-16. Eastbound Goodwell, OK train handling and speed comparison.

5. Detailed Coupler Force System Validation

The third major element of validation of TEDS is the coupler force model. The only measured revenue service data available for this purpose is from an ASME paper [5] and an AAR report [9]. We selected the cresting event from these documents because the large changes in coupler force can be compared with the predictions of the draft gear model, and the loaded stop event can be compared with the predictions of the speed and stopping distance model.

5.1 Unit Train Cresting Operation

For this validation process, published test data for a revenue service unit coal train was obtained from a paper presented at an October 1992 ASME Rail Technology Division (RTD) meeting and a report issued by the American Association of Railroads [5, 9]. A summary of the train in this revenue service test is provided in Table 5.1-1, while the weight and length distributions are shown in Figure 5.1-1 and Figure 5.1-2, respectively.

Table 5.1-1. Conventional unit train summary.

No. of Locomotives	Head-end	4
	Middle	2
	Remote/Rear	0
Total Horsepower		20,200
No. of Cars	Total	99
	Empty	2
	Loaded	97
Trailing Tons		13,958
Total Tons		15,061
Horsepower/Ton		1.34
Train Length (Including Locomotives) in feet		6,086

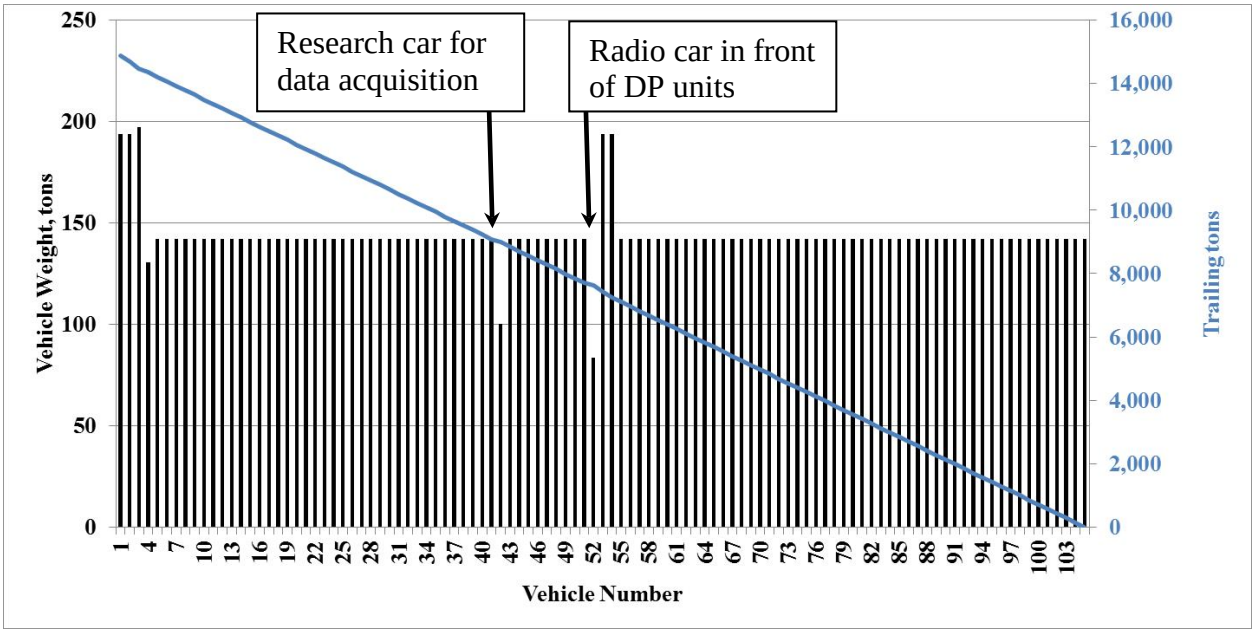


Figure 5.1-1. Conventional unit train weight distribution.

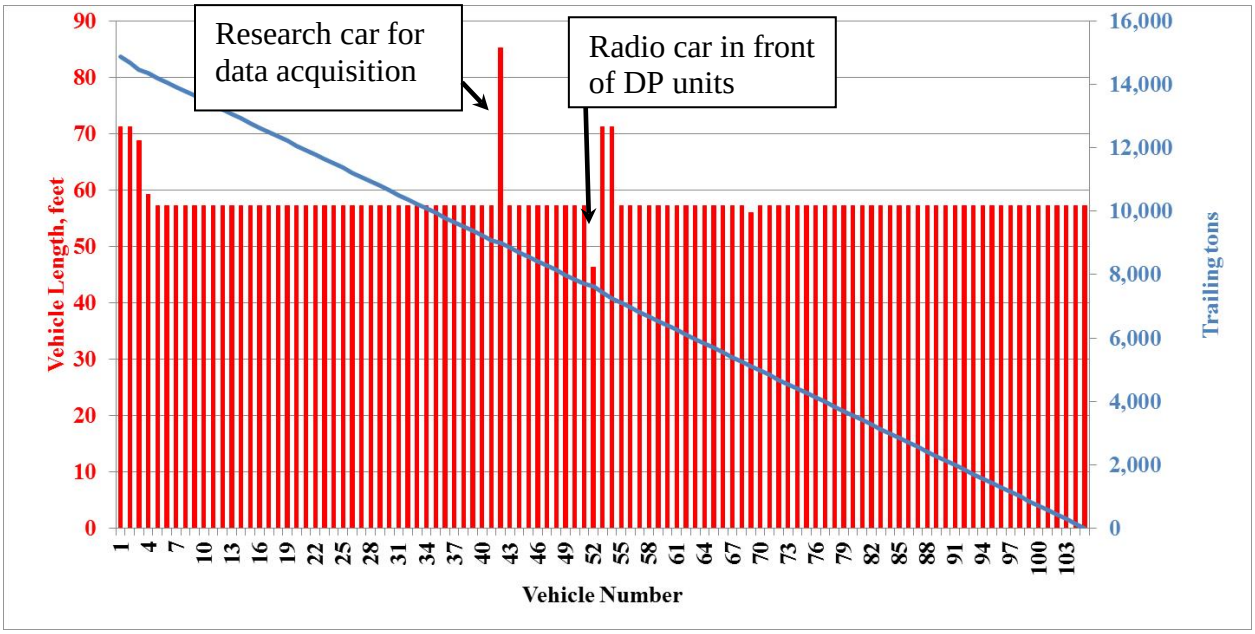


Figure 5.1-2. Conventional unit train length distribution.

Figure 5.1-3 shows the elevation profile, while Figure 5.1-4 compares the train speed predicted by TEDS and with the measured speed, together with the train handling for this scenario. The predicted speed matches the measured speed very well. Each of the throttle position changes are reflected in the speed at each of the knee points.

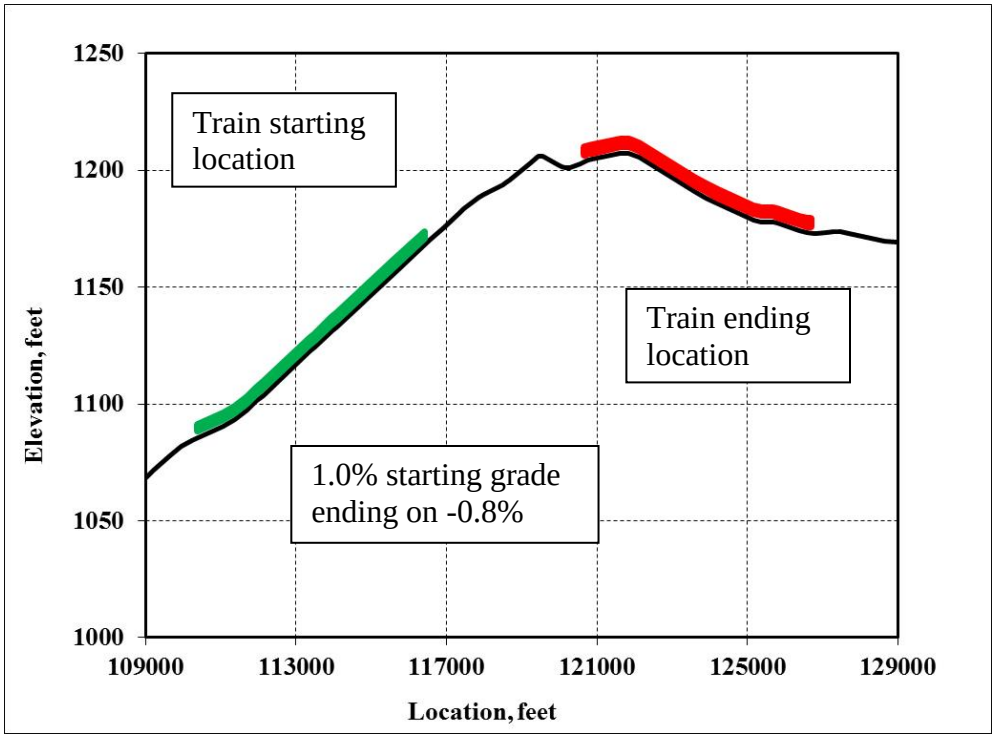


Figure 5.1-3. Cresting operation elevation profile.

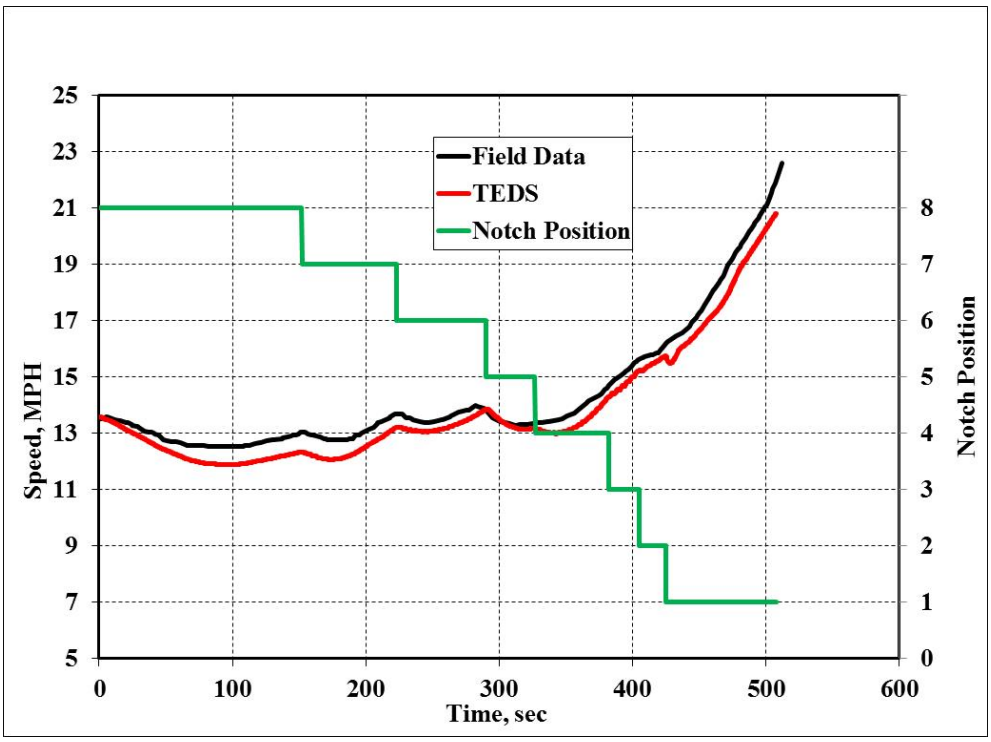


Figure 5.1-4. Comparison of predicted speed to measured speed for cresting operation.

The coupler force was measured and plotted for cars 1, 17, and 57 on the train. The comparison of the predicted coupler force to the measured coupler force is shown in Figure 5.1-5 through Figure 5.1-7. In all cases the predicted coupler force matches the measured coupler force well.

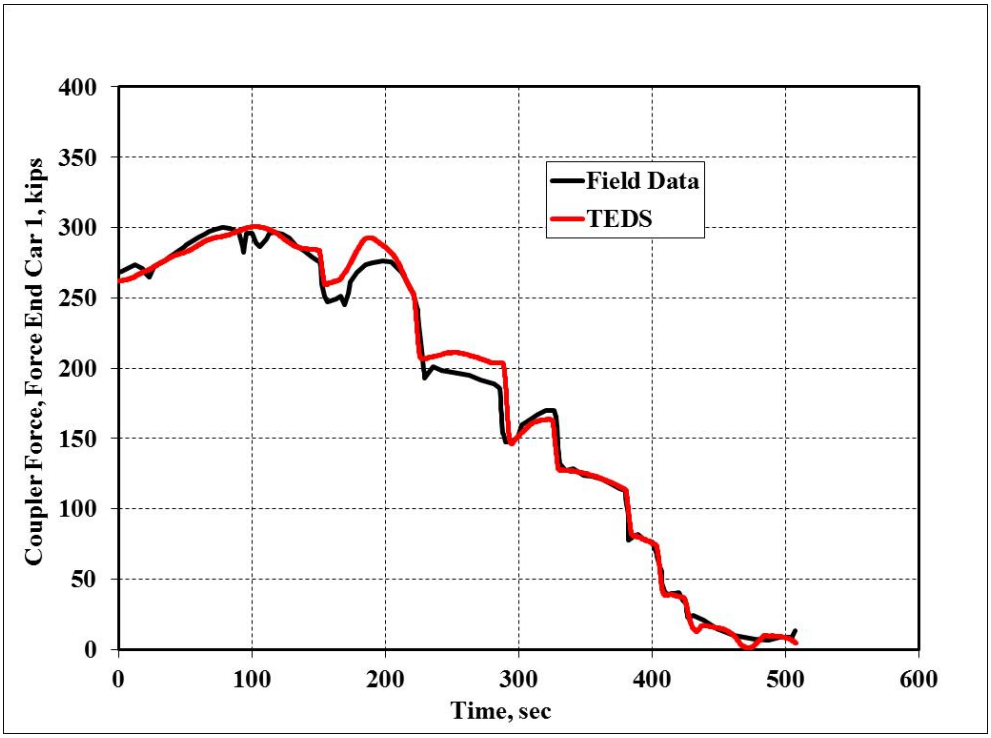


Figure 5.1-5. Comparison of predicted to measured coupler force on car 1 for the cresting operation.

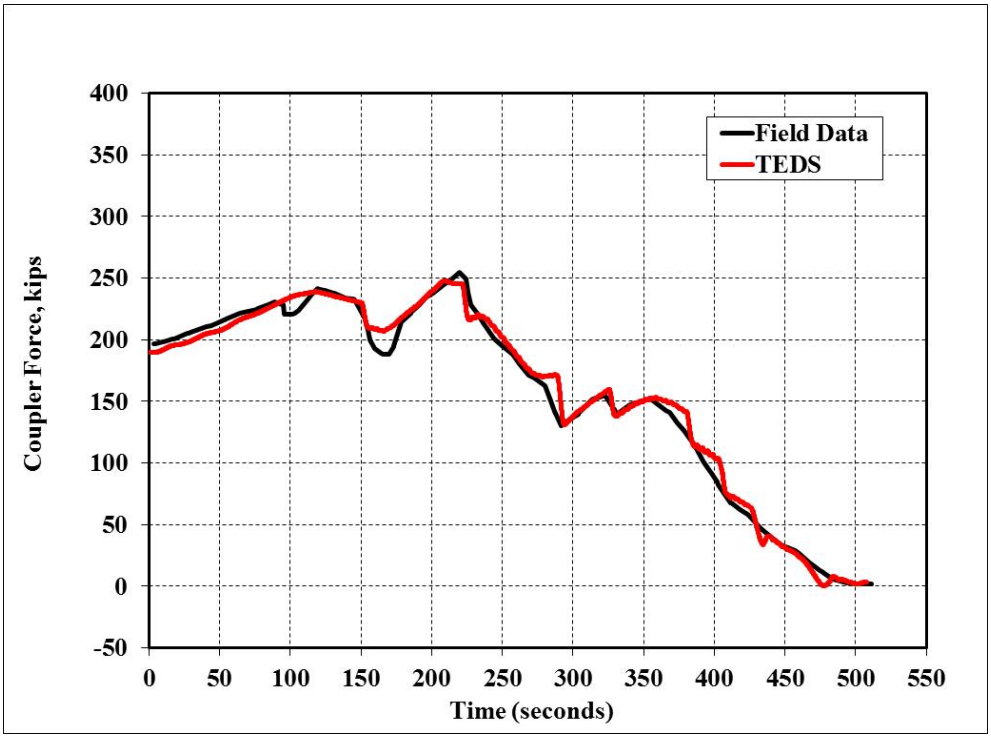


Figure 5.1-6. Comparison of predicted to measured coupler force on car 17 for the cresting operation.

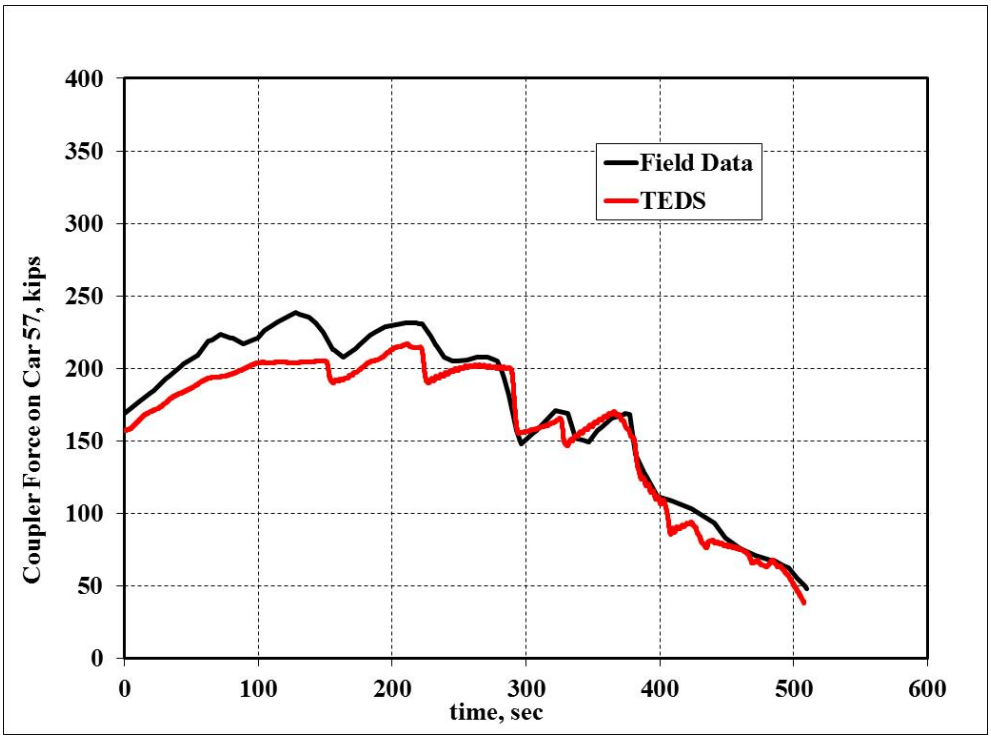


Figure 5.1-7. Comparison of predicted to measured coupler force on car 57 for the cresting operation.

5.2 Unit Coal Train Full Service Application Stop

The unit train's full service stop included the air brake system response discussed in Section 4.1. The track profile for this scenario is shown in Figure 5.2-1. The TEDS prediction of train speed is shown in Figure 5.2-2. The speed profile shows a good match, and the stopping location is within 15 feet, which is excellent. The increase in speed shown toward the end of the profile in both the test data and in the TEDS simulation is due to the release of the air brakes.

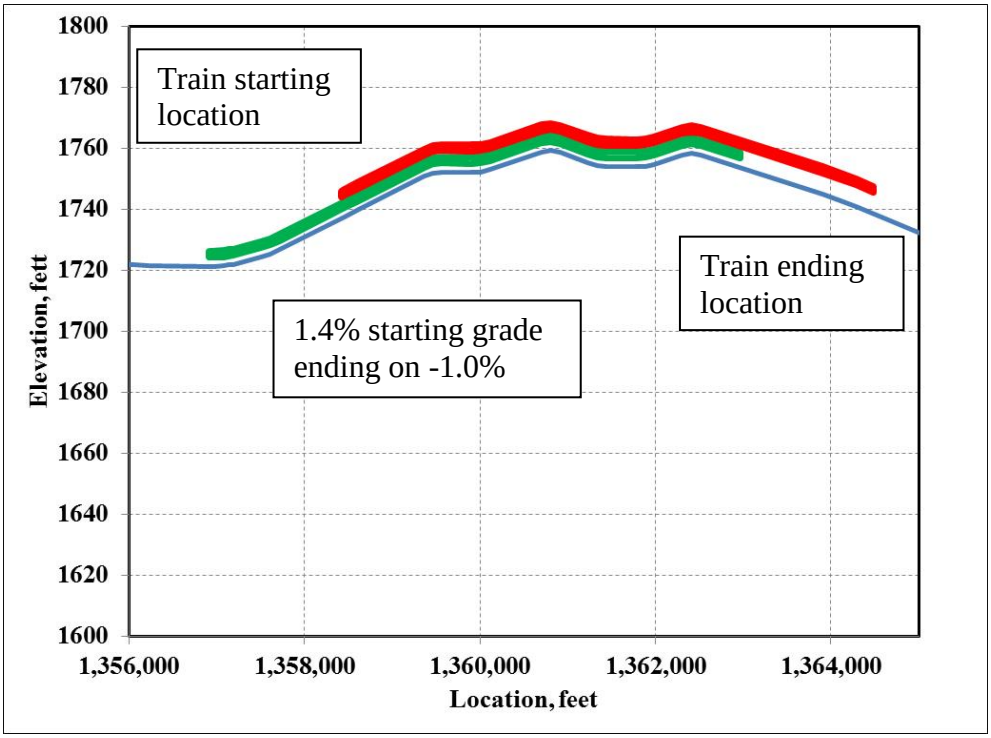


Figure 5.2-1. Full service application track profile.

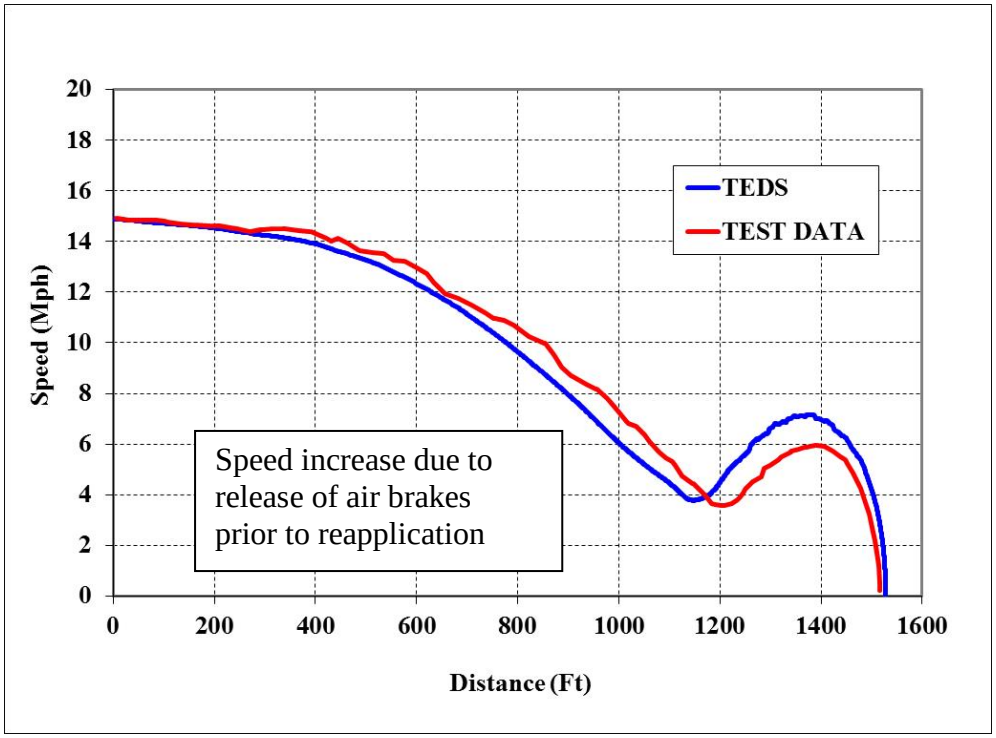


Figure 5.2-2. TEDS predicted speed compared to measured test data.

6. Conclusions

Validation criteria were developed and used to compare predictions made by TEDS at the component and system level with publicly available published laboratory and field data.

The air brake model predictions for the conventional automatic brakes as well the ECP brakes followed all of the test rack and test train trends well and matched the magnitudes well. The draft gear model predictions matched the impact data well, as well as the limited test train measured data available. TEDS predicted train speeds and stopping distance well. The model predicted a very good match of recorded train speed for relatively long distances.

Overall, the validation demonstrated that TEDS is a high fidelity model that realistically predicts longitudinal train behavior under a variety of operating conditions, including acceleration, braking, steady state running, operating over hilly terrain, and certain emergency conditions. Further, the effort demonstrated that TEDS' predictions are realistic for both gross train dynamics, measured by parameters such as position, velocity, and stopping distance, as well as, for inter-car dynamics, measured by parameters such as coupler forces.

7. References

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Abbreviations and Acronyms

AAR	American Association of Railroads
ASME	American Society of Mechanical Engineers
DP	Distributed Power
ECP	Electronically Controlled Pneumatic brakes
EOC	End-of-Car cushioning unit
FRA	Federal Railroad Administration
kips	kilo pounds
lbs	pounds
mph	miles per hour
NTSB	National Transportation Safety Board
TEDS	Train Energy and Dynamics Simulator
TOES	Train Operations and Energy Simulator