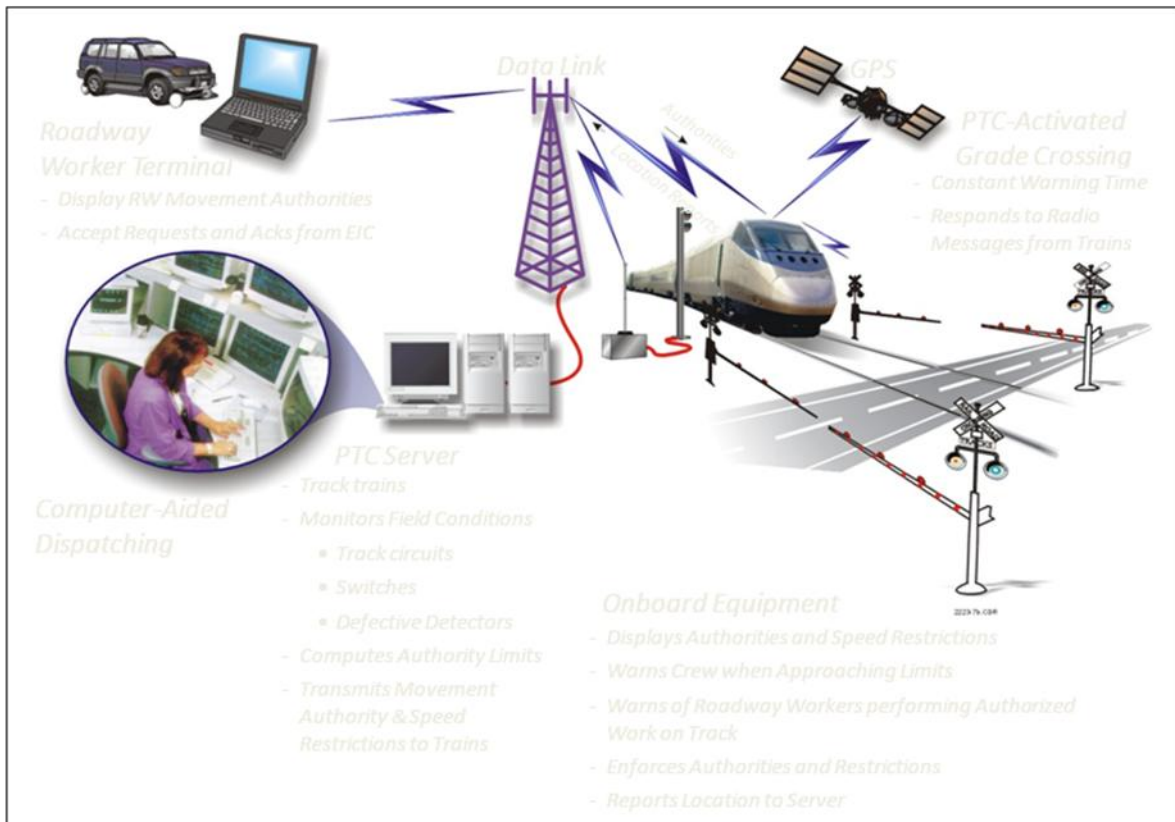U.S. Department of
Transportation

**Federal Railroad
Administration**

Passenger Train Braking Model Development – Phase I

Office of Railroad
Policy and Development
Washington, DC 20590

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 2011	3. REPORT TYPE AND DATES COVERED Technical Report

4. TITLE AND SUBTITLE Passenger Train Braking Model Development – Phase I	5. FUNDING NUMBERS DTFR 53-00-C-00012 Task Order 267
6. AUTHOR(S) Brian Smith, Joe Brosseau, and Jeremy Dasher	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Transportation Technology Center, Inc. P.O. Box 11130, 55500 DOT Road Pueblo, CO 81001	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Railroad Policy and Development Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD-11/21

11. SUPPLEMENTARY NOTES
Program Manager: Terry Tse

12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public online through the FRA Web site at http://www.fra.dot.gov.	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Transportation Technology Center, Inc., identified the requirements for developing a passenger train braking performance model, which herein results in submission of a stand-alone model requirements document, a summary of responses to an industry survey of passenger equipment and brake hardware, and suggestions to move forward with a passenger train braking performance model capable of evaluating positive train control braking enforcement algorithms.

14. SUBJECT TERMS Passenger train braking performance model, PTC braking enforcement algorithms, positive train control	15. NUMBER OF PAGES 58
	16. PRICE CODE

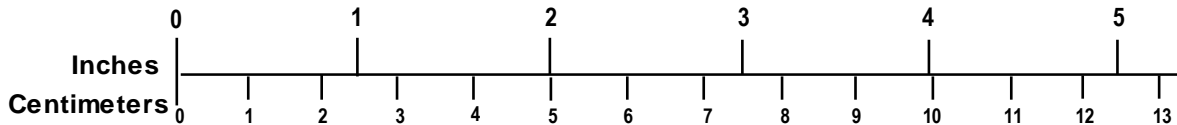| 17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

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)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
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)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
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)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
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)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

	0	1	2	3	4	5
Inches						

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Centimeters														

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
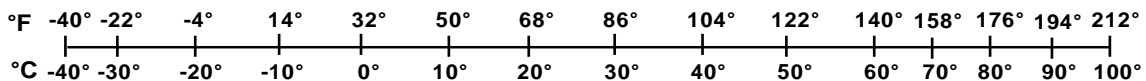
For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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Executive Summary

The Federal Railroad Administration (FRA) contracted with the Transportation Technology Center, Inc. (TTCI), in Pueblo, CO, to conduct investigative work on a passenger train braking performance model intended for use in developing, analyzing, and testing positive train control (PTC) braking enforcement algorithms for passenger and commuter train operations.

The work has produced the following recommendations:

1. Develop a stand-alone passenger train braking performance model capable of modeling longitudinal passenger train response for use as an evaluation/development tool for passenger PTC applications.

2. Pursue a fluid dynamics model of the air brake system that can accurately model not only the air brake equipment but also the interface to variable load sensors and wheel slide control systems. (TTCI believes that the reduction in cost and time to develop a simplified model {compared with more rigorous modeling} would be more than offset by the time and cost associated with the measurements and testing required to acquire the empirical data inputs required. Although a rigorous model will be more complex and time-consuming to develop, it will be less complex and time-consuming to use.)

3. Develop the model to include the most common types of passenger equipment in operation today (albeit the data received to date is extremely limited), with the ability to add additional components in the future, as necessary.

The first phase of work, reported here, is focused on the following three specific efforts:

(1) Development of the requirements for the passenger air brake control valve and associated model components,

(2) A survey of the passenger and commuter agencies in the United States to determine what brake system hardware they use currently on their fleets, and

(3) Development of a plan for moving forward with development of the brake system model components and passenger brake model.

Given the urgency of implementing PTC within both mandated and self-imposed deadlines (2012 in California and 2015 elsewhere), TTCI was also tasked with evaluating whether an empirical model could be developed and ready to use in less time than the development of a more detailed, scientifically pure model.

An approach for developing and evaluating the performance characteristics of a PTC braking enforcement algorithm through the use of computer simulations, supplemented by limited field testing on track, has shown the potential to drastically reduce the development time and cost of these tasks for the freight sector. A similar approach is envisioned for use in the development and evaluation of PTC braking enforcement algorithms for passenger trains.

As was shown in related freight train system work, an adequately detailed model of the braking system is essential to ensure that the goals of PTC can be met and that required safety levels can be protected. Simulation software capable of modeling braking performance for passenger trains, including sufficient detail of the characteristics of the air brake systems and the effects of varying wheel-rail adhesion conditions, is not currently available.

Output from this effort includes a requirements specification document for the design of a passenger train braking performance model, shown as Appendix A. One conclusion of the project, resulting in a related plan as to how to move forward, was that a stand-alone model would be the best and likely earliest available tool for industry use. Therefore, the requirements specification not only covers the requirements for passenger air brake system components (as originally envisioned) but also includes the requirements for the entire stand-alone model.

An industry survey was generated and sent to 28 passenger and commuter agencies. Appendix B contains a summary of the four returned responses. Enough survey data was returned to suggest that moving forward with a stand-alone model, incorporating the following features (which constitute the key differences between passenger and freight air brake systems), would provide a suitable initial model for the intended application:

- A two-pipe (brake pipe and main reservoir pipe) brake system
- An air brake control valve set up for both pneumatic and electronic overlay control
- Capability for blended braking
- Variable loads valves
- Wheel slide control hardware

1.   Introduction

The Rail Safety Improvement Act (RSIA) of 2008 mandates a deadline of 2015 for PTC systems to be operational on all lines over which passenger trains or freight trains carrying toxic inhalation hazard hazmat goods operate. As reported here, this effort is being undertaken to facilitate development of tools and technology applicable to passenger and commuter PTC implementation efforts. A key component for the successful implementation of PTC technology is a safe and operationally efficient predictive braking enforcement algorithm.

To date, most PTC braking enforcement algorithm research efforts have focused on freight train operations. Because of the differences in hardware and operational characteristics between passenger and freight equipment, there is a need for a passenger-specific braking performance model to facilitate this type of research with a focus on passenger train operations.

The results of this program and the documents generated by this effort will assist in developing and evaluating PTC predictive braking enforcement algorithm logic for passenger trains.

1.1   Background

PTC is an emerging train control technology proposed to enhance the safety of train movements. A mandate for the inclusion of PTC within the North American rail infrastructure has been made by the Department of Transportation, FRA, under RSIA of 2008, for passenger, freight, and mixed-train operations. Safety may be improved by installing onboard systems that can predict the stopping distance of trains accurately and that, as a last resort, can apply the brakes automatically to stop the train safely if the engineer fails to act. As a related benefit, the technology might also yield improved train performance and throughput capacity when future generation systems are fully developed. Currently, however, typical predictive braking enforcement algorithms force trains to initiate braking to an upcoming stop or to lower speed limit "target" considerably sooner than normal train-handling practices, which increases operating time for trains and reduces line capacity.

Therefore, a braking enforcement algorithm capable of protecting targets without interfering with railroad operations is critical to PTC. Much like the need to develop a comprehensive braking enforcement algorithm in PTC systems designed for freight train operations, the need for a comprehensive braking enforcement algorithm exists in the passenger rail industry as well.

Computer simulations, supplemented by limited field testing on track, were used to develop and evaluate the performance characteristics of an enforcement algorithm. These simulations revealed the potential to drastically reduce the development time and cost of PTC efforts related to freight equipment. The simulations also allow for a greater variety of enforcement scenarios to be tested. A similar approach is envisioned for use in the development and evaluation of enforcement algorithms for passenger trains.

An essential component of the methodology used for the development and evaluation of enforcement algorithm logic for freight trains is a braking performance simulator that incorporates an adequately detailed model of the braking system to ensure that the proper safety levels and goals of PTC can be met.

Many years of research and development were undertaken to fully understand the freight control valve inner- and interworkings, as well as various arrangements of the air brake system, which allowed development of comprehensive models that simulate the fluid dynamics of air flow within and among the various components. This work culminated in the development of a train dynamics and energy simulation model with model components that can be expanded to a large population of freight equipment. The result of this is an industry-accepted model that has been used and validated numerous times.

Simulation software capable of modeling braking performance for passenger trains, including sufficient detail of the characteristics of the air brake systems and the effects of varying wheel-rail adhesion conditions, is not currently available. Rather, empirical models (based on small samples of specific equipment or air brake laboratory testing) have typically been developed for passenger equipment. Commonly, only a limited amount of model validation has been done on these models and only on specific rail equipment. From a PTC perspective, these types of models tend to result in overly conservative stopping estimates and cannot be modified easily for additional configurations. Many times these models have been developed for operating crew-training purposes in which the level of detail and accuracy of the model is limited, and the model is not intended for engineering design and test purposes.

Use of existing freight braking performance models for passenger applications is not sufficient, except in specific cases in which passenger equipment is run with a single-pipe, freight-like configuration. For these types of simulations, accepted industry models can be used. With passenger equipment, however, several factors need to be properly accounted for that existing freight models and, for that matter, many current passenger models do not consider fully.

There are numerous differences between the brake systems of freight and most modern passenger equipment. To begin, freight equipment typically uses a single air line system for both control and supply, whereas typical modern passenger equipment uses two separate air lines for the brake system. One line is used for control (brake pipe), whereas the other used for air supply (main reservoir pipe). In simple terms, this allows the operator to have controlled or graduated release of the brakes on passenger equipment, which is not available on freight equipment, other than on electronically controlled pneumatic applications.

In addition, it limits the opportunity for the operator to inadvertently run short of air within the train. In many cases, passenger equipment can also be used with single-line freight systems, but performance and capability return to that of a freight train braking system. The two-line system capability does, however, lead to significant differences within the control valve between freight (generally AB-type) and passenger (generally 26C or KE) equipment.

In addition to the differences in the operation of the control valves, other differences between freight and passenger braking systems include:

- the ability for automatic blended braking of dynamic brakes and air brakes,
- combination disc and tread brakes,
- variable (proportional) load sensors, and
- wheel slip control systems to help optimize braking performance during low and variable adhesion conditions.

These details need to be accounted for properly to make the simulations as accurate as possible. Therefore, a multiphased program was necessary to develop a train braking performance model for passenger trains with more detail for those components that have a significant effect on passenger train stopping distance. This model can then be used to develop and test PTC enforcement algorithm logic for passenger trains.

1.2   Objectives

This multiphased project is being performed to develop a train braking performance model for passenger trains with sufficient detail for use in PTC enforcement algorithm development and testing.

Phase I work identifies the requirements and level of detail (determine specific items that need to be included) required for each of the model components to satisfy the overall model requirements for PTC enforcement algorithm development and testing for passenger trains.

1.3   General Approach

The original project plan contained four phases:

> Phase I: Identification of the requirements for components that need to be included in the train braking performance model for passenger trains.
>
> Phase II: Development of the primary passenger-specific model components.
>
> Phase III: Development of a train braking performance model for passenger trains that incorporates the components developed in Phase II.
>
> Phase IV: Validation of the model developed in Phase III.

With the findings from Phase I (specifically the recommendation to move forward with a standalone model), Phases II and III will likely be combined into a single phase.

The effort described here is limited in scope to Phase I work tasks only. The approach for Phase I (identification of the requirements) was broken into three primary tasks:

1. Survey the passenger and commuter rail industry to verify the most commonly used types of brake systems and hardware.

2. Identify the brake system model components and level of detail required, based on the application requirements and the results of the industry survey.

3. Develop an approach for the next phase of work.

1.4   Scope

Phase I focused on the development of a passenger air brake model requirements. This includes developing the requirements document for a passenger-focused air brake model, based on existing hardware, as well as identification of potential future follow-on efforts.

1.5   Organization of the Report

This report is organized into major sections describing the proposed capabilities of the model and a summary of the work components identified during Phase I.

Section 2 outlines the intended application of the model, along with some of the resulting capabilities, flexibility, and limitations within the requirements. Section 3 details the specific output of the work tasks identified, and Subsection 3.3 contains recommendations for future work efforts.

With the main output from the work effort being the development and presentation of the requirements document, the requirements document is included as Appendix A.

Since a survey of the industry hardware was required to help define the final form and details to be included in the model, Appendix B contains a summary of the survey responses received. It has been mentioned previously that the response to the survey was very limited.

2.   Proposed Model Capabilities

The passenger train braking performance model will have the capability to evaluate PTC predictive enforcement algorithm logic for a number of different passenger and commuter train operations. As such, the ability to input (or modify) the performance of a wide variety of equipment has been included.

This section covers a brief description of where the passenger braking performance model will be applicable and what types of equipment and operations it will be designed to consider. All capabilities described in this section are covered in the requirements document included as one of the final output products from this effort in Appendix A.

The passenger train braking performance model will be used to evaluate the performance of PTC predictive enforcement algorithms for passenger (including commuter) trains. TTCI recommends that the results of the simulations be supplemented with some amount of limited field testing to provide a more complete evaluation. In addition, field testing can be used to help evaluate minor modifications to stop distance algorithms, removing the need to evaluate every possible algorithm change on moving hardware.

The model requirements were designed to consider all currently understood types of passenger/commuter rail consists. These include:

- Push/pull service with a locomotive, passenger coach(es), and cab car

- Passenger trains pulled by lead locomotive(s) and consist with a variety of passenger coaches

- Diesel multiple unit (DMU), electric multiple unit (EMU), and possible combinations with coaches.

No specific speed limitations are included in the model requirements; however, there may be practical limitations for the accuracy of the stop distance estimates for operations above 90 mph, based on the simple estimates required for aerodynamic resistances (covered in the extensibility section of the requirements document). The model will include a two-pipe passenger style air brake system (brake pipe and main reservoir pipe). It will include the ability to control the brakes with either the pneumatic control or through an electronic overlay system (for vehicles so equipped). The main reservoir line will be considered fully charged at all times with a user-selectable constant pressure.

The maximum number of vehicles capable of being modeled will be limited to 25, which should encompass the longest passenger train consists operating in North America.

Proper representation of variable load devices and their impact on brake shoe force will be included. In addition, model components such as wheel slide system capabilities will be included. Depending on the friction between the wheel and rail, increased stop distances due to wheel slide can be modeled.

Friction along the track can be input into the model and will be user-selectable. Variations in friction as a result of passing axles may be considered through user input as well.

3.   Summary of Work Components

Phase I consisted of three major work components:

(1) Development of the requirements for the brake system components of the passenger train braking performance model.

(2) Distribution of an industry survey to gather information on the type of brake system hardware in use today.

(3) Development of a work plan from Phase I results to develop an appropriate model.

To fully consider the options available to get a usable model in place as soon as possible and to limit the development costs, TTCI engineers investigated two paths for developing the full passenger brake model.

The first path was to consider developing the necessary passenger air brake components that could be integrated into existing industry models. The second path was to consider developing a stand-alone model capable of being expanded for the variety of passenger brake systems only.

To reach a decision, TTCI engineers considered many factors, including the need to design a two-pipe air brake system, the ability to offer an electronic overlay control capability, the basic differences in the brake valves used for passenger equipment, and related differences in items such as blended braking and wheel slide control capability, which were not part of other accepted industry models.

After considering the complications of each path, TTCI engineers decided to recommend development of a stand-alone model. As such, all efforts mentioned moving forward will focus on the development of a standalone model.

3.1   Requirements Document

Most of the effort in this program was spent on developing the requirements for the brake system components of the model. To properly identify the requirements for the brake system components, and once the decision to move forward with a stand-alone model was reached, it was necessary and practical to specify requirements for the entire stand-alone model, beyond those of just the brake system components. This included requirements for other items that will contribute longitudinal force components within the model such as tractive effort, rolling resistance, aerodynamic resistance, coupler and draft gear interaction, and forces as a result of track grades.

Therefore, the requirements document is more encompassing than originally planned, and it is written to encompass all components that would be required to offer the model as a stand-alone tool to industry. The requirements document makes reference to the types of accuracies that model components should include. The requirements document is included in this report as a stand-alone component and is included as Appendix A.

3.1.1 Consideration of Model Complexity

Through the process of developing the requirements for the passenger train braking performance model components, an additional related effort was conducted to determine the level of complexity of the air brake system model components required to allow the final product to meet the overall goals of PTC enforcement algorithm development and testing.

In this case, complexity is defined as the level to which the air brake system model components are considered from a mathematical or, more appropriately in this case, a fluid dynamics perspective. In simple terms, this amounts to a determination of whether a mathematical representation of the relevant fluid dynamics properties of the air brake system is necessary or if a simple relationship between brake system inputs and outputs can be used, considering the implication on timing and costs required for model development and the related implications to the end-user. It should be noted that models currently used for freight braking enforcement algorithm development and testing are of the more rigorous fluid dynamics type.

The two choices are:

1. Develop a simplified or empirical model (one where a high level of component performance identification is required as user input) where simple interaction to the rest of the model is considered.

2. Develop a rigorous model (one where a more in-depth definition of component performance is included in the model) where a precise technical interaction to the rest of the model is included.

Investigating further into the goals of the passenger train braking performance model and understanding model end-user needs are critical to help define which path should be followed. In addition, recognizing the capability and flexibility needs of the model is essential, the model must be adjustable so that it can accurately represent braking performance for any variety of passenger equipment (push/pull, locomotive–coach service, EMU/DMU).

Table 1 gives a general description of the model development opportunities and the benefit or detriment of each.

Even with the potential for higher initial development cost and somewhat longer development time associated with development of a more rigorous version of the model, Table 1 shows that the economic and time impact to the end goal of developing and testing PTC braking enforcement algorithms would likely cancel any gains found by moving forward with a simplified model. In addition, users face these cost and time constraints each time the simplified model approach is applied to gather the information required. As such, the selection of the more rigorous (fluid dynamics) model was seen as the best choice to move forward.

Table 1. Decision Topics for Selection of Model Complexity

Model Type	Benefit	Detriment
Simplified Model	Quick model deployment Lower model development cost	Fewer user selections available within model Increased user field test cost to measure inputs for model (for every type of equipment in the model) Increased time for end-user to be able to utilize model Limited ability to consider variations in inputs such as wheel slide/variable load components Expansion capability if equipment does not fit typical input parameter entry Complex path to model validation if consist makeup changes
Rigorous Model	Increased user selections available within the model Short time for user to implement model Increased flexibility for user to modify included components Included component will be validated Shorter time to model validation Simpler path to validation if consist changes	Longer model development Higher model development cost

3.2 Industry Survey of Passenger Braking Equipment

TTCI prepared an industry survey and distributed it to 28 separate passenger and commuter entities whose operation will fall under the RSIA 2008 mandate. Of the 28 entities, 4 have responded with technical information about the hardware and braking equipment that is used on their particular road at the conclusion of Phase I.

The data gathered includes general information about powered (locomotive, EMU, DMU) equipment, as well as numbers and types of passenger coach/car equipment. It describes the types of brake valves used on each type of equipment and specifies if the vehicles are equipped with variable load measuring equipment (used to adjust the brakes based on the load of each

vehicle), as well as to determine whether wheel slide control equipment is in place (used to optimize the braking of each truck if low adhesion causes the wheels to lock up during braking).

The types of brake hardware and additional components will have an impact on the stopping distance for various vehicle types. As such, these items need to be accounted for properly in the model to make it as accurate as possible.

In addition, the type of draft gear on each vehicle was included as a requested feedback component in the survey. Draft gear was included for consideration of longitudinal accelerations and the potential relationship to wheel slide. Many of the draft gear and coupler components used in passenger equipment result in little to no slack motion between passenger vehicles. However, with wheel slide control expected to be a critical component of this model, consideration of longitudinal forces amplified or diluted because of draft gear characteristics can be accounted for as necessary.

Appendix B contains the industry survey description and summary.

3.3   Recommendations for Future Work

This work has produced the following recommendations:

1. Develop a stand-alone passenger train braking performance model capable of modeling longitudinal passenger train response for use as an evaluation/development tool for passenger PTC applications.

2. Pursue a fluid dynamics model of the air brake system that will have the ability to accurately model not only the air brake equipment but also the interface to variable load sensors and wheel slide control systems. (TTCI believes that the reduction in cost and time to develop a simplified model {compared to more rigorous modeling} would be more than offset by the time and cost associated with the measurements and testing required to acquire the empirical data inputs required. Although a rigorous model will be more complex and time-consuming to develop, it will be less complex and time-consuming to use.)

3. Develop the model to include the most common types of passenger equipment in operation today (albeit the data received to date is extremely limited), with the ability to add additional components in the future, as necessary.

Subsequently, TTCI has been awarded another contract from FRA to proceed on the work above.

Appendix A. Passenger Air Brake Model Requirements Document

1.   BACKGROUND AND SCOPE

The purpose of this document is to specify requirements for computer simulation software that models the longitudinal motion of passenger trains in response to train handling commands, the characteristics of the vehicles within the train, and the characteristics of the track over which it is operating. The intent is that the computer simulation software specified by this document will be used to support development and testing of brake enforcement algorithm logic for PTC systems for passenger trains, among numerous other potential applications.

An overview of the specified simulation software and its use in the intended application is provided, along with the detailed requirements for the software. Each of the requirements sections of this document generally contains two parts: narrative text and explicit requirements. The narrative text includes background information, goals, and other supplemental information provided to clarify the requirements. The explicit requirements, each containing the word "shall," follow in a numbered or lettered list beneath the narrative text. Goals are explicitly identified as such and use the word "will" rather than "shall."

2.   APPLICABLE DOCUMENTS

None.

3. SYSTEM OVERVIEW

The passenger train braking performance model specified by this document will simulate passenger train motion in the longitudinal direction (along the track). The model will be capable of simulating a wide variety of passenger equipment, track characteristics, environmental conditions, and train operating commands. Where possible, these will be user definable/ selectable, such that the user can model the majority of passenger train operating conditions. In cases where user definable/selectable equipment is not possible and/or practical, the model will include the most common type(s) of equipment and be designed to allow for additional equipment to be added to the model in the future, if desired.

The model is intended to support a variety of applications; however, the initial expected application is as a component in the verification process of PTC braking enforcement algorithm logic. PTC is an emerging train control technology proposed to enhance the safety of train movements, including that achieved by predicting the stopping distance of the train and automatically applying brakes to stop the train safely when necessary. A braking enforcement algorithm capable of stopping trains short of stop signals and other equipment without interfering with railroad operations is critical to the successful implementation of PTC.

An approach to developing and evaluating the performance characteristics of PTC braking enforcement algorithm logic through the use of computer simulations, supplemented by limited field testing on track, has shown the potential to drastically reduce the time and cost of these tasks for freight trains. It also facilitates a greater variety of enforcement scenarios to be tested. A similar approach is suggested for use in the development and evaluation of enforcement algorithms for passenger trains.

The computer simulation component of this approach involves quantifying the variability in passenger train stopping locations, relative to a given target, following penalty enforcement by the PTC braking enforcement algorithm logic for a variety of operating scenarios. This is achieved by running batches of simulations, interfacing with the PTC braking enforcement algorithm logic, where parameters that affect passenger train stopping distance are varied within each simulation, using a Monte Carlo approach.

To support this application, the model will be capable of being run either by a user or through an external piece of software. Each simulation will have a defined consist, made up of predefined vehicles, operating over a defined track section. The user or external controlling software will provide these as inputs to the model, along with initialization commands. The simulation will then be executed through operating commands provided by the user or external controlling software.

4.   FUNCTIONAL REQUIREMENTS

The primary objective of the passenger train braking performance model is to simulate the longitudinal motion (position, velocity, acceleration) of a passenger train by modeling the response of each of the vehicles in the train consist to the forces acting on it.

a) The longitudinal position of each vehicle in the specified train consist, in relation to a specified track section, shall be updated at each time step in response to the longitudinal velocity of the vehicle.

b) The longitudinal velocity of each vehicle in the specified train consist shall be updated at each time step in response to the longitudinal acceleration of the vehicle.

c) The longitudinal acceleration of each vehicle in the specified train consist shall be updated at each time step in response to the longitudinal forces acting on each vehicle.

The longitudinal forces acting on each vehicle include the following:

- Tractive forces for powered vehicles
- Forces from the brake system
    - Dynamic brake forces for powered vehicles
    - Forces due to friction braking (disc or wheel tread)
- Coupler forces from adjacent vehicles
- Resistive forces due to aerodynamics, bearing friction, rolling resistance, curving resistance, and wheel set rotational inertia
- Gravitational forces due to the track grade

The model will determine these forces by modeling the response of a number of individual train and vehicle components to inputs specified by the user and to other internal model components. The subsections that follow specify the requirements for these user inputs and internal model components as well as the required outputs of the model.

4.1   User Inputs

For a given simulation, the passenger train braking performance model will allow the user to input/specify the passenger train consist makeup, characteristics of each of the vehicles in the consist, track profile characteristics, environmental conditions, and train operating commands. In some cases, these inputs will be static throughout the simulation, whereas in others, the user will be able to change or modify these at any time during the simulation. The required inputs are specified in the following subsections.

4.1.1   Vehicle Inputs

A vehicle will be defined by characteristics specified by the user. The model will allow the user to define and save vehicles, such that they can be used in multiple consists and simulations. For a given simulation, the characteristics that define a vehicle will remain constant.

a) The passenger train braking performance model shall allow the user to define and save any number of vehicles.

b) Each vehicle defined by the user shall be given a unique identifier, specified by the user.

c) The model shall allow the user to edit any previously defined vehicle and save it as a new vehicle.

Vehicles in the passenger train braking performance model will be classified by whether they are powered or nonpowered. Powered vehicles can produce tractive effort, may be capable of dynamic braking and may be equipped with independent braking capability (e.g., locomotive/EMU/DMU equipment). The specific characteristics that must be defined by the user will vary depending on whether the vehicle is a powered or nonpowered vehicle.

d) Each vehicle shall be classified by the user as a powered or nonpowered vehicle.

Section 4.1.1.1 specifies the required user inputs for all vehicles. Section 4.1.1.2 specifies the additional required user inputs for vehicles classified as powered vehicles.

4.1.1.1 Inputs for All Vehicles

This section specifies the requirements for user inputs for any vehicle defined in the model. This section is broken up into functional components of the vehicle, including general inputs, brake system inputs, resistance inputs, and coupler/draft gear inputs.

4.1.1.1.1 General Inputs for All Vehicles

The light weight (tare weight) of each vehicle will be specified by the user when the vehicle is defined. Load conditions for each vehicle will be specified by the user when the vehicles are assembled into a consist (see Section 4.1.2).

a) The light weight (tare weight) of each vehicle shall be defined by the user.

b) The length of each vehicle, measured between the pulling faces of the nonloaded (centered) couplers, shall be defined by the user.

c) The number of trucks shall be defined by the user for each vehicle.

d) The location of each truck in relation to the car body shall be specified by the user for each vehicle.

e) The number of axles on each truck shall be defined by the user for each vehicle.

f) The axle spacing on each truck shall be defined by the user for each vehicle.

4.1.1.1.2 Brake System Inputs for All Vehicles

The automatic brake valve is the valve that the operator uses to control pneumatic brake applications and releases. Typically, powered vehicles and cab cars will be equipped with an automatic brake valve.

a) For each vehicle, the user shall specify if the vehicle is equipped with an automatic brake valve.

b) The user shall specify the length of a 1.25-inch brake pipe between the automatic brake valve and the gladhand on each end of each vehicle equipped with an automatic brake valve.

The control valve is the valve on each vehicle that controls brake cylinder pressure in response to changes in brake pipe pressure. The model will initially include two types of control valves: the 26-C and the 26-F. The 26-F is typically used on locomotive equipment, because it includes a

quick release portion that interfaces the actuation pipe. The 26-C is typically used on passenger equipment. Additional control valves are addressed in Section 7.0 Extensibility Requirements.

c) The user shall specify the type of each air brake control valve for each vehicle.

d) The user shall specify the length of a 1.25-inch brake pipe between each air brake control valve and the gladhand on each end of each vehicle.

The user will be able to adjust the default values of parameters that specify control valve characteristics. This allows simulating control valves with a range of performance characteristics and associated components in various system configurations. These parameters represent physical characteristics normally accessible to the mechanical department but not to the train crew.

e) The model shall allow the user to modify the default size of the control valve choke that controls brake cylinder application rate for each control valve on each vehicle.

f) The model shall allow the user to modify the default service valve diaphragm area ratio for each control valve on each vehicle.

g) The model shall allow the user to modify the default brake cylinder pressure limiting valve setting for each control valve on each vehicle.

h) The model shall allow the user to modify the default emergency limiting valve setting for each control valve on each vehicle.

A number of external reservoirs are used in conjunction with the control valve on the vehicle to realize the pneumatic logic. The user will be able to adjust the default sizes of these external volumes.

i) The model shall allow the user to modify the default volume of the control reservoir for each control valve on each vehicle.

j) The model shall allow the user to modify the default volume of the selector reservoir for each control valve on each vehicle.

k) The model shall allow the user to modify the default volume of the displacement reservoir for each control valve on each vehicle.

l) The model shall allow the user to modify the default volume of the supply (auxiliary) reservoir for each vehicle.

B-1 auxiliary vent valves are typically used on longer vehicles to assist in the propagation of the pneumatic brake signal throughout the train for service brake applications.

m) The user shall specify each B-1 auxiliary vent valve for each vehicle.

n) The user shall specify the length of a 1.25-inch brake pipe between each B-1 auxiliary vent valve and the gladhand on each end of each vehicle.

Emergency vent valves are typically used on longer vehicles to assist in the propagation of the pneumatic brake signal throughout the train for emergency brake applications.

o) The user shall specify each emergency vent valve for each vehicle.

p) The user shall specify the length of a 1.25-inch brake pipe between each emergency vent valve and the gladhand on each end of each vehicle.

Variable load devices are used to adjust the braking force on the vehicle proportionally according to the weight of the vehicle to achieve a uniform brake rate.

q) The user shall specify if each vehicle is equipped with a variable load device.

r) The user shall specify the minimum and maximum brake cylinder pressures for the variable load device characteristic for each equipped vehicle.

s) The user shall specify the minimum and maximum vehicle weight for the variable load device characteristic for each equipped vehicle.

Wheel slide control systems are used to improve the braking performance of the vehicle by adjusting the brake cylinder pressure on sliding axles to reestablish rolling. The wheel slide control system model will model the response of a generic wheel slide control system based on characteristics supplied by the user.

t) The user shall specify if each vehicle is equipped with a wheel slide control system.

u) The user shall specify wheel slide detection characteristics of the wheel slide control system for each equipped vehicle.

v) The user shall specify the brake cylinder pressure dump characteristics of the wheel slide control system for each equipped vehicle.

w) The user shall specify the rate of brake cylinder pressure decrease during a brake cylinder pressure dump condition for each equipped vehicle.

x) The user shall specify the brake cylinder pressure buildup characteristics of the wheel slide control system for each equipped vehicle.

y) The user shall specify the rate of brake cylinder pressure increase during a brake cylinder pressure buildup condition for each equipped vehicle.

Brake units are composed of a brake cylinder, brake rigging, and brake shoe/pad in a single unit. There are two types of brake units: tread brake units (TBUs) that apply brake shoe force against the wheel tread and disc brake units (DBUs) that apply brake pad force against a brake disc.

z) The user shall specify the number of TBUs per axle for each vehicle.

aa) The user shall specify the number of DBUs per axle for each vehicle.

bb) The user shall specify the volume of the brake cylinder, including the piping from the relay valve to the brake cylinder, on each TBU and each DBU on each vehicle.

cc) The user shall specify the piston stroke on each TBU and each DBU on each vehicle.

Brake force will be calculated for each brake unit (TBU/DBU) individually. The brake force characteristic will define the relationship between brake cylinder pressure and brake shoe/pad force for each brake unit (TBU/DBU). This characteristic will take into account brake rigging efficiency, lever ratios, etc.

dd) The user shall specify the brake force characteristic for each TBU and each DBU, individually, on each vehicle.

The contribution of each brake unit (TBU/DBU) toward the total retarding force on the vehicle generated by the friction brake system will be calculated based on the friction characteristic of the brake shoe/pad for each brake unit (TBU/DBU). The friction characteristic will define the

relationship between brake shoe/pad coefficient of friction and vehicle speed for each brake unit (TBU/DBU).

 ee) The user shall specify the friction characteristic of the brake shoe/brake pad on each TBU and each DBU, individually, on each vehicle.

4.1.1.1.3 Resistance Inputs for All Vehicles

The passenger train braking performance model will use a form of the Davis resistance equation to model resistance on the vehicle as a result of aerodynamic, bearing friction, and rolling resistance. The Davis equation models vehicle resistance as $Aw + Bn + Cvw + Dv^2$, where w is the vehicle weight in tons, n is the number of axles on the vehicle, v is the velocity of the vehicle in miles per hour, and A, B, C, and D are the Davis equation resistance coefficients. The user will specify these coefficients for each term in the Davis equation.

 a) The Davis equation resistance coefficients for each vehicle shall be defined by the user.

 b) The Davis equation aerodynamic resistance coefficient (velocity-squared term) shall be defined for both the A-end and the B-end of the vehicle.

The wheel diameter will be used by the model, along with the number of brake discs and traction motors, to determine wheel set rotational inertia.

 c) The wheel diameter shall be selected by the user from a discrete number of options for each axle on each vehicle.

The curving resistance characteristic of the vehicle will define the relationship between curving resistance and degree of curvature.

 d) The longitudinal curving resistance characteristic of each vehicle shall be defined by the user.

4.1.1.1.4 Coupler/Draft Gear Inputs for All Vehicles

Draft gear characteristics will be defined by force/displacement characteristic curves. This limits the draft gear modeling capability to friction draft gears, which is expected to be sufficient for modeling of passenger trains. Additional characteristics required to define more complex draft gears (e.g., hydraulic cushioning units) are addressed in Section 7.0 Extensibility Requirements. Default draft gear characteristics will be included in the model, but the model will allow the user to modify the default characteristics, if desired.

 a) The free slack of each coupler shall be defined by the user for each vehicle.

 b) The model shall include a default force/displacement characteristic curve for a simple draft gear.

 c) The model shall allow the user to define custom force/displacement characteristic curves for each draft gear on each vehicle.

4.1.1.2   Inputs for Powered Vehicles

The following are additional requirements that apply only to vehicles classified as powered vehicles.

 a) The user shall specify which axles are powered axles for each powered vehicle.

b) Tractive effort characteristic curves shall be defined by the user for each powered vehicle.

c) Tractive effort characteristic curves shall define the tractive force produced by the powered vehicle at each discrete throttle notch and speed.

Dynamic braking allows the operator to apply retarding force to each equipped vehicle using the resistance of the traction motors, with the excess energy dissipated as heat in a resistor grid.

d) The user shall specify whether each powered vehicle has dynamic brake capability or not.

e) Dynamic brake characteristic curves shall be defined by the user for each powered vehicle specified as having dynamic brake capability.

f) Dynamic brake characteristic curves shall define the retarding force produced by the vehicle at each discrete dynamic brake notch and speed.

Powered vehicles equipped with dynamic braking capability may contain a feature to limit the overall retarding force on the vehicle known as the dynamic brake interlock (DBI). The DBI pressurizes the actuation pipe when dynamic braking is active. This activates the quick release function of the 26-F control valve, which bails any automatic air brake application. Powered vehicles equipped with a DBI must be equipped with a 26-F control valve.

g) The user shall specify whether each powered vehicle equipped with dynamic braking capability and a 26-F control valve is equipped with a DBI feature.

Independent braking allows the operator to apply and release brakes on the powered vehicle independently from the other vehicles in the consist. Vehicles equipped with independent brake capability must be equipped with a 26-F control valve to allow bailing of the automatic brake on the powered vehicle. Vehicles equipped with independent brake capability must also be equipped with a J-type relay valve. The J-type relay valve evaluates the automatic and independent brake signals to determine the amount of brake cylinder pressure to apply. Initially, the model will include two types of J-type relay valves: the J1 and the J1.6-16. Additional J-type relay valves are addressed in Section 7.0 Extensibility Requirements.

h) The user shall specify whether each powered vehicle equipped with a 26-F control valve has independent brake capability or not.

i) The user shall select which J-type relay valve to use on each powered vehicle equipped with independent brake capability from a discrete list of modeled J-type relay valves.

Powered vehicles equipped with both dynamic brakes and independent brakes may contain a feature to limit the total retarding force on the vehicle known as the independent pressure switch (IPS). The IPS limits dynamic braking effort when the independent brake pressure exceeds a preset value.

j) The user shall specify whether each powered vehicle equipped with both dynamic brakes and independent brakes capability is equipped with an IPS feature.

k) The user shall specify the pressure setting for the IPS on each equipped powered vehicle.

Powered vehicles equipped with dynamic brakes may also be equipped with automatic blended braking. Automatic blended braking automatically applies a combination of dynamic and friction brakes to achieve the braking demand specified by the pressure in the brake cylinder application pipe. Typically, a minimum amount of brake cylinder pressure is first applied. The

appropriate dynamic brake is then applied to match the brake demand, supplemented as necessary with additional brake cylinder pressure.

l) The user shall specify whether each dynamic brake-equipped powered vehicle is equipped with automatic blended braking.

m) The user shall specify the minimum brake cylinder pressure used by the automatic blended braking system on each equipped powered vehicle.

4.1.2   Consist Inputs

The passenger train braking performance model will allow the user to define and save any number of passenger train consists, made up of combinations of previously defined vehicles. For any given simulation, the consist parameters will remain constant.

a) The passenger train braking performance model shall allow the user to define and save any number of consists.

b) Each consist defined by the user shall be given a unique identifier, specified by the user.

c) The model shall allow the user to edit any previously defined consist and save it as a new consist.

d) The user shall specify which previously defined vehicles are included in each consist and their position in the consist.

e) The model shall limit the number of vehicles in a consist to 25.

f) The user shall specify the orientation of each vehicle in each consist.

g) The user shall specify the load on each vehicle for each consist.

h) The user shall specify whether each consist is equipped with an electronic overlay brake system.

4.1.3   Track Profile Inputs

The passenger train braking performance model will run simulations on user-defined track sections. Each track section will define a discrete section of track over which a simulation can be run. For any given simulation, the characteristics of the track section will remain constant.

a) The passenger train braking performance model shall allow the user to define and save any number of track sections.

b) Each track section shall have a defined length, specified by the user.

c) For each track section, the user shall define the elevation and longitudinal track position at each grade change.

d) For each track section, the user shall define the degree of curvature and longitudinal track position at each change in curvature.

e) For each track section, the user shall define the length of the entry and exit spirals for each change in curvature.

f) The user shall have the option to add reference labels at any location along each track section.

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4.1.4 Environmental Condition Inputs

Environmental conditions will be specified by the user during the initialization of each simulation.

a) The user shall define the ambient air temperature for each simulation.

b) The user shall define the ambient air pressure for each simulation.

Coefficient of friction between the wheel and rail will be user definable in a number of ways. First, the user will define the base wheel/rail coefficient of friction characteristic along the length of the track section. Second, the user can define a change in wheel/rail coefficient of friction due to axles passing over the track contamination (e.g., step function, linear change, etc.). The user will specify a change from the base wheel/rail coefficient of friction (either an absolute change or a percent change) for each axle in the consist. Finally, the user can define a threshold above which the previously defined change in wheel/rail coefficient of friction will not apply.

c) The user shall define the wheel/rail coefficient of friction and longitudinal track position at each change in wheel/rail coefficient of friction gradient.

d) The user shall specify the characteristic change of the wheel/rail coefficient of friction on a per axle basis.

e) The user shall specify a maximum wheel/rail coefficient of friction above which the characteristic change does not apply.

The effect of adhesion on the slide condition of each axle will be determined based on the adhesion demand compared against the available adhesion. The user will specify the difference required to initiate sliding and reestablish rolling.

f) The user shall specify the amount of adhesion deficit to initiate sliding on a rolling axle.

g) The user shall specify the amount of adhesion surplus to reestablish rolling on a sliding axle.

Sliding axles will be modeled by limiting the contribution to the vehicle retarding force from the sliding axle(s) to that achievable with a user supplied adjustment to the coefficient of friction between the rail and the wheel for sliding axles.

h) The user shall specify the adjustment to the coefficient of friction between rail and wheel for sliding wheels as a factor of the coefficient of friction for the rolling wheel.

4.1.5 Simulation Initialization Inputs

Simulation initialization inputs specify either constants throughout the simulation or conditions present at the start of the simulation.

The active control vehicle is the vehicle from which the train is operated. The active control vehicle must be equipped with an automatic brake valve. The automatic brake valve on the active control vehicle is set to the passenger position. Automatic brake valves on all other vehicles so equipped are set to the cut out position.

a) The user shall specify which vehicle in the consist is the active control vehicle.

b) The user shall define the position of the control valve branch pipe cut-out cock (cut in or cut out) for all control valves on each vehicle.

c) The user shall define the position of the brake cylinder cut-out cock (cut in or cut out) on each truck of each vehicle so equipped.

The model will assume that the main reservoir pipe is always charged (essentially an infinite source of air).

d) The user shall define the main reservoir pipe pressure for the consist.

e) The user shall define the maximum equalizing reservoir pressure for the active control vehicle in the consist.

f) The user shall define the delay time for producing dynamic brake effort after changing the power selector switch from power to dynamic braking.

g) The user shall define the delay time for producing tractive effort after changing the power selector switch from dynamic braking to power.

h) The user shall define the position of the isolation switch (run or isolate) in each powered vehicle in the consist.

i) The user shall define the position of the traction motor isolation switch (run or isolate) on each traction motor (powered axle) for each powered vehicle in the consist.

j) The user shall define the flow rate for train line (brake pipe) leakage.

k) The user shall define the initial location of the consist relative to the track section for each simulation.

l) The user shall specify the orientation of the consist to the track section for each simulation.

m) The user shall define the direction of travel for each simulation.

n) The user shall define the initial speed of the consist for each simulation.

4.1.6 Operating Command Inputs

Operating commands specify control settings typically available to the operator of the train.

a) The model shall allow the user to initiate a pneumatic emergency brake application on the active control vehicle.

b) The model shall allow the user to initiate an electronic overlay emergency brake application on the active control vehicle of a consist equipped with an electronic overlay system.

The model will allow the user to initiate an undesired emergency on any vehicle in the consist. This can be used, for instance, to simulate a burst air hose, train separation, or other equipment failure.

c) The model shall allow the user to initiate a pneumatic emergency brake application from any vehicle in the consist.

d) The model shall allow the user to specify any pneumatic service brake pipe pressure reduction initiated from the automatic brake valve of the active control vehicle.

e) The model shall allow the user to specify any electronic overlay service brake pipe pressure reduction initiated from the automatic brake valve of the active control vehicle of a consist equipped with an electronic overlay system.

f) The model shall allow the user to initiate any pneumatic brake release from the automatic brake valve of the active control vehicle.

g) The model shall allow the user to initiate any electronic overlay brake release from the automatic brake valve of the active control vehicle of a consist equipped with an electronic overlay system.

h) The model shall allow the user to specify the position of the throttle lever of the active control vehicle.

i) The model shall allow the user to specify the position of the dynamic brake lever of the active control vehicle, if equipped.

j) The model shall allow the user to specify any independent brake application initiated from the independent brake handle of the active control vehicle, if equipped.

k) The model shall allow the user to bail off any automatic brake application from the active control vehicle, if equipped.

l) The model shall allow the user to apply sand on any axle on any equipped vehicle.

4.2   Tractive Effort Model

The objective of the tractive effort model is to represent the force on the vehicle generated by the traction motors of a powered vehicle.

a) The tractive effort produced by each powered vehicle shall be modeled in response to the throttle setting commands on the active control vehicle based on the tractive effort characteristic for the vehicle.

b) The calculated tractive effort shall be adjusted based on adhesion conditions.

4.3   Brake System Model

The primary objective of the brake system model is to simulate the brake retarding force generated by each vehicle in the consist in response to electronic and pneumatic control settings. The brake system model will include a number of components that interact with one another to represent the entire brake system on a passenger train.

Two types of braking will contribute to the overall braking force: dynamic braking and friction braking. In some cases, these will be controlled independently, whereas in other cases, automated blended braking will determine the contribution of each from a single control setting.

c) The brake system model shall model the dynamic brake and pneumatic brake system control settings in response to a blended brake control setting from the active control vehicle based on the blended brake characteristic of the vehicle.

Total braking force for any vehicle is limited by the available adhesion. Should the total braking force (dynamic plus friction) for any axle exceed the available adhesion, the force will be adjusted to represent that of the sliding wheel(s).

d) The brake system model shall determine the slide condition of each axle on each vehicle based on the available adhesion, the adhesion demand, and the user-specified characteristics to initiate sliding and reestablish rolling.

e) The brake system shall adjust the retarding force on each vehicle based on the slide condition of each axle on the vehicle and the user-supplied coefficient of friction for sliding axles.

4.3.1   Dynamic Brake Model

The dynamic brake model will represent the functionality of the dynamic brake system on each powered vehicle in the consist. The dynamic brake model will include support for the DBI feature.

f) The dynamic brake force produced by each powered vehicle shall be modeled in response to dynamic brake setting commands on the active control vehicle, either from the blended braking algorithm or from the user, based on the dynamic brake characteristic of the vehicle.

g) The dynamic brake force calculation shall be adjusted based on the position of the IPS.

h) The dynamic brake model shall interface with the DBI model.

i) The DBI model shall simulate air flow into and out of the actuating pipe (from main reservoir when energized to the atmosphere when deenergized) in response to dynamic braking being active (DB Setup and active braking effort).

4.3.2   Friction Brake System Model

The friction brake system model will represent the functionality of the pneumatic brake system on each vehicle in the consist. In some cases, this will include the functionality of the electronic overlay system.

a) The friction brake system model shall simulate the retarding force on each vehicle in the consist resulting from the frictional force on the wheel tread from each TBU on the vehicle, based on the user specified friction characteristic of the brake shoe and wheel tread.

b) The friction brake system model shall model the retarding force on each vehicle in the consist resulting from the frictional force on the disc from each DBU on the vehicle, based on the user specified friction characteristic of the brake pad and disc.

c) The contribution to the vehicle retarding force shall be calculated individually for each brake unit (TBU/DBU) to account for potential differences in friction characteristics specified by the user.

d) The force generated by each brake unit (TBU/DBU) on each vehicle shall be modeled in response to the pressure in the brake cylinder component of the given brake unit (TBU/DBU), based on the user specified brake force characteristic of the brake unit (TBU/DBU).

e) The force generated by each brake unit (TBU/DBU) shall be calculated individually to account for potential differences in brake force characteristics specified by the user.

The brake cylinder pressure of each of the brake units (TBU/DBU) on each vehicle will be determined by modeling the response of a number of components in the pneumatic portion of the friction brake system.

4.3.2.1   Blended Braking Model

The blended braking system apportions the brake demand specified by the automatic brake valve between the dynamic brake and the friction brakes. A minimum amount of friction braking is applied, a dynamic brake is used to the extent that it is available for the prevailing conditions, and any remaining demand is supplied by the friction brake. The friction brake portion is continually adjusted by the blending system to obtain the desired level of brake retarding force on the vehicle. Hence, the braking rate (deceleration) is more nearly uniform over the stop as compared with straight friction braking in which a constant brake cylinder pressure can lead to increased brake retarding force as the speed decreases.

a) The blended braking model shall represent the blended braking characteristics of the vehicle.

b) The blended braking model shall simulate the distribution of dynamic braking effort and friction braking on the vehicle as a function of vehicle speed and the pressure in the brake cylinder application pipe output from the control valve model.

c) The blended braking model shall adjust the automatic pressure signal entering the J-type relay valve based on the distribution of dynamic braking and friction braking.

d) The blended braking model shall control the dynamic brake setting for the dynamic brake model based on the distribution of dynamic braking and friction braking.

Automatic blended braking is disabled when the operator manually applies dynamic braking.

e) The blended braking model shall account for the dynamic brake setting from the user.

4.3.2.2   Brake Pipe Model

The brake pipe is the means for transmitting the pneumatic brake signal throughout the train. The brake pipe model will assume that the angle cocks are closed on each end of the train and opened between each car on the train. The local brake pipe pressure at each control valve in the brake system drives the control valve logic. The local brake pipe pressure is affected by the flow of air through adjacent sections of the brake pipe. Air may flow into or out of the brake pipe from a variety of potential sources, including:

- Automatic brake valve on the active control vehicle
- Pneumatic air brake control valve(s) on each vehicle
- Electronic overlay magnet valve(s) on each vehicle
- Auxiliary venting devices on each vehicle
- Emergency vent valves on each vehicle
- Leakage in the brake pipe line

Requirements for modeling air flow into or out of the brake pipe because of each of these devices are discussed in the relevant sections below.

f) The brake pipe model shall determine the pressure distribution in the pipe at each time step.

g) Simulation of the local pressure and airflow velocity throughout the pipe shall be determined by iteratively solving the relevant fluid dynamic equations.

h) The spatial resolution of the pressure distribution solution shall be fine enough to capture the local brake pipe pressure for each modeled pneumatic device connected to the pipe.

i) The brake pipe model shall consider the ambient temperature effect on air density when simulating the flow of air and pressure distribution in the brake pipe.

j) The brake pipe model shall consider the effects of pipe wall friction on the airflow velocity and pressure gradient in the brake pipe.

k) The brake pipe model shall consider the effects of air flowing into or out of the pipe at various locations along the brake pipe.

l) The brake pipe model shall simulate air flow out of the brake pipe because of leakage in the brake pipe line, with the amount of leakage specified by the user.

4.3.2.3   Automatic Brake Valve Model

The automatic brake valve allows the engineer to control the train brakes by commanding service or emergency brake applications and releases. This valve directly controls the equalizing reservoir pressure, which, in turn, controls the brake pipe pressure by allowing air to escape from the pipe for an application or by feeding air into the pipe for a release. For this passenger braking model, the brake pipe cut-off valve will be assumed always in the "Passenger" position. This allows the equalizing reservoir (and hence the brake pipe) pressure to be increased in graduated steps, thereby allowing a graduated release of the brakes.

The automatic brake valve model will represent the functionality of this valve.

a) The automatic brake valve model shall simulate air flowing into and out of the equalizing reservoir on the active control vehicle (from the main reservoir to equalizing in release and from equalizing to the atmosphere in application) in response to the automatic brake valve handle setting command as specified by the user.

b) The automatic brake valve model shall simulate the air flow into or out of the brake pipe on the active control vehicle in response to the equalizing reservoir pressure (from main reservoir through relay valve to brake pipe in release or from brake pipe to the atmosphere through relay valve in application).

The main reservoir pressure will be modeled as an infinite source of air, with a fixed pressure, defined by the user.

c) The main reservoir pressure shall be modeled as a fixed value, as specified by the user.

d) The automatic brake valve model shall simulate the rapid venting of air from the brake pipe to the atmosphere through the vent valve at the active control vehicle in response to an emergency brake application command from the user.

e) The automatic brake valve model shall simulate the venting of air from the equalizing reservoir to the atmosphere through the emergency valve in response to an emergency brake application command from the user.

4.3.2.4 Independent Brake Valve Model

The independent brake valve allows the operator to apply brakes on the controlling vehicle independently from the automatic brake applied on all cars. The independent brake valve directs air from the main reservoir into the independent application and release pipe, which interfaces with the J-type relay valve model supplying the required independent brake system signal. The independent brake valve also allows the operator to bail off automatic brake applications on the controlling vehicle by directing main reservoir pressure to the actuating pipe, which interfaces the quick release portion of the 26-F control valve.

a) The independent brake valve model shall simulate air flow into and out of the independent application and release pipe (from main reservoir in application to the atmosphere in release) in response to the independent brake valve handle setting as specified by the user.

b) The independent brake valve model shall simulate air flow into and out of the actuating pipe (from main reservoir when in bail position to the atmosphere when in release position) in response to a bail command from the user.

c) The independent brake valve model shall model the activation of the IPS if the pressure in the independent application and release pipe exceeds the IPS activation pressure, specified by the user.

4.3.2.5 26-F Control Valve Model

The 26-F control valve model will represent the functionality of a 26-F control valve and associated components in the brake system of a powered vehicle. The primary requirement is to simulate the control of the pressure buildup and release in the brake cylinder application pipe (signal for the brake cylinder pressure) in response to changes in the local brake pipe pressure.

a) The 26-F control valve functionality shall be modeled using a physical representation of the actual pneumatic logic, including the action of the various internal valve components controlling the flow of air between reservoirs and internal volumes.

b) The pressure in each reservoir and volume shall be updated based on the modeled flow rate and the resulting pressures used to influence the internal valve component states.

c) The calculation time step used for fluid dynamics/airflow model shall be small enough to accurately capture the control valve and brake pipe system response to an emergency application and its propagation through the brake pipe.

d) The model shall include the following control valve characteristics:
   - Differential pressures and logic controlling actuation of internal valve components
   - Mass flow rate of air controlled by orifice chokes
   - Size of reservoirs and internal volumes

The local brake pipe pressure, supplied by the brake pipe model, will be provided as an input to the 26-F model. The mass flow rate of air between the 26-F valve and the brake pipe is required as an input to the brake pipe model.

e) The 26-F control valve model shall output the pressure in the brake cylinder application pipe (signal for the J-type relay valve that controls the brake cylinder pressure).

f) The 26-F control valve model shall output the mass flow rate of air between the 26-F control valve and the brake pipe.

g) The 26-F control valve model shall account for the position of the branch pipe cut-out cock (for 26-F control valve isolation).

The 26-F control valve model will incorporate a number of valve components that control the pneumatic logic by directing the flow of air among the various internal volumes and external reservoirs. A brief description of each of these components is provided.

The service valve controls the brake cylinder application pipe pressure buildup and release based on the relationship between the brake cylinder application pipe pressure and the amount of brake pipe reduction. The rate of brake cylinder application pipe pressure buildup is influenced by the choke size and the service valve diaphragm area ratio, specified by the user.

The brake cylinder pressure limiting valve limits the brake cylinder application pipe pressure resulting from a service reduction to a preset maximum value, specified by the user.

The emergency limiting valve limits the brake cylinder application pipe pressure resulting from an emergency reduction to a preset maximum value, specified by the user.

The charging valve terminates initial quick service activity and assists in the charging of the selector and control reservoirs.

The selector valve controls the response to initial quick service and to release (either graduated or direct mode).

The quick release valve provides the bail (or actuation) function. Brake cylinder application pipe pressure is reduced to 0 in response to pressure in the actuation pipe of the locomotive. The actuation pipe is pressurized when the engineer actuates the bail function (e.g. by depressing the independent brake valve handle) or as commanded by the DBI system.

h) The functional logic of the following valve components shall be included in the 26-F control valve model:
- Service Valve
- Brake Cylinder Pressure Limiting Valve
- Emergency Limiting Valve
- Charging Valve
- Selector Valve
- Quick Release Valve

The 26-F control valve model will incorporate the various internal volumes and external reservoirs used to supply air and control the pneumatic logic of the valve. A brief description of each of these internal volumes and external reservoirs is provided.

The brake cylinder displacement volume connects to the brake cylinder application pipe. Pressure in this volume is used (along with the independent brake pressure) to pilot a J-type relay valve (such as J-1 or J-1.6-16 valve), which controls brake cylinder pressure using air from the supply (auxiliary) reservoir. The volume of the brake cylinder displacement volume is specified by the user.

The supply (auxiliary) reservoir associated with each 26-F valve provides a local source of air for the brake cylinders and for control valve operation. This reservoir is charged from the brake

pipe under the control of the 26-F valve. The volume of the supply (auxiliary) reservoir is specified by the user.

The control reservoir associated with each 26-F valve is charged to the brake pipe pressure during release and used as a reference pressure to gauge the amount of brake pipe reduction during brake application. The volume of the control reservoir is specified by the user.

The selector reservoir associated with each 26-F valve is used in association with the internal selector valve to control various functions such as quick service and the release mode. The volume of the selector reservoir is specified by the user.

The quick service volume is a small internal volume used to help accelerate the initial service reduction through the train.

i) The following reservoirs and internal volumes, which operate in conjunction with valve components, shall be included in the 26-F control valve model:

- Brake Cylinder Displacement Volume
- Auxiliary Reservoir
- Control Reservoir
- Selector Valve Volume
- Quick Service Volume

j) The pressure in each reservoir and volume shall be determined based on the modeled flow rate of air, and the resulting pressures used to influence the associated valve states.

4.3.2.6   J-type Relay Valve Model

J-type relay valves combine the brake signals from the automatic brake system (26-F valve output) and the independent brake system to determine the target brake cylinder pressure for the control vehicle. On the basis of this target, the J-type valve controls the air flow into or out of the brake cylinders on the vehicle. Different types of J valves are characterized by the relationship between the output pressure (brake cylinder target pressure) and the two input pressures (automatic and independent pressures).

a) The J-type relay valve model shall include models for the J-1 valve and the J1.6-16 valve.

b) Each J-type relay valve model shall represent its corresponding pneumatic logic to determine the brake cylinder pressure target as a function of automatic and independent pressure signals.

c) Each J-type relay valve model shall control the brake cylinder pressure by directing air from the supply (auxiliary) reservoir to the brake cylinders or from the cylinders to the atmosphere, according to the J valve target.

4.3.2.7   26-C Control Valve Model

The 26-C control valve model will represent the functionality of a 26-C control valve and associated components in the brake system of a passenger coach. The primary requirement is to model the automatic control of the pressure buildup and release in the brake cylinder application pipe (signal for brake cylinder pressure) in response to changes in the local brake pipe pressure.

a) The 26-C control valve functionality shall be modeled using a physical representation of the actual pneumatic logic, including the action of the various internal valve components controlling the flow of air between reservoirs and internal volumes.

b) The pressure in each reservoir and volume shall be updated based on the modeled flow rate and the resulting pressures used to influence the internal valve component states.

c) The calculation time step used for fluid dynamics/air-flow model shall be small enough to accurately capture the control valve and brake pipe system response to an emergency application and its propagation through the brake pipe.

d) The model shall include the following control valve characteristics:
   - Differential pressures and logic controlling actuation of internal valve components
   - Mass flow rate of air controlled by orifice chokes
   - Size of reservoirs and internal volumes

The local brake pipe pressure, supplied by the brake pipe model, will be provided as an input to the 26-C model. The mass flow rate of air between the 26-C valve and the brake pipe is required as an input to the brake pipe model.

a) The 26-C control valve model shall output the pressure in the brake cylinder application pipe (signal for piloting the brake cylinder pressure).

b) The 26-C control valve model shall output the mass flow rate of air between the 26-C control valve and the brake pipe.

c) The 26-C valve model shall account for the position of the brake pipe cut-out cock (for 26-C control valve isolation).

The 26-C control valve model will incorporate a number of valve components that control the pneumatic logic by directing the flow of air among the various internal volumes and external reservoirs. A brief description of each of these components is provided.

The service valve controls the brake cylinder application pipe pressure buildup and release based on the relationship between the brake cylinder pressure and the amount of brake pipe reduction. The rate of brake cylinder application pipe pressure buildup is influenced by the choke size and the service valve diaphragm area ratio, specified by the user.

The brake cylinder pressure limiting valve limits the brake cylinder application pipe pressure resulting from a service reduction to a preset maximum value, specified by the user.

The emergency limiting valve limits the brake cylinder application pipe pressure resulting from an emergency reduction to a pre-set maximum value, specified by the user.

The charging valve terminates initial quick service activity and assists in the charging of the selector and control reservoirs.

The selector valve controls the response to initial quick service and to release (either graduated or direct mode).

The emergency portion detects an emergency brake pipe reduction and rapidly dumps brake pipe pressure locally to help accelerate the propagation through the train.

d) The functional logic of the following valve components shall be included in the 26-C control valve model:

- Service Valve
- Brake Cylinder Pressure Limiting Valve
- Emergency Limiting Valve
- Charging Valve
- Selector Valve
- Emergency Portion

The 26-C control valve model will incorporate the various internal volumes and external reservoirs used to supply air and control the pneumatic logic of the valve. A brief description of each of these internal volumes and external reservoirs is provided.

The brake cylinder displacement volume pilots the relay valve, which controls brake cylinder pressure using air from the supply (auxiliary) reservoir.

The supply (auxiliary) reservoir associated with each 26-C valve provides the local source of air for the brake cylinders and for control valve operation. This reservoir is charged from the brake pipe under control of the 26-C valve.

The control reservoir associated with each 26-C valve is charged to the brake pipe pressure during release and used as a reference pressure to gauge the amount of brake pipe reduction during brake application.

The selector valve volume associated with each 26-C valve is used in association with the internal selector valve to control various functions, such as quick service and the release mode.

The quick service volume is a small internal volume used to help accelerate the initial service reduction through the train.

The quick action chamber is an internal volume used by the emergency portion for detecting and responding to an emergency brake pipe reduction.

e) The following reservoirs and internal volumes, which operate in conjunction with valve components, shall be included in the 26-C control valve model:
- Brake Cylinder Displacement Volume
- Auxiliary Reservoir
- Control Reservoir
- Selector Valve Volume
- Quick Service Volume
- Quick Action Chamber

f) The pressure in each reservoir and volume shall be determined based on the modeled flow rate of air and the resulting pressures used to influence the associated valve states.

4.3.2.8   Electronic Overlay System Model

The electronic overlay system uses electronically controlled magnet valves to vent air from the brake pipe locally at each equipped vehicle during a brake application. It also uses magnet valves to supply air to the brake pipe from the supply (auxiliary) reservoir on each equipped vehicle during a brake release. The control valve on each vehicle responds as usual to the local brake pipe pressure.

a) The electronic overlay system model shall simulate air flow from the brake pipe to the atmosphere at each equipped vehicle during a brake application.

b) The electronic overlay system model shall simulate air flow from the supply (auxiliary) reservoir to the brake pipe at each equipped vehicle during a brake release.

4.3.2.9   B-1 Auxiliary Vent Valve Model

B-1 auxiliary vent valves are used to help propagate the pneumatic brake pipe signal down the brake pipe for service brake applications. The B-1 auxiliary vent valve vents a small amount of air out of the brake pipe when a reduction in local brake pipe pressure is detected. The B-1 auxiliary vent valve model will represent the functionality of this device.

a) The B-1 auxiliary vent valve model shall simulate air flow out of the brake pipe in response to changes in local brake pipe pressure.

4.3.2.10   Emergency Vent Valve Model

Emergency vent valves are used to help propagate the pneumatic brake pipe signal down the brake pipe for emergency brake applications. A generic emergency vent valve will be modeled, as it is assumed that all types of emergency vent valves (e.g., #8, KM-2, VX, etc.) operate similarly.

a) The emergency vent valve model shall simulate the rapid flow of air out of the brake pipe in response to a sufficiently rapid decrease in local brake pipe pressure.

4.3.2.11   Variable Load Valve Model

The variable load valve adjusts the target brake cylinder pressure supplied by the control valve to the relay valve on the vehicle proportionally based on the load of the vehicle.

a) The variable load valve model shall interface with the control valve model of the vehicle to incorporate the vehicle loading condition into the determination of the brake cylinder pressure based on the variable load characteristics supplied by the user.

4.3.2.12   Wheel Slide Control System Model

The wheel slide control system adjusts brake cylinder pressure based on an indication of a sliding axle (axle rotation compared with vehicle speed, which is determined by radar or comparative velocity feedback from the axles on the vehicle). When sliding is detected, the brake cylinder pressure retarding that axle is vented at a rapid rate. When rolling has been reestablished, the brake cylinder pressure is allowed to build back up to the commanded level. Some wheel slide control systems include a holding feature in which the brake cylinder pressure is held steady at an intermediate level while the axle reestablishes the rolling condition.

a) The wheel slide control system model shall represent a generalized wheel slide control system with user adjustable characteristics.

b) The wheel slide control system model shall interface with the brake system model to adjust the brake cylinder pressure based on the slide condition of the axle(s) and the characteristics of the wheel slide control system supplied by the user.

4.4   Coupler and Draft Gear Model

The primary goal of the coupler and draft gear model is to represent the response of the draft gear to relative displacement between adjacent vehicles.

a) The coupler and draft gear model shall model the response of the draft gear/coupler and the forces applied to each vehicle based on the displacement between adjacent vehicles.

4.5 Resistive Force Model

The resistive force model will represent the forces acting on each vehicle as a result of aerodynamic resistance, number of axles, weight of each vehicle, and the coefficients of friction acting on the components.

a) The resistive force model shall model the retarding force on each vehicle in the consist resulting from the aerodynamic characteristics and orientation of the vehicle.

b) The resistive force model shall model the retarding force on each vehicle in the consist resulting from the Davis equation resistance components.

c) The resistive force model shall model the retarding force on each vehicle in the consist resulting from the curving resistance based on the characteristic curving ability of the vehicle.

d) The rotational inertia of the vehicle shall be simulated for each axle on each vehicle based on the wheel diameter, number of brake discs, and whether the axle is powered.

4.6 Track Grade Force Model

The objective of the track grade force model is to represent the gravitational force acting on each vehicle in the consist as a result of the track grade.

a) The track grade force model shall model the force acting on each vehicle because of track grade.

5. EXTERNAL INTERFACE REQUIREMENTS

The passenger train brake performance model will interface with the user of the model or an external software application known as the test controller/logger (TCL). The general requirements for these interfaces are specified in this section. The specific interface to the TCL software application will be provided in a separate document.

b) The passenger train braking performance model shall incorporate a user interface that allows the user to:

- Build and save required input elements for the simulation (track, vehicle, consist).
- Select predefined input elements (track, vehicle, consist) for a given simulation.
- Enter required and optional initialization data for a given simulation.
- Enter operating commands during a simulation.

c) The user interface shall provide output data at each time step to the user during the simulation.

d) The passenger train braking performance model shall incorporate an interface to the TCL software application that allows the TCL software to:

- Specify predefined input elements (track, vehicle, consist) for a given simulation.
- Send required and optional initialization data for a given simulation.
- Send operating commands during a simulation.

e) The interface to the TCL software application shall send output data at each time step to the user during the simulation.

6.   PERFORMANCE REQUIREMENTS

The initial intended application of the passenger train braking performance model will involve running large batches of braking simulations. To achieve this, the model will be required to operate faster than real time. Although the simulation run time is highly dependent on the specific simulation details and the hardware on which the model is run, nothing in the model should prevent the simulation from running faster than real time should the application support it.

f) The passenger train braking performance model software shall be capable of running through the simulation faster than real time.

g) The passenger train braking performance model software shall not preclude running multiple instances of the executable software on a single machine.

7. EXTENSIBILITY REQUIREMENTS

The functional requirements for the passenger train braking performance model specified in Section 4 are intended to support the initial application of the model. It is recognized, however, that other applications may require additional functionality. The model will be designed to allow for additional expansion to support this additional functionality.

a) The passenger train braking performance model shall be designed so that additional passenger train control valves can be added in the future and made user-selectable in the definition of the vehicle.

b) The passenger train braking performance model shall be designed so that additional J-type relay valves can be added in the future and made user-selectable in the definition of any powered vehicle.

c) The passenger train braking performance model shall be designed so that more complex draft gears characteristics can be added in the future and made user-selectable in the definition of the vehicle.

d) The passenger train braking performance model shall be designed so that a more complex representation of the aerodynamic resistance of various vehicles may be added/incorporated in the future.

e) The passenger train braking performance model shall be designed so that forces on the train because of wind speed and direction may be added to the model in the future, along with appropriate user input.

8. NOTES

8.1 Acronym/Abbreviation List

DBI   dynamic brake interlock

DBU   disc brake unit

IPS   independent pressure switch

PTC   positive train control

TBU   tread brake unit

TCL   test controller/logger

8.2 Glossary of Terms

Actuating Pipe – a pipe used on powered vehicles that interface with the 26-F control valve to release any automatic brake application, on that vehicle only, when pressurized.

Automatic Brake Valve – a valve that allows the train operator to make automatic brake applications and releases by moving the valve handle to control the pressure in the equalizing reservoir and brake pipe.

Bail – a term used to describe the release of an automatic brake application on a powered vehicle, via the 26-F control valve, by pressurizing the actuation pipe.

Blended Braking – a function used on some powered vehicles, where a combination of dynamic braking and friction braking is automatically applied to achieve the brake demand specified by an automatic brake application.

Brake Cylinder Cut-out Cock – a valve used to cut out the brake cylinders on a single truck, typically on locomotives or other powered vehicles.

Brake Cylinder Pressure Limiting Valve – a valve associated with the control valve on the car that limits the amount of brake cylinder pressure during a service brake application.

Brake Pipe – a pipe that runs the length of the train that is used to transmit signals for automatic brake applications and releases.

Braking Enforcement Algorithm – a component of the PTC onboard system that predicts train stopping distance, based on current conditions, and enforces an air brake application to stop the train in the event of any potential violation of authority or speed limit.

B-1 Auxiliary Vent Valve – a valve that is used to help propagate service brake application signals in the brake pipe by locally venting a small amount of air; typically used on long cars (greater than 75 feet of brake pipe).

Control Reservoir – a reservoir that is used by the control valve to provide a reference pressure in determining the amount of brake pipe pressure reduction.

Control Valve – a brake valve on each vehicle that controls brake cylinder pressure in response to changes in local brake pipe pressure.

Control Valve Branch Pipe Cut-out Cock – a valve used to cut out the control valve on a single vehicle.

Control Valve Emergency Portion – a component of the control valve that detects an emergency brake application and reacts to rapidly dump brake pipe pressure to assist in the propagation of the pneumatic emergency brake signal.

Davis Equation – an equation developed to estimate rail car resistance because of a variety of factors, including aerodynamic, rolling, and bearing friction.

Disc Brake Unit – a compact unit that incorporates the brake cylinder, brake rigging, and brake pad associated with each brake disc.

Displacement Reservoir – a reservoir used to pilot the relay valve on a vehicle based on pressure controlled by the control valve.

Dynamic Brake – a method of producing retarding force on the vehicle by using the resistance in the traction motors and dissipating the energy as heat through a resistor grid.

Dynamic Brake Interlock – a feature on powered vehicles with a dynamic brake in which the actuation pipe is pressurized when dynamic braking is active, effectively bailing off any automatic brake application on that vehicle.

Electronic Overlay – a system of magnet valves on each vehicle that electronically respond to signals from the automatic brake handle to locally vent or charge brake pipe pressure resulting in decreased application and release times.

Emergency Limiting Valve – a valve associated with the control valve on the car that limits the amount of brake cylinder pressure during an emergency brake application.

Emergency Vent Valve – a valve that detects an emergency brake application and reacts to rapidly dump brake pipe pressure to assist in the propagation of the pneumatic emergency brake signal.

Equalizing Reservoir – a reservoir associated with the automatic brake valve that provides the target pressure for the brake pipe.

Independent Application and Release Pipe – a pipe used on powered vehicles with independent brake capability that interfaces with the J-type relay valve to apply or release brake cylinder pressure based on the position of the independent brake valve handle.

Independent Brake Valve – a valve that allows the operator to make brake applications and releases on the powered vehicle independent of any automatic brake application; also typically allows the operator to bail off automatic brake applications.

Independent Pressure Switch (IPS) – a feature on powered vehicles with independent and dynamic brake capability where the dynamic brake force is limited when the brake cylinder pressure exceeds a specified value.

Isolation Switch – a switch on a powered vehicle that allows the vehicle to operate, control other units, or be controlled by other units.

J-type Relay Valve – a relay valve on powered vehicles that control air flow to the brake cylinders based on the independent and automatic brake signals.

Main Reservoir Pipe – a pipe that runs the length of the train and provides main reservoir pressure to the supply reservoirs on each vehicle.

Positive Train Control – a form of train control where train movement authorities and speed limits are transmitted electronically and automatically enforced to prevent violations.

Powered Vehicle – a vehicle capable of producing tractive effort; may also be capable of producing dynamic brake effort and may have independent brake capability.

Power Selector Switch – a switch on a powered vehicle that determines if the vehicle is set up for power or dynamic brake.

Selector Reservoir – a reservoir that is used by the control valve to control various functions such as quick service and the release mode.

Supply (Auxiliary) Reservoir – a reservoir on each vehicle used to supply air to the brake cylinders during a brake application.

Test Controller/Logger – an external software used to generate and run large batches of simulations using Monte Carlo techniques to randomly vary input parameters.

Tread Brake Unit – a compact unit that incorporates the brake cylinder, brake rigging, and brake shoe associated with the brakes on each wheel.

Variable Load Device – a valve used to adjust the brake cylinder pressure proportionally to the weight of the vehicle.

Wheel Slide Control System – a system used to determine wheel slide conditions and to adjust brake cylinder pressure to assist in reestablishing rolling.

26-C Control Valve – a control valve frequently used in passenger equipment.

26-F Control Valve – a control valve frequently used in locomotives and other powered vehicles.

Appendix B.
Passenger/Commuter Industry Survey for Air Brake Equipment 2010

Although it is recognized that a wide variety of passenger/commuter equipment exists in the United States, no formal database exists that identifies specific brake equipment parameters needed to develop an optimized passenger train braking performance model. To fill this need, TTCI conducted a survey of passenger/commuter agencies to gather necessary information needed to develop an air brake model focused on passenger equipment. The focus of the survey effort is to determine what types of brake system hardware are in service. The primary goal of this survey was to determine the most prevalent types of brake equipment being used today. Given this data, the requirements for the passenger train braking performance model were developed for the most common types of braking equipment. The secondary goal was to identify uncommon types of equipment. The uncommon components were then compared to their more common counterparts. This comparison was to determine if the functionality of the components was similar enough that only the more prevalent component need be modeled.

The following list of items was identified to assist in developing brake module components and questions concerning these items were included in the survey.

- Locomotives (models/manufacturer, number in operation, year of construction, brake control equipment, any special configuration) – as applicable.
- Railcars (DMU, EMU, Push/Pull) (models/manufacturer, year of construction, special configuration, number of powered axles) – as applicable.
- Brake system description (single line air, dual line air, electronic overlay, blended braking
- Specific brake valve/components (manufacturer, model number)
- Wheel slide control system (characteristic response)
- Load sensor use
- Draft gear characteristics
- Power (Diesel, Biofuel, Electric - Voltage, Current)

Twenty-eight passenger/commuter agencies were contacted and received surveys by December 1, 2010. The surveys were then sent out again on the December 10, along with a cover letter from the FRA stating the goal of the project. Followup emails and telephone calls were made just after the beginning of 2011 as a reminder to all of the agencies. Many agencies agreed to participate but only four responses were received as of January 31, 2011. The results have been summarized in the following table.

Passenger/Commuter Agency	A	B
Number of Locomotives	155	0
Number of Cab Cars	187	1
Number of EMUs	171	0
Number of DMUs	0	5
Number of Trailer Cars (bi-level)	647	0
Number of Trailer Cars	0	0
Brake System Type(s)	26L, Wabtec Epic, and 30CDW	NYAB CCBII and 26L
Control Valve Model(s)	26F and 30CW module	26F
Automatic Brake Valve Model(s)	26C, PS68, Knorr KBMGS2-P and 30ACDW	26-B-1
Is Blended Braking used?	Yes	Yes
Are Variable Load Sensors Used?	No	Yes
Are Wheel Slide Control Systems Used?	Yes	Yes
Number of Full Service Brake Applications Per Hour	25 per hour	14 per hour
Type(s) of Couplers Used	Type H, Type F and BBM60 Electrics	Type H
Notes:		Voith hydrodynamic transmissions used for dynamic braking

Table 1A. Passenger Brake Survey Summary.

Passenger/Commuter Agency	C	D
Number of Locomotives	14	2
Number of Cab Cars	11	0
Number of EMUs	0	72
Number of DMUs	4	0
Number of Trailer Cars (bi-level)	15	0
Number of Trailer Cars	2	10
Brake System Type(s)	NYAB CCBII and 26L	26L and Knorr
Control Valve Model(s)	26F	
Automatic Brake Valve Model(s)	26C and 26-B-1	26C and 26CK
Is Blended Braking used?	Yes	Yes
Are Variable Load Sensors Used?	Yes	Yes
Are Wheel Slide Control Systems Used?	Yes	Yes
Number of Full Service Brake Applications Per Hour	10 per hour	9 per hour
Type(s) of Couplers Used	Type H	Type H- Wabtec - 0D09272
Notes:		

Table 1B. Passenger Brake Survey Summary (Continued)

**U.S. Department
of Transportation**

**Federal Railroad
Administration**

1200 New Jersey Avenue, SE
Washington, DC 20590

DEC   6 2010

Dear Colleague:

By now you will have been contacted by the Transportation Technology Center (TTCI) in Pueblo, Colorado for the purpose of gathering data related to the upcoming mandated implementation of Positive Train Control (PTC) systems on U.S. passenger and commuter systems. The Federal Railroad Administration (FRA) Office of Research and Development has contracted TTCI to conduct background brake related research in the passenger/commuter equipment area. As mentioned by their first contact, this effort is focused on <u>developing the requirements</u> for a broad based passenger brake system performance model for passenger/commuter equipment. From this Phase I effort, and subsequent follow on work, we plan to provide a tool that agencies can utilize to accurately predict the variability of stopping distance of their rail equipment under a wide range of actual and/or potential operating scenarios. This tool, used in concert with other PTC planning tools, is intended for use in identifying, early on, areas where system throughput could be negatively impacted by the installation of a PTC system, and developing methods to improve/optimize functions of the PTC system to help reduce this negative operational impact.

As mentioned previously, TTCI has already provided a cover letter and general system hardware survey (Phase I efforts) that will help determine what types of equipment/brake system hardware are commonly in use by U.S. passenger and commuter agencies today. This information will be used in the development of the requirements for the passenger/commuter brake system model and help focus future model development (Phase II efforts) on the types of equipment impacted by the PTC mandate.

We at FRA support this effort and ask you to respond to the TTCI survey with an appropriate level of effort for your particular passenger operation, in a timely fashion.

If you have any questions, please contact me at the address/phone number attached.

Sincerely,

Terry Tse

Terry Tse
Program Manager – Train Control
Federal Railroad Administration
US Department of Transportation

To: Date:

From: Brian Smith Technical Manager – PMBU Transportation Technology Center, Inc
P.O. Box 11130 55500 DOT
Road Pueblo, Colorado 81001

Subject: Survey for purposes of defining the requirements for developing a passenger air brake model to support Positive Train Control (PTC) mandate.

Dear Sir/Madam,

The pending PTC requirements of 2015 (or earlier in certain cases), mandate that passenger/commuter systems, in addition to most freight roads, be equipped with hardware capable of implementing a safe brake enforcement application in situations when the engineer does not properly respond. To support the PTC mandate, FRA has put forth the first phase of a research and development program to assist passenger/commuter agencies in reaching their PTC goals with minimal operational impacts.

While it is recognized that a wide variety of passenger/commuter equipment exists in the U.S., no formal database exists that identifies specific brake equipment parameters needed to develop an optimized enforcement braking model. To fill this need, TTCI has been contracted by the FRA to conduct a survey of passenger/commuter agencies and gather necessary information needed to develop an air brake model focused on passenger equipment. Please find attached a letter from Mr. Terry Tse (Program Manager, Train Control) of the FRA, asking for your organization's support for this project.

Program Goal: The program goal is to identify the level of technical detail and variety of inputs required to generate an optimal braking model to be used in developing safe stopping enforcement algorithms that will have less negative operational impact than existing PTC enforcement algorithms. A follow-on effort will be proposed, as necessary, to develop the actual model components required and incorporate them into an appropriate braking model.

The output of the overall effort will allow the user to input the specific characteristics for particular passenger/commuter equipment and derive the information necessary to offer a PTC-compliant braking algorithm.

It is recognized that the goal of stopping safely has to be met while recognizing and limiting potential negative impacts to performance from use of overly conservative estimates.

The focus of the Phase I effort is to determine what types of brake system hardware are in service today. The following list of items has been identified to assist in developing brake module components (considering issues of brake hardware and common draft gear).

Items:
1   Locomotives (models/manufacturer, year of construction, brake control equipment, any special configuration) – as applicable.
2   Railcars (DMU, EMU, Push/Pull) (models/manufacturer, year of construction, special configuration, number of powered axles) – as applicable.
3   Brake system description (single line air, dual line air, electronic overlay, blended braking
4   Specific brake valve/components (manufacturer, model number)
5   Wheel slide control system (characteristic response)
6   Load sensor resolution
7   Draft gear characteristics
8   Power (Diesel, Bio-fuel, Electric -Voltage, Current)

The attached WORD file is the survey that we are asking you to fill out. We request that you furnish as much information as possible. Also, please provide a point of contact for any follow up clarifications.

If you have any questions, please do not hesitate to contact me at the address/email/phone number listed below. We appreciate your cooperation in this effort and intend to help ultimately to provide a usable tool to help you meet your passenger PTC needs.

Sincerely,

Brian Smith Tech. Manager – PMBU Transportation Technology Center, Inc.
P.O. Box 11130 55500 DOT
Road Pueblo, Colorado 81001
719-584-0558 office 719-251-
6562 cell brian_smith@aar.com

1. **Please give a brief description of all passenger Train consists currently used in your operation.**
   (Type and number of rail vehicles – Locomotives, Rail cars, DMU, EMU, Push/Pull)

Note: The boxes below the questions will expand as needed to accommodate your answers

2. **What types of locomotives are used in your operations?**
   (Models/manufacturer, year of construction, brake control equipment, any special configuration)

3. **What types of railcars are used in your operations?**
   (Unpowered, DMU, EMU, models/manufacturer, year of construction, special configurations, number of powered axles {if applicable})

4. **Please give a brief description of the typical brake system and hardware. Please include information such as type of equipment, model numbers, and manufacturers.**
(***Control valves*** *{26C, KE}**, number of air/electrical supply/control lines, what type of overlay {CS-1, CS-2 etc}), J Valves. Manufacturer(s) and Models*)

5. **What types of brake units are used?**
   (Tread brake units, disc brake units, both)

6. **Is blended braking used in your operations?**
   (If so give a brief description)

7. What types of variable load sensors are used, what is the resolution of the sensor?
(Manufacturer, model number, response characteristics)

8. What types of wheel slide control systems are used in your operation?
(Manufacturer, model number, characteristic response – brief description)

9. **What is your most severe braking duty cycle - equivalent number of full service applications per hour?**

10. **What types of draft gears/couplers are used?**
    (Manufacturer, model number, characteristics (if available), slackless etc.)

11. What types of base power sources are used?
   (Diesel, Biofuel, Electric - Voltage, Current)

12. Please list contact information for an individual within your organization that would be available for follow-up questions if needed.

Name:

Job Title:

Address:

Phone # (Office):

Phone # (Cell):

E-mail Address:

13. It would be very beneficial to have any brake system schematics and component documentation for the items listed in this questionnaire.

Abbreviations and Acronyms

DMU   diesel multiple unit

EMU   electric multiple unit

FRA   Federal Railroad Administration

PTC   positive train control

RSIA   Rail Safety Improvement Act [2008]

TTCI   Transportation Technology Center, Inc.