An Examination of Amtrak's Acela High Speed Rail Simulator for FRA Research Purposes

Technical Memorandum

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Preface

This technical memorandum presents the results from a study designed to examine the applicability of the Amtrak Acela high speed rail simulator for human-centered research purposes. This work was performed under contract DTFR53-95-C-00049 for the Federal Railroad Administration Office of Research and Development. Dr. Thomas Raslear was the Contracting Officer's Technical Representative. The author would like to thank Dr. Raslear and Mr. Michael Coplen, also of the FRA Office of Research and Development, for their guidance and support throughout this project.

Special thanks are due to a number of individuals and companies who made this study possible. First and foremost, thanks are due to Amtrak, and in particular, Mr. Terry Foley, Mr. Harold Shaw, Mr. Jay Gilfillan and Mr. Mark Burris for enabling the author and the evaluation team to see and experience the Acela high speed rail simulator, and for providing valuable insights and answers to many questions.

The author would also like to thank each of the evaluation team members—Dr. Jordan Multer, Dr. Judith Bürki-Cohen, Mr. Dave Muller, Mr. Mike Bartelme and Dr. June Pilcher—for their contributions toward this technical memorandum. The findings from this study would not have been possible without their collective expertise. Thanks are also due to Mr. Charles Radgowski from Corys Training and Engineering Support Services (T.E.S.S.) for providing technical answers and information on the Acela simulator, and answering the author's numerous questions throughout the project.

The author would also like to thank several individuals from Foster-Miller. Thanks to Ms. Sarah Acton for her assistance in helping to research behavioral and physiological sensor technologies that can be used for human-centered research in a locomotive simulator. Thanks also to Mr. Jeff Crane for assisting in managing the evaluation team meeting, which played such an integral role in this research. Thanks, too, to Ms. Judith Gertler and Ms. Susan McDonough for reviewing, and providing important feedback to, drafts of this technical memorandum.

Thanks are also due to Dr. Stephen Popkin, Volpe National Transportation Systems Center (NTSC), for playing a key role in the initial formulation, planning and execution of this research; to Dr. Frederick Gamst for providing background materials on locomotive engineer operation; and to Mr. Robert Harvey, Brotherhood of Locomotive Engineers, for reviewing and providing feedback on a draft of the locomotive engineer performance measures.

The author also wishes to thank Mr. Richard Fisher of the Providence and Worcester Railroad, and Mr. Pierce Haviland of Metro North Railroad, for providing the author with opportunities to ride the head-ends of a freight train and passenger train, respectively, and to experience what it "feels like" to be in the cab of an operating locomotive.

Lastly, the illustrations on the cover of this technical memorandum and in Figure 2 have been provided by, and reprinted with permission from, Mr. Charles Radgowski and Corys T.E.S.S.

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Abbreviations

ACSES	Advanced Civil Speed Enforcement System
CAD	Computer-aided design
CCD	Charge-coupled device (camera)
CDU	Cab display unit
CGI	Computer-generated imagery
Corys T.E.S.S.	Corys Training and Engineering Support Services
CRM	Crew resource management
CRT	Cathode ray tube
CTA	Cognitive task analysis
FOV	Field-of-view
FRA	Federal Railroad Administration
FRA OR&D	Federal Railroad Administration Office of Research and Development
HSR	High speed rail
I/O	Input/output
LCD	Liquid crystal display
NEC	Northeast Corridor
OEM	Original equipment manufacturer
PTC	Positive train control
SME	Subject matter expert
UI	User interface
Volpe NTSC	Volpe National Transportation Systems Center

Executive Summary

Amtrak recently completed upgrading the northeast corridor (NEC) to become the nation's first high speed rail corridor. As part of this upgrade, Amtrak acquired a simulator to train its locomotive engineers on the operation of the new Acela trainsets that will run along the NEC. The U.S. Congress subsequently mandated the Federal Railroad Administration (FRA) Office of Research and Development to review Amtrak's Acela high speed rail simulator to determine its suitability as a research tool for use by the FRA. The FRA has expressed an interest in using the Acela high speed rail simulator to research a number of human-centered locomotive engineer issues, such as training, fatigue and alertness, the safety of new technologies, and communication.

The purpose of the research described in this technical memorandum is to determine whether the Amtrak Acela high speed rail simulator facility is capable of being used by the FRA to conduct research on human-centered issues. The FRA expected that some modifications would likely have to be made to the existing simulator to adapt it to their needs. Given this, the overall project goals were to:

- Assess the current functional capabilities of the Acela high speed rail simulator.
- Identify characteristics of the current simulator configuration that restrict the ability to (1) conduct human-centered locomotive engineer research and (2) collect operator performance data.
- Propose modifications to the Acela high speed rail simulator to meet the needs of the FRA's research goals and agenda.

Since only a small portion of all U.S. rail operations are high speed (defined as greater than 125 mph for the purpose of this research), an additional goal of this project was to propose design recommendations for a non-high speed locomotive simulator. This type of locomotive simulator would replicate lower speed passenger rail operation as well as all types of freight rail operations.

The overall approach that was used in this research involved focusing on the transition from what the Acela simulator currently is capable of doing to what the Acela simulator should be able to do to satisfy the FRA's research needs. First, the cognitive and physical job tasks that are required of a locomotive engineer were delineated. Structured interviews with FRA human factors program managers provided a means to collect information on the FRA's research goals and requirements with respect to the use of a locomotive simulator. A team of experts was then convened to evaluate the Acela high speed rail simulator in its current configuration and make recommendations regarding modifications to the simulator to accommodate the FRA's research needs.

The Acela high speed rail simulator uses state-of-the-art technology to realistically reproduce both the inside-the-cab environment and the external physical environment from Washington, DC to Boston, Massachusetts (i.e., the NEC). The simulator uses motion, sound, and visual cues via computer-generated imagery (CGI) to reproduce the "look-and-feel" of the real Acela trainset operating along the NEC. The entire NEC is replicated, including many of the physical features that exist in the real NEC. Although Amtrak cannot change the virtual world, they can modify much of the operating environment.

Currently, data collection is primarily observation-based. That is, Amtrak instructors rely on direct observation of the engineer to monitor and evaluate his or her adaptation to the new Acela trainset equipment. The simulator is capable of generating a limited number of quantitative, performance-based data, however.

Use of the Acela simulator as a research tool will require greater control over scenario development and control, data collection and reduction, and experimental control, than currently exists. The evaluation team proposed a number of desired capabilities in a range of costs. Ultimately, the implementation of any of these capabilities depends on the number of experiments that the FRA expects to conduct, as well as the fiscal resources available to invest in the simulator modifications.

To assist the FRA in making informed decisions regarding the use of the Acela simulator to study human-centered issues, two approaches were taken to recommending possible modifications to the Acela high speed rail simulator. The first approach is based on the number of experiments that the FRA expects to conduct using the Acela simulator. The number of studies will influence whether (1) many substantial, up-front modifications should be made to expand the simulator's general capabilities and increase the flexibility of the simulator to accommodate a number of research experiments over time, or (2) specific modifications should be made to the simulator one experiment at a time, where the modifications address the particular needs of the given experiment and research design. The former approach will be expensive and time-consuming at first, but ultimately, will be less expensive *if* the simulator is used frequently to conduct research. This approach will also increase flexibility in conducting research using the simulator and will facilitate standardization across experiments. If only a few experiments will be conducted, however, the numerous up-front modifications may result in higher costs per experiment. In this case, the latter, "one experiment at a time," approach will be less time-consuming up-front and may be less expensive in the end. In addition, the FRA may be able to control much of the scenario and experimental protocol due to specific modifications that can be requested for the particular experiment.

Given the FRA's expected research needs and the limited high speed passenger rail operations in the U.S., the consensus among evaluation team members was that the FRA should fund simulator research projects one experiment at a time, costing out the simulator requirements for each experiment as needed. An advantage of this approach is that after the experiment, the FRA will not be responsible for any other simulator-related costs. This approach assumes that the FRA's use of the simulator would be extremely limited.

Since it may not be feasible to know or approximate the number of experiments that will be conducted over the course of the next 5-10 years, a second approach is provided. The second approach addresses simulator modifications based on the amount of time and monetary resources necessary to make modifications to the Acela simulator. Five levels of effort are identified. Each level is associated with increased capabilities along with increased implementation time and costs. Specific costs associated with technologies or levels of effort are not provided, as these values will change over time. More important to the study is the delineation of the resources, technologies and systems that are associated with each level of effort.

On the lower end of the time and cost spectrum (i.e., the first "level" of effort) is the implementation of a basic video and audio data collection system along with an external gyro/accelerometer to collect motion-based information such as lateral accelerations. A personal computer could manage these data and tap into the Acela simulator's network to collect additional simulator data that are already produced by the simulator computer system. At the other end of the spectrum, Corys, which designed and built the Acela simulator, could produce a new, highly realistic, customized visual database similar to the NEC environment that already exists. Along with the highly realistic virtual environment, Corys could provide a suite of tools to give researchers a high degree of experimental and scenario control, and enable researchers to collect a number of customized data from the simulator.

As a general rule of thumb, the more time and money invested, the greater the simulator capabilities and the more control that the FRA will have over scenario and environmental development, and data collection. However, minimal modifications can still produce very high-quality research results, and these minimal modifications should be seriously considered. Ultimately, the FRA will have to work closely with Amtrak and Corys to implement any of the recommended modifications, and conduct experiments using the Acela high speed rail simulator.

Suggestions for the design and development of a non-high speed locomotive simulator to accommodate conventional passenger and freight operations are also provided. These recommendations should be considered a first step in more fully specifying the requirements for a locomotive simulator. As specific research needs are elucidated and formalized by the FRA, the requirements for a locomotive simulator will become more extensive and complete.

The recommendations for a non-high speed locomotive simulator that are discussed in this technical memorandum are based on one "cornerstone" recommendation made by the evaluation team: a simulator research facility should be built to house several locomotive simulators. The simulator facility envisioned would be interdisciplinary, and would be capable of conducting a number of different types of railroad-related research in addition to locomotive engineer performance. Such a facility could be supported by both federal and industry-funded research. The recommendations that are provided are equally appropriate to the design and development of a single conventional locomotive simulator and facility, however.

A basic simulator research facility, as envisioned by the evaluation team, would contain the following components or elements:

- Three locomotive "bays": one motion-based simulator, one static simulator, and one developmental area where simulator components can be maintained and developed off-line.
- Multiple interchangeable cabs that can be moved to any of the three "bays."
- Multiple locomotive engineer control stands that represent different types of equipment.
- Multiple train dynamic models to represent different types of equipment, different types and amounts of loads, etc.
- A range of operating scenarios.

This facility would be capable of researching topics in a number of areas, including human factors and operations safety, track structures, materials and configurations, train dynamics, and advanced technologies. A number of recommendations are discussed in terms of simulator system architecture design, system requirements, operational requirements, data collection requirements, and physical/experiential requirements.

The overall theme that guided the recommendations for a non-high speed locomotive simulator is that it is desirable to build as much flexibility into the simulator (facility) design as possible, from the outset of the design process. This design goal will expand the simulator's functionality, reduce the cost of future modifications, and increase the operating life of the simulator.

Issues around simulator fidelity are also addressed. A major issue related to simulator fidelity, due to the additional cost associated with it, is whether motion is necessary in a simulator, and if so, how much is necessary. A possible solution to the need for motion is to design a locomotive simulator to contain partial motion or displacement. Partial motion should facilitate participant acceptance, it would provide vestibular cues, and it would be less costly to build than a full-motion simulator.

The recommended next step with respect to the Acela high speed rail simulator is to determine what the FRA wants to use the simulator for, what kinds of data it wants to collect, and the number of experiments that may be run on the Acela simulator. Once this has been done, the following steps should be taken:

1. Identify and prioritize locomotive engineer research and data needs.
2. Determine available budget and time considerations.
3. Determine (and prioritize if necessary) desired modifications.
4. Discuss research and data needs, and desired modifications, with Amtrak and Corys, as appropriate.

Possible next steps that the FRA might take with respect to the future development of a non-high speed rail locomotive simulator include the following:

1. Determine the need for a non-high speed locomotive simulator facility.
2. Determine how much fidelity would be needed or desired (e.g., the quality of the visual system, whether to have motion, and if so, how much?).
3. Calculate the approximate cost of the desired simulator facility.
4. Determine a budget.
5. Match the budget to the desired simulator facility.
6. If necessary, change aspects of the desired simulator facility to align with fiscal budget.

Two distinct research projects are also proposed.

1. If it is desirable to further explore whether motion is necessary in locomotive simulation, an experiment could be designed to study locomotive engineers' performances in the Acela simulator with or without motion, and then participants' performances could be compared to their performance operating the real Acela on the actual NEC. This would indicate whether there are differences between performances in the simulator with and without motion.
2. If the FRA is interested in determining which visual, auditory and vestibular cues a locomotive simulator should provide, a second project could focus on deconstructing an engineer's territory knowledge in terms of the visual, vestibular and aural cues that the environment provides to the engineer and that the engineer uses in operating the train safely and efficiently.

1 Introduction

This section begins with a brief background to the research described in this technical memorandum. The chapter then elaborates on the specific goals of the research, discusses the overall approach that was taken in conducting the research, and lastly presents the organization of the technical memorandum.

1.1 Background

Within the last year, Amtrak completed upgrading the northeast corridor (NEC) to become the nation's first high speed rail corridor. Though definitions vary, in this technical memorandum high speed rail refers to passenger train operation at speeds in excess of 125 mph. A major cornerstone to the high speed NEC corridor is the introduction of the new Acela trainsets. As part of the upgrade to the high speed rail corridor, Amtrak had a simulator built to train its locomotive engineers on the new Acela trainsets. Since Amtrak engineers were already familiar with the NEC territory, the focus of the training was on familiarizing engineers on the new Acela equipment. The simulator was developed by Corys Training and Engineering Support Services (Corys T.E.S.S., referred to as Corys for the remainder of the technical memorandum) in conjunction with Bombardier (the original equipment manufacturer, or OEM, for the Acela trainsets).

Subsequently, the U.S. Congress mandated the FRA Office of Research and Development (OR&D) to review Amtrak's Acela high speed rail simulator to determine its suitability as a research tool for use by the FRA. The FRA has expressed an interest in using the Acela high speed rail simulator to research a number of human factors or human-centered locomotive engineer issues, such as training, fatigue and alertness, new technologies, and communication.

1.2 Purpose

The purpose of the research described in this technical memorandum is to determine whether the Amtrak Acela high speed rail simulator facility is capable of being used by the FRA to research human-centered research issues. It was expected that some modifications would likely have to be made to the existing simulator to adapt it to the needs of the FRA. Given this, the overall project goals are as follows:

- Assess the current functional capabilities of the Acela high speed rail simulator.
- Identify limitations to the current simulator configuration that limit the ability to (1) conduct human-centered locomotive engineer research and (2) collect operator performance data.
- Propose modifications to the Acela high speed rail simulator to meet the needs of the FRA's research goals and agenda.

Since only a small portion of all U.S. rail operations are considered to be high speed, an additional goal of this project is to propose design recommendations for a conventional (i.e., non-high speed) locomotive simulator. A conventional locomotive simulator would replicate lower speed passenger rail operation as well as all types of freight rail operations. Conventional rail operations currently make up a majority of all rail operations in the U.S. The FRA has not indicated that it will develop or sponsor the development of such a simulator. Rather, the FRA is interested in leveraging off of the knowledge gained from the evaluation of the Acela simulator in the event that it does decide to develop or sponsor the development of a conventional locomotive simulator in the future.

1.3 Overall approach

The overall approach that was used in this research involved focusing on the transition from what the Acela simulator currently is capable of doing to what the FRA would like the simulator to be able to do to satisfy its research needs. A team of experts was convened to evaluate the Acela simulator in its current configuration and make recommendations regarding modifications to the simulator to accommodate the FRA's research goals. Structured interviews with FRA program managers were used to collect information on the FRA's research goals. The evaluation team then met for a multi-day meeting to evaluate the Acela simulator, review the FRA's research goals, and make recommendations with respect to modifications to the Acela simulator to meet the FRA's research needs. This overall approach is illustrated in Figure 1. The technical approach that was used in carrying out this research is discussed in greater detail in Section 2.

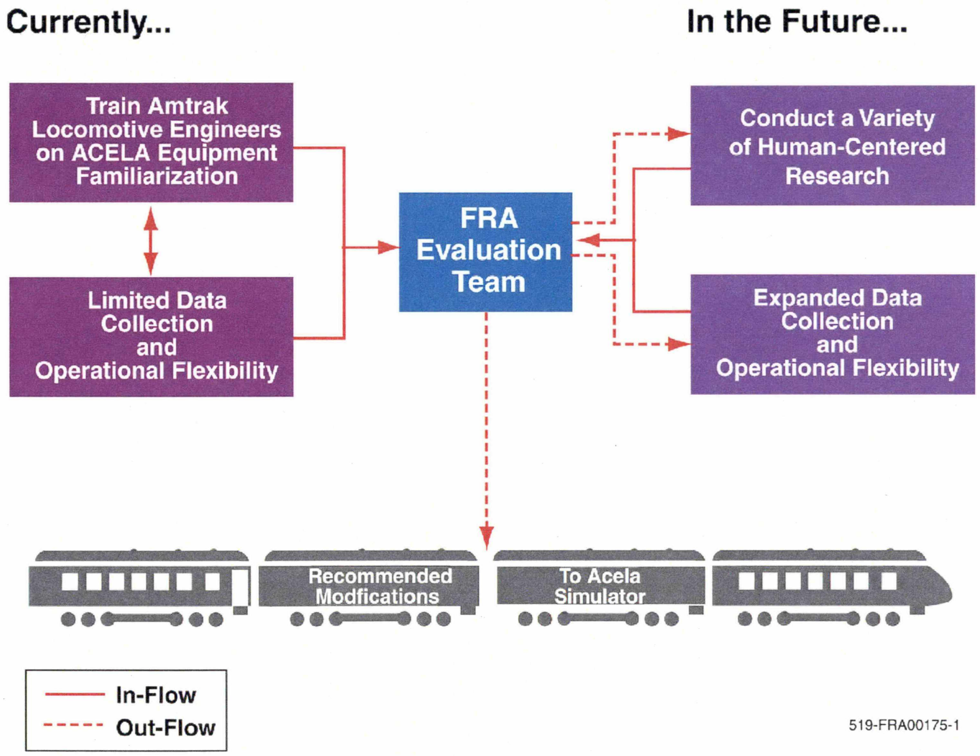

Figure 1. Overall approach to the evaluation of the Acela high speed rail simulator for FRA research purposes

1.4 Organization of the technical memorandum

The technical memorandum is divided into several major sections. Section 2 describes the technical approach that was used to conduct the research. The section elaborates on the overall approach illustrated in Figure 1. Section 3 describes the job of a locomotive engineer in some detail to provide a context in which to understand what a locomotive simulator generally is designed to do. Section 4 presents some research questions that the FRA may want to address using a locomotive simulator such as the Acela high speed rail simulator. Section 4 also discusses the FRA's requirements for a locomotive research simulator. Section 5 presents information about the Acela simulator's current configuration and capabilities. Section 6 presents recommended modifications to the Acela simulator to address the FRA's research goals and needs. Section 7 presents some recommendations for the design of a conventional locomotive simulator. Section 8 presents key findings from this research program, and provides some recommendations for possible future research activities. A list of references used in conducting the research is presented in section 9.

Two appendices are provided. Appendix A presents descriptive biographies of each of the evaluation team members who participated in the research, while Appendix B includes a discussion of physiological and behavioral sensor technologies that may be applied in a locomotive simulator setting to collect additional operator performance-related data.

2 Technical Approach

The technical approach involved data collection through structured interviews and a 2 ½ day meeting of simulation experts. First, a structured interview was conducted with FRA OR&D Human Factors Program Managers to identify research needs and concerns, as well as simulator requirements. Based on the interview, a list of locomotive engineer human factors research questions was generated, along with a set of simulator requirements (see section 4).

Next, a site visit to the Acela simulator training facility in Wilmington, Delaware provided an initial appreciation of the simulator's capabilities and an opportunity to ask some preliminary questions about the facility. As part of the site visit, a structured interview was conducted with several Amtrak instructors to determine how the simulator is currently being used, identify some of the simulator's current capabilities and functionality, and learn from instructors' experiences with the simulator.

A team of experts was then convened to participate in a multi-day meeting to discuss and generate modifications to the Acela simulator and make recommendations for the design of a conventional locomotive simulator. The following areas of expertise were identified as critical to the success of the evaluation team:

- Simulation hardware
- Virtual environments and generation of scenery
- Simulation software (i.e., integration of simulation components)
- Human factors, simulation, and human performance modeling
- Experimental design
- Human perceptual systems
- Locomotive engineer operation
- General railroad operations

Based on the areas of expertise identified above, an evaluation team was established that consisted of the following individuals:

1. Mr. Stephen Reinach, Foster-Miller, Inc.
2. Dr. Judith Bürki-Cohen, Volpe NTSC
3. Dr. Jordan Multer, Volpe NTSC
4. Dr. June Pilcher, Bradley University
5. Mr. Michael Bartelme, KQ Corporation
6. Mr. David Muller, Riverside Technical Design

Appendix A presents brief biographies for each of the evaluation team members. Table 1 illustrates the areas of expertise that each member brought to the evaluation team.

Table 1. Evaluation Team Member Expertise Matrix

	Evaluation Team Member					
Area of Expertise	Reinach	Bürki-Cohen	Multer	Pilcher	Bartelme	Muller
Simulation hardware					**X**	**X**
Virtual environment / scenery generation					**X**	
Simulation software		**X**			**X**	**X**
Human factors, simulation, human performance modeling	**X**	**X**	**X**	**X**	**X**	
Experimental design	**X**	**X**	**X**	**X**	**X**	
Human perceptual systems	**X**				**X**	
Expertise in locomotive engineer operation			**X**	**X**		
Expertise in general railroad operations	**X**		**X**			

During the first day of the 2 ½ day meeting, the evaluation team members toured the Acela simulator and met with Amtrak training staff to discuss the Acela simulator's current capabilities and use, and discussed basic train handling requirements and techniques. As part of the tour, evaluation team members had an opportunity to "drive" the simulator in order to experience first-hand the visual, audio, and motion aspects of the Acela simulator. On the second day, the team met all day to discuss modifications to the Acela simulator in order to meet the FRA's human factors research needs. Mr. Chuck Radgowski, a representative from Corys T.E.S.S., presented background information on the simulator design, and participated in the all-day discussion in order to answer technical questions on the Acela simulator design. On the third day, the evaluation team met alone to discuss basic elements for the design of a conventional freight and passenger locomotive simulator.

Many, though not all, of the recommendations in this technical memorandum are based on the consensus of the evaluation team. To make these recommendations, evaluation team members used information from the structured interviews with the FRA Human Factors program managers and Amtrak Acela simulator instructors; information provided by Mr. Charles Radgowski of Corys; conversations with Amtrak instructors who use and are in charge of the simulator; and a hands-on "kick the tires" demonstration of the Acela simulator. A copy of the Acela simulator specifications could not be obtained for review for this research. The remaining sections of this technical memorandum are based on the technical approach described here.

3 The Job of a Locomotive Engineer

To begin, one must understand the job of a locomotive engineer. Gamst (1991, pp. 6-7) describes the job of a locomotive engineer as the following:

> "As governed by myriad authoritative rules guiding his actions, a locomotive engineer safely and efficiently operates and maintains an engine (i.e., a locomotive). By means of the engine, he controls a train or cut (string) of cars in the following kinds of services:...passenger...freight ...work [non-revenue]...and yard/terminal/switching....Engineers operate their engines with regard to a thorough knowledge of operating, air brake, and other authoritative rules and move trains on main lines in accordance with timetable, train order, general bulletin order, wayside signal indication, and other authority for rail traffic control.... Engines and trains are handled by engineers with regard to a familiarity with profile, alignment, and other physical characteristics of the track over which runs are made, an understanding of the track-train dynamics of a great range of variation in marshalling of trains, and skilled knowledge in the operation of tractive power and the... braking systems controlled and monitored from the engineer's workspace in the cab."

As the job description indicates, the job of a locomotive engineer places a number of cognitive and physical demands on the engineer. Many of these demands come in the form of engineer-oriented tasks that he or she must routinely carry out to safely and efficiently operate a train. Table 2 and Table 3 present a number of the cognitive (Roth, 2000) and physical demands that are placed on a locomotive engineer, along with examples of each type of task demand. Ideally, a locomotive simulator would be able to reproduce each of these cognitive and physical task demands.

Table 2. Locomotive engineer cognitive job demands

Demand (Roth, 2000)	Example
• Memory demands	Information regarding temporary speed restrictions in place
• Knowledge demands	Knowledge of operating rules in effect
• Possess and maintain situation awareness	Knowledge of the location of the next speed change
• Detect and recognize objects on or around the right-of-way	Recognize a trespasser ahead on the track
• Detect and recognize violations of expectations	Determine whether an (unexpected) signal change occurred
• Monitor information provided inside the cab	Determine whether a piece of equipment is malfunctioning
• Monitor radio communication	Recognize when a dispatcher is calling
• Formulate appropriate responses to situations	Respond appropriately to a signal change
• Plan and make decisions	Decide how much air brake application is needed for a given situation
• Establish priorities and manage workload and attentional demands	As a grade-crossing is approached, decide to answer the radio before entering the grade-crossing or afterward
• Maintain sustained attention/vigilance	Determine whether the train is dragging equipment
• Coordinate and cooperate with others	Discuss with a dispatcher which siding to take

Table 3. Locomotive engineer physical job demands

Demand	Example
• Make throttle adjustments	Move throttle from one position to the next
• Make brake adjustments	Application of air brakes
• Acknowledge the alerter	Move alerter stick
• Communicate with other parties via radio and phone	Call dispatcher
• Record movement authorities and other required forms and logs	Record a dispatcher-conveyed movement authority using a Form D or track warrant
• Scan/monitor in-cab displays through the use of vision and hearing	Look at various displays and gauges
• Scan/monitor the external environment through the use of vision, hearing and feel	Look out the front window
• Respond to in-cab operational alarms	Arrange to drop off malfunctioning locomotive at a siding

4 FRA Research Questions and Requirements

This section is divided into two sections. Section 4.1 presents a set of research questions that the FRA OR&D human factors program managers may want to address using a locomotive simulator such as the Acela high speed rail simulator. Section 4.2 presents a list of FRA requirements for a locomotive research simulator if one were to be built from scratch. The research questions and simulation requirements provided direction for the evaluation of the Acela simulator, and assisted the evaluation team in proposing modifications to the Acela simulator that would be necessary to accommodate the FRA's research questions and simulation requirements. The research questions and simulation requirements also provided direction for the recommendations regarding the possible development of a conventional locomotive simulator (see section 7).

4.1 Locomotive engineer human factors research questions

There are a number of human factors or human-centered questions that can be addressed through the use of a locomotive simulator. To obtain a better understanding of what questions the FRA may be interested in addressing using a locomotive simulator, a matrix was developed that contains a list of locomotive engineer-related human factors research questions that may serve as possible areas of future study by the FRA. After a list of questions was generated, FRA human factors program managers reviewed the list and added questions. Each research question is classified in terms of the types of research that it addresses. Some questions may address one or two research areas while other research questions cover multiple research areas. The research questions and research areas that each question addresses are presented in Table 4.

Table 4. FRA research questions and general research areas

	Human Factors Locomotive Engineer Research Questions	Hi-Speed Simulation	Conventional Simulation		Testbed for evaluating changes to FRA rulemaking	Advanced system design/new technologies (e.g., PTC)	Innovative display designs	Fatigue/alertness/work schedules	Physical ergonomics	Critical incidents	Workload	Distraction	Stress	Situation awareness	Operator performance	Communication/CRM	Training	Information-processing and decision making	Simulator validation
1	How does digital communication affect locomotive engineer performance?	x	x			x					x			x	x	x			
2	How does Positive Train Control (PTC) affect locomotive engineer performance?	x	x			x					x			x	x	x			
3	What are the effects of alternative HOS/work schedules on locomotive engineer performance?	x	x		x			x							x				
4	Examine locomotive engineer's ability to respond to unplanned or emergency events?	x	x							x	x	x	x	x	x				
5	How do different advanced display configurations/designs affect locomotive engineer performance?	x	x			x					x			x	x	x			
6	Examine locomotive engineer errors	x	x												x				
7	Examine communication, cooperation and coordination between train crew and dispatcher	x	x												x	x			
8	Examine crew resource management (CRM), and its effects on train crew performance	x	x												x	x			
9	Investigate the effects of individual or environmental stressors on locomotive engineer performance	x	x						x				x		x				
10	Compare the performance of novice locomotive engineers to that of experienced locomotive engineers. The results can be used in cognitive task analysis (CTA) development, and can be incorporated into loco engineer training	x	x												x		x		
11	Evaluate the effectiveness of novel locomotive engineer training aids, devices, or methods	x	x			x	x								x		x		
12	Study the effect of distraction, interruptions, and lapses in attention on locomotive engineer performance	x	x							x		x		x	x			x	
13	Evaluate napping strategies and other fatigue countermeasures	x	x					x	x						x				
14	Evaluate the effect of different training strategies on locomotive engineer performance	x	x												x		x		

Table 4. FRA research questions and general research areas (continued)

Human Factors Locomotive Engineer Research Questions		Research Area/Topic																
		Hi-Speed Simulation	Conventional Simulation		Testbed for evaluating changes to FRA rulemaking	Advanced system design/new technologies (e.g., PTC)	Innovative display designs	Fatigue/alertness/work schedules	Physical ergonomics	Critical incidents	Workload	Distraction	Stress	Situation awareness	Operator performance	Communication/CRM	Training	Information-processing and decision making	Simulator validation
15	Validate different locomotive engineer decision-making strategies	x	x							x	x	x	x	x	x	x	x	x	
16	Examine different ways to present verbal information (e.g., special bulletins, slow orders, etc.) to the locomotive engineer	x	x			x	x				x			x	x	x		x	
17	Examine the effect of training engineers to operate both conventional and high-speed trainsets	x	x		x										x		x	x	
18	Simulator validation studies	x	x																x
19	Compare performances of locomotive engineers using simulator with and without motion (this has implications for CFR training simulator requirements/certification)	x	x		x										x		x		
20	Study signal standardization issues	x	x		x										x			x	
21	Study the safety of cell phone use while operating a locomotive	x	x								x	x		x	x	x		x	

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4.2 Simulator requirements

To obtain a more thorough understanding of what simulator features or qualities are important to the FRA OR&D, FRA human factors program managers were asked to identify those features of a locomotive simulator that are critical to its acceptance by the FRA and the railroad industry. These requirements can be thought of as a wish list, and are based on the FRA's experience with locomotive simulators and their sensitivity to the needs of the railroad industry and labor organizations. The list of requirements is based on the development of a simulator from scratch (i.e., no constraints), although it is desirable for the Acela simulator to accommodate as many of these system requirements as possible.

The following locomotive simulator features were identified as critical for conducting human factors research:

- The calculation, derivation and collection of simulator data should be clear and readily understood by novice users (i.e., those not intimately familiar with the simulator).
- The simulator architecture should be flexible enough to accommodate both current and future human factors research needs, in terms of both operating/environmental scenarios, and performance measures.
- The simulator should be able to (1) collect a number of train handling and operating variables and (2) convert these variables into monetary values. The reason for converting the variables into monetary values is to show the relationship between safety-based data and economic data.
- The simulator should be able to convey (through some tool or analysis) the connection between what an engineer does (e.g., brake application) and how the train performs (e.g., draft and buff forces).
- The simulator should enable scenarios to be developed via library and original coding, as well as by input from an external source, such as a file containing directly-captured digital data on a territory generated from a separate device. The FRA is sponsoring an ongoing project that may be capable of capturing and generating this type of data.
- The turn-around time for the data should be minimal. Ideally, a researcher would be able to run participants in the morning and be able to look at operator and train performance data in the afternoon. This includes the ability not only to conduct a playback of someone's performance in the simulator, but also to produce statistical analyses of the data. This will facilitate the examination of potential problems that can be remedied before further simulations are run. Ideally, the simulator data would be processed in real-time or near real-time for immediate feedback.
- The simulator should support the addition of auxiliary plug-in equipment, sensors, and other data collection tools and displays to the simulator input/output (I/O) system or directly into the locomotive cab interface. For example, a researcher may want to study an advanced technology or display that must be added to the cab control stand configuration.
- The simulator should be capable of integrating data from a plugged-in device with simulator train performance and operator performance data.
- The simulator design should maximize the simulator's ability to operate with and connect to

future auxiliary technologies (i.e., 5-10 years after the simulator is developed).

- The simulator should be initially designed so that future changes that may be needed will involve minimal monetary resources and time investments.

5 The Acela High Speed Rail Simulator

The Acela high speed rail simulator began operating in 1999, and is part of a multi-million dollar Amtrak training facility located in Wilmington, Delaware. The simulator was primarily developed to familiarize Amtrak locomotive engineers with the new Acela equipment. The simulator uses state-of-the-art technology to realistically reproduce both the inside-the-cab environment and the external physical environment from Washington, DC to Boston, Massachusetts (i.e., the NEC).

The simulator uses motion, sound, and visual cues via computer-generated imagery (CGI) to reproduce the "look-and-feel" of the real Acela trainset operating along the NEC. The entire NEC is replicated, including many of the physical features that exist in the real NEC such as graffiti on the sides of buildings, and the specific grade-crossings located on the New York-to-Boston section of the NEC.

Section 5 describes the current configuration, set-up and operation of the Acela high speed rail simulator, and is divided into two sections. Section 5.1 provides an overall description of the simulator's physical configuration and operation, and section 5.2 discusses the simulator's data collection system.

5.1 Acela simulator configuration and operation

Section 5.1 provides an overall description of the Acela high speed rail simulator. It is organized into four parts. The first part describes the physical layout of the simulator system; the second part discusses the development and validation of the simulator by Corys T.E.S.S.; the third part discusses issues related to programming the simulator; and finally, the fourth part, describes the operation of the simulator.

Currently the Acela simulator can be configured to replicate an entire high speed, unibody, Acela trainset or some combination of high speed locomotive (also referred to as "head-end power" or HEP) and train consist. Although similar, each has its own train handling characteristics and cab layout. It takes about an hour to reconfigure the simulator from the high speed trainset to the high speed locomotive and consist, or vice versa. Reconfiguration involves physical changes to the cab (e.g., displays) as well as software modifications to reflect differences in train handling. In both configurations, the simulator is strictly used for equipment familiarization since the Acela high speed equipment is different than other Amtrak equipment. There are over 100 equipment-based faults that can be replicated in the simulator to familiarize and train engineers on the Acela equipment. The visual environment is currently limited to the NEC since this is the only high speed rail corridor in which the Acela currently operates.

5.1.1 Acela high speed rail simulator physical configuration

The Acela high speed rail simulator is made up of three primary components:

1. The trainee workstation (i.e., the simulator cab)
2. The instructor or operator workstation
3. The technical room

Figure 2 illustrates the simulator's physical configuration. All three system components are connected via an Ethernet-based network. Each component is described in more detail in the following sections.

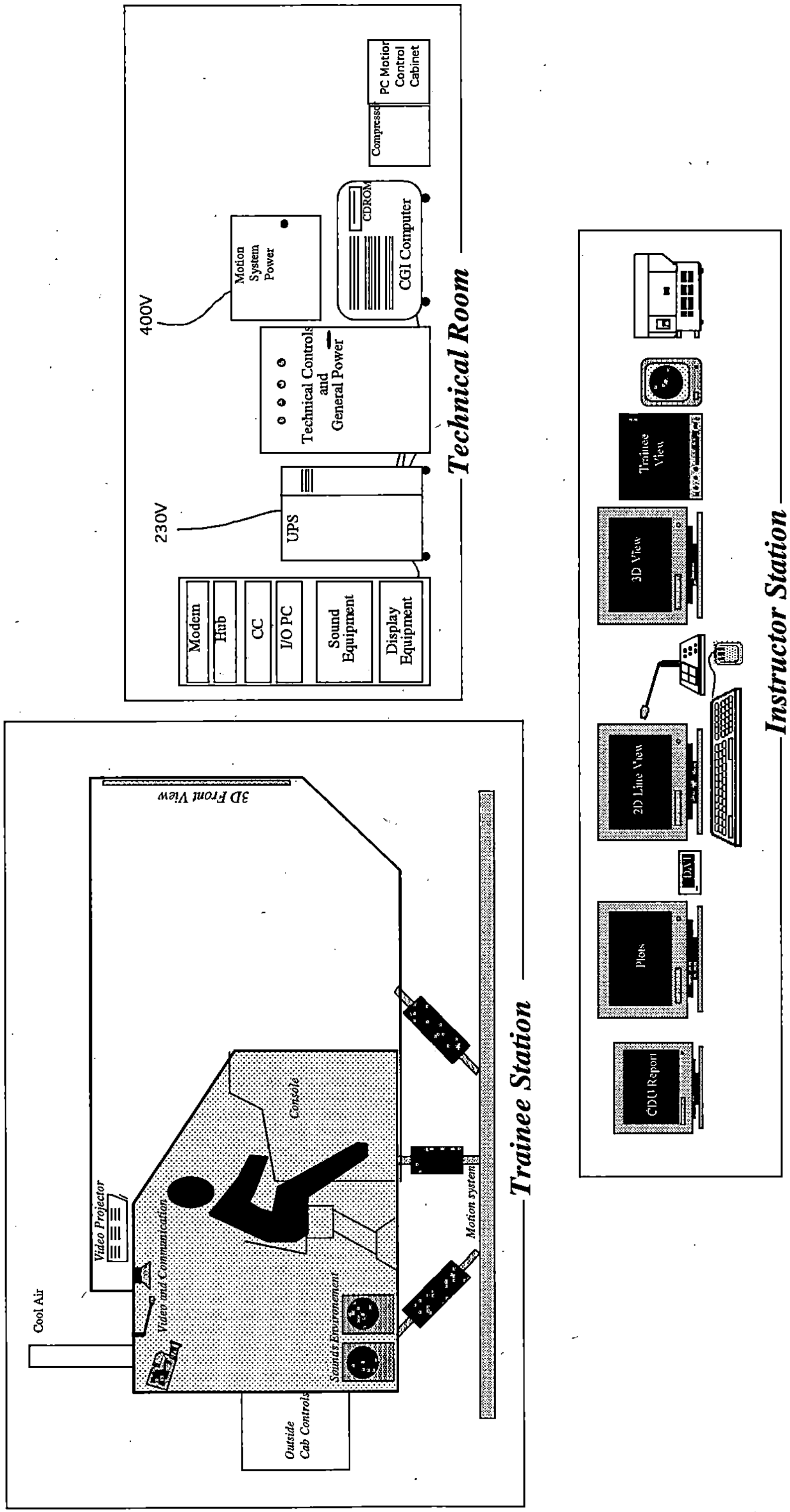

Figure 2. Acela simulator components (illustration provided courtesy of Corys T.E.S.S.)

Trainee workstation (i.e., simulator cab)

The trainee workstation is primarily made up of the locomotive cab. This cab (and train handling characteristics) can be configured in one of two ways: as an Acela high speed trainset (the sloped nose design) or as a high speed locomotive.

The high speed trainset can be configured in one of three ways, though on all trainset configurations, there is power at both the lead and rear of the train. Possible Acela trainset configurations include:

1. One leading power unit followed by six passenger coaches followed by one trailing power unit (1-6-1)
2. One leading power unit followed by 10 coaches followed by one trailing power unit (1-10-1)
3. Dual high speed trainsets-- one leading power unit followed by six coaches followed by one power unit followed by another power unit followed by six coaches followed by one trailing power unit (1-6-1-1-6-1). This might be the case when one trainset is "towing" another trainset.

The high speed locomotive may be configured one of six ways, and may include either one or two leading high speed locomotives. Possible configurations include:

1. One leading locomotive followed by eight passenger coaches
2. One leading locomotive followed by a combination of 18 coaches and cars
3. Two leading locomotives followed by a combination of 30 coaches and cars
4. One leading locomotive followed by a combination of 15 coaches and cars
5. One leading locomotive followed by a combination of 19 coaches and cars
6. One leading locomotive followed by a combination of 23 coaches and cars

The simulator's motion is electronically controlled. Motion can be actuated along five axes: lateral, longitudinal, vertical, roll and pitch.

Inside the cab there are two chairs, one for the engineer and one for an instructor or "conductor." The engineer's work station is located on the right-hand side of the cab (see Figure 3). The engineer has a forward, approximately 45 degree "out-the-cab" field-of-view (FOV) of the CGI-generated environment (see Figure 4). In front of the engineer, and below the forward view are two computerized cab display units (CDUs) that contain many of the in-cab displays such as train speed. The CDUs are driven by a 50MHz PC that contains a 10 Mb PCMCIA card used for storage (there is no hard drive) and which operates on Windows 3.1. VisualBasic is used to program the CDU interfaces. The CDUs and the cab controls appear exactly the same as those found on the real Acela equipment. These include the throttle, brake, and reverser; the in-cab signal system display; the horn and bell controls; and other controls and displays/alarms. Also found inside the trainee workstation are a video camera (located to the right of the engineer) and microphone, and the sound system that is used to display realistic locomotive and train sounds (see Figure 5).

Figure 3. View of locomotive engineer's console in the Acela simulator

Figure 4. Forward "out-the-cab" view from the Acela simulator

Figure 5. Side view of the Acela simulator cab

According to Corys, the simulated distance at which point an engineer can correctly identify a signal (referred to as sight distance) is about one mile (1500 m). The distance at which signs can be read is less than that for signals, and depends on the sign. These less-than-perfect sight distances are a function (and limitation) of the CGI system. The evaluation team suggested that in the real world, one can read a signal about two miles away. The actual sight distance in the simulator may also vary slightly from simulation to simulation depending on the visual projection system (e.g., brightness/intensity, power, etc.). Currently the resolution for the visual system is 1024 lines by 768 lines (1024x768) using a cathode ray tube (CRT) projection system (3 tubes). According to Corys, this system may be replaced with an LCD projector in the near future.

The similarity between the real NEC and the simulated NEC virtual world is very high, due in large part to input by NEC locomotive engineers during the design of the simulator. For example, lateral shifting introduced by interlockings is simulated. There are also 10 "rough areas" which are simulated. These rough areas include a visual discoloration of the track and a corresponding motion cue.

Instructor or operator workstation

The instructor workstation has two primary functions: to control or operate the simulator and to program simulator scenarios. The instructor workstation contains several computers and monitors, a TV that provides a view of the engineer inside the simulator cab, a printer, and additional equipment such as an intercom to communicate with the engineer inside the simulator cab, an emergency shut down button, and telephone (see Figure 6 and Figure 7). A data display presents simulated vehicle performance data over time or distance (see the far left monitor in Figure 6). The variables that are available, and the number that are displayed at one time, can be specified by the instructor as long as the variables are available (i.e., computed by the current simulator model). Examples include train speed, acceleration, and brake pipe pressure. The data presented in the CDUs can also be duplicated at the instructor's workstation (see the right-hand monitor in Figure 6). The middle display in Figure 6 presents a track schematic that can be used by the instructor to follow the simulated train's progress. Figure 7 presents the forward "out-the-cab" view as seen by the engineer and the closed-caption video of the engineer inside the simulator. The instructor can initiate and terminate a simulated scenario from his or her workstation, and can remain in communication with the engineer in the cab for the duration of the run. Further, an instructor can program the simulator "off-line" using the computers at the workstation. Additional discussion of Acela simulator programming is provided in section 5.1.3.

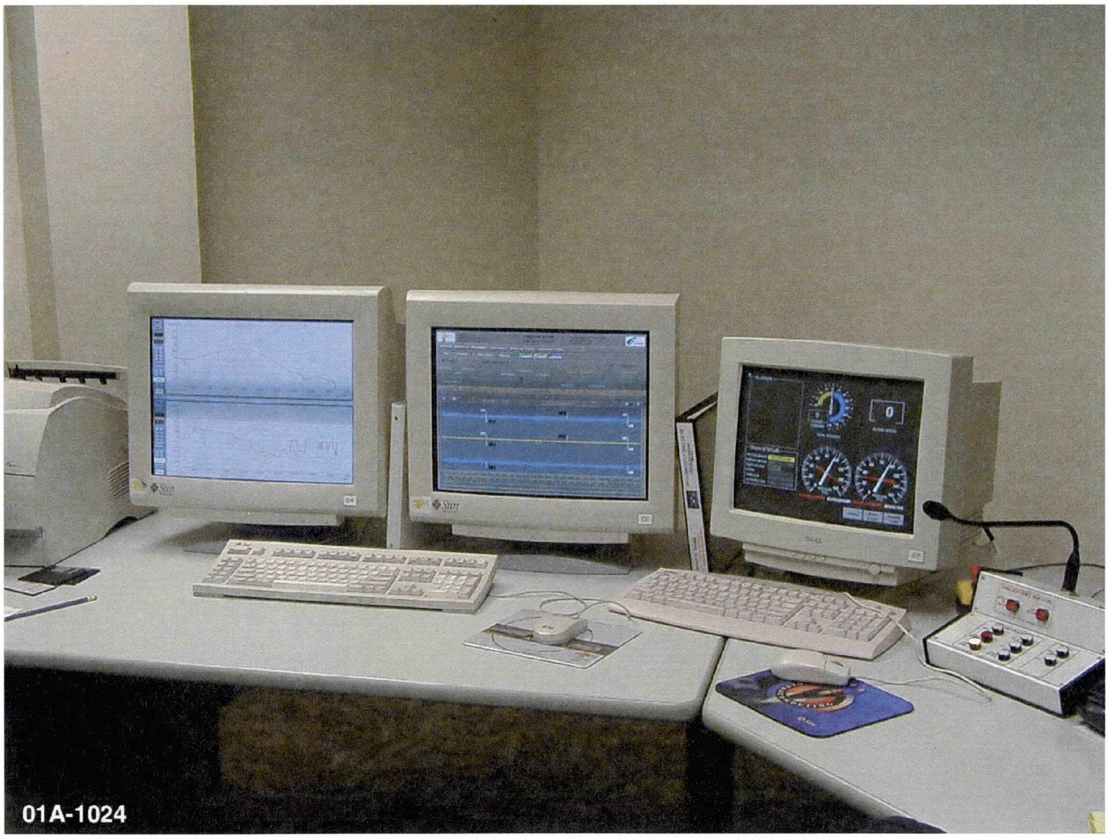

Figure 6. View of the left side of the Acela simulator instructor workstation

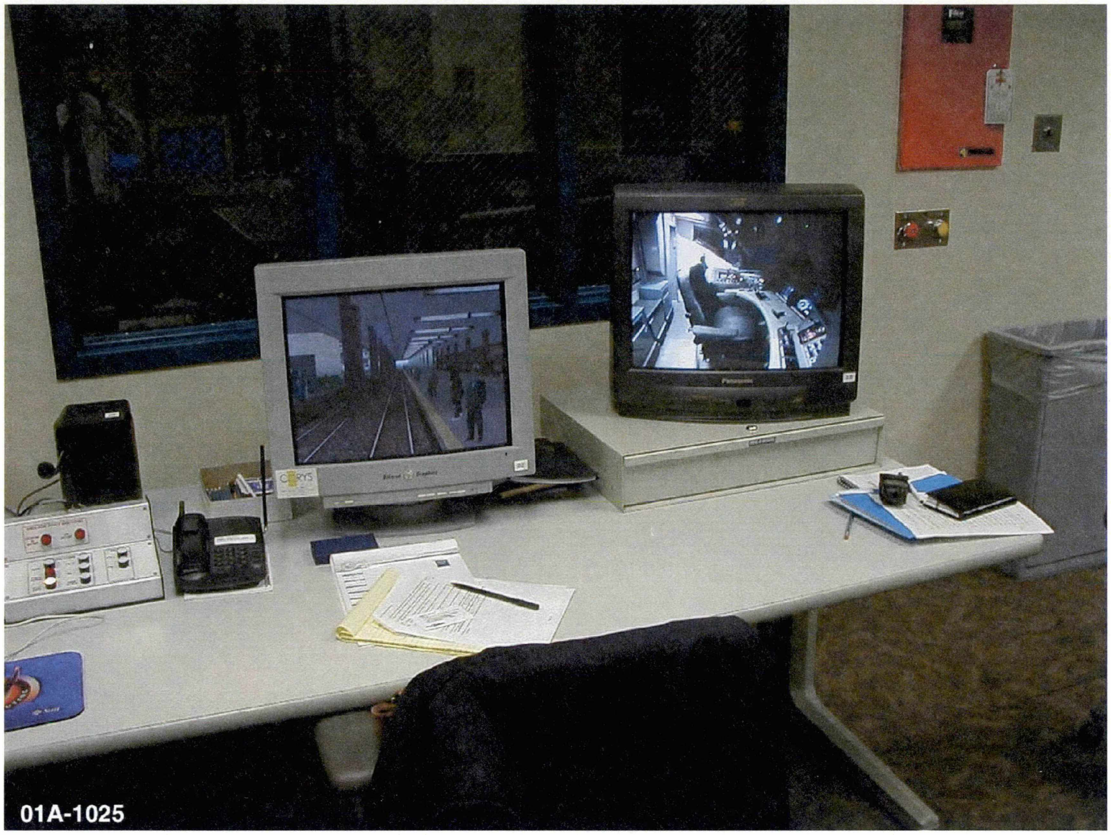

Figure 7. View of the right side of the Acela simulator instructor workstation

Technical room

The technical room (see Figure 2) contains most of the simulator's computing power. In the technical room, multiple computers communicate with one another via Ethernet hub. The computer systems' power sources are located here, too, as are a number of I/O buses and ports. Some of the expansion I/O ports include the following:

- Digital inputs: 33 located in the front of the cab and 9 located in the rear of the cab
- Digital outputs: 17 front and 26 rear
- Analog inputs: 26 front
- Serial inputs: 2 RS-232 ports located in the technical room with additional expansion possible
- Ethernet hub: 6 ports located in the technical room

5.1.2 Development and validation of the Acela high speed rail simulator

Corys T.E.S.S. designed, developed and validated the Acela simulator, including the NEC virtual environment, with the help of NEC locomotive engineers and Amtrak personnel. The result is a very detailed and accurate representation of the NEC physical environment. This was necessary for locomotive engineers to "buy-in" to the simulation. That is, it was essential that the virtual world faithfully replicate the physical characteristics of the NEC with which the locomotive engineers were familiar.

Amtrak cannot modify much of this virtual "world." However, Amtrak personnel can build their own operating scenarios, which affect the operation of the simulated train within the virtual world. The different features of the operating scenario that can be modified using the existing simulator configuration are discussed more fully in section 5.1.3, and include ambient weather and time-of-day, wayside speed signs (for temporary speed restrictions), signal changes and objects along the track.

The basic approach that Corys used to develop the simulator environment involved several steps. First, the virtual grade was developed. Then track was "laid." Then the surrounding environment (e.g., buildings, mountains, etc.) was added. Lastly, "road furniture" (i.e., the signs, signals, grade-crossings and overpasses along the right-of-way) were added. Each aspect of the virtual world was specifically designed by Corys T.E.S.S. for Amtrak.

The source of the Acela train performance data on which the simulator is based comes from Bombardier, the company that is building the Acela trainsets. According to Corys, the Acela simulator performance data are derived from functional definitions (i.e., specifications) and on-board data collection of an Acela trainset operating on the Transportation Technology Center, Inc. test track (i.e., real operational data). The Acela simulator also underwent a "factory acceptance test" in Chicago prior to its online operation in Delaware. The factory acceptance test focused on validating the visual system, including the roadbed/right-of-way and the peripheral objects in the virtual environment.

The Acela simulator does not perfectly replicate the performance and operation of the real Acela trainset since it does not use actual Acela or Amtrak control systems. However, it has been designed to have a high degree of "intended reality" since many of the malfunctions that are simulated require accurate modeling of the entire system. Despite the accurate modeling, the current Acela model is imperfect in a few areas due to the use of early design information from Bombardier, which is not consistent with the existing Acela train. Corys and Amtrak are currently working on upgrading the simulator model to match the "final" Bombardier design of the Acela train.

With respect to the visual system, due to the complex nature of rendering tracks using CGI (they are computationally and visually some the most complex objects to display), particularly those in the foreground, not all sidings are modeled in the simulator. The CDUs and the hardware cab controls are exactly the same as those found in or on the true Acela trainset, however.

A significant component of the Acela simulator is the "data logger." The data logger is responsible for pulling out the relevant performance data that are of interest to researchers. Though not currently extensively used, there is potential to modify the data logger system to enhance data collection to satisfy FRA research needs. This will be discussed more fully in section 6.1.2.

Lastly, though not relevant to the front-end use of the simulator for research purposes, simulator operation is based on four modeling tools that are used to control and manipulate the simulator "behind-the-scenes." The four tools are referred to as "electrix," "controlix" "hydraulix," and "graphset." These four tools drive the simulator and interact via a central processor called "cortex." Corys has also developed a programming language called metatext, which is an internal tool for defining some functions of the simulator.

5.1.3 Programming the Acela high speed rail simulator

Currently, Amtrak training instructors program the simulator scenarios at the instructor's workstation via a "point-and-click" interface. Amtrak staff trained full-time for approximately 5-to-6 weeks to learn how to program and operate the simulator. In essence, an instructor sets up a scenario that includes the route that the simulated train will take, the signal aspects, weather and time-of-day, and the behaviors of the lead and oncoming trains. A locomotive engineer then "operates" the simulated train in the established scenario.

A simulator scenario is made up of software files that specify the (1) initial state of objects (e.g., trains, signals, track) and (2) the events that will occur during the simulation. An event is an instructor-selected command to effect a change along the track, to the signals, to on-board malfunctions, etc. that can occur immediately or that can be triggered later according to a (a) particular time or (b) simulated train position (e.g., milepost 13).

When building a scenario, an individual may modify the following specific simulation variables:

1. Train consist: One can choose from among six high speed train consists and three high speed trainsets (see section 5.1.1 for specific configurations).
2. Environment: The simulated time-of-day and external conditions can be manipulated. These include the rail condition (dry, wet or poor), sky (automatic, light, overcast, or sunny), snow (yes or no), and visibility (normal, mist or fog; and distance of visibility).
3. Route: Specific tracks can be selected for the route, and switches and signals can be manipulated accordingly.
4. Switches: A switch's alignment can be adjusted immediately by the instructor (i.e., in real-time), after a certain time, or when the simulated train arrives at a particular location.
5. Signals: There are two types of signals from which to choose- wayside and in-cab.
6. Station density: Station platform density can be set to low, medium or high.
7. Grade-crossing: A number of grade-crossing states can be selected. They include (1) no fault, (2) broken gates, (3) broken gates with an oncoming car, (4) open gates with an oncoming car and (5) a vehicle blocking the grade-crossing.
8. Catenary faults: The catenary system can experience either (1) no fault or a (2) sagged condition.
9. Track defects: Track conditions include (1) no fault, (2) invisible sagged track, or (3) visible sagged track.
10. Train malfunctions: There are over 130 different train faults from which to select, based on a number of fault types. These include faults in the air supply system, braking system, propulsion, trailing locomotives, power supply, mechanical system, speed sensing, alerter/recorder unit, tilting system, displays, doors, fire suppression system, actions, and train orders.
11. Placeables: Placeables are objects or entities that can be placed on the same track as the simulated train, or an adjacent one. Placeables include objects (deer, refrigerator, boulder) in

the track, a flagman with hand signals, an oncoming train, or a lead train. However, the oncoming train is not 100% faithful to Amtrak operation in that it operates on any non-occupied track rather than on specific tracks. This conflicts with Amtrak routing on the NEC where some tracks are predominantly one direction or the other.[1]

There are also a number of re-play/re-start points located throughout a scenario. Further, an instructor can place additional re-play/re-start points along a scenario during a run. These are designated points within a scenario where an instructor may want to be able to return so that the locomotive engineer can repeat that part of a run, or so that the instructor can re-play or review a specific section of the run. Currently, an instructor can only "place" simulation re-play or re-start points along the route during an actual scenario. That is, the instructor cannot place re-start or re-play points along a route before a simulator run, or after the scenario is over. Further, re-play/re-start points can not be placed at a location after a train has passed that point (i.e., post-hoc placement) in the simulation. For example, if an instructor sees that an engineer is having difficulty around milepost 20, he or she cannot place a re-start button located at milepost 15.

5.1.4 Operating the Acela high speed rail simulator

To operate the Acela simulator, first a scenario must be programmed. Then, a locomotive engineer enters the simulator (i.e., the cab). An instructor or operator sits at the instructor workstation. The individual sitting at the instructor workstation outside the simulator acts not only as the operator, but also fulfills the role of individuals with whom the engineer in the simulator must interact and communicate. These might include the train's conductor, a flagman, a dispatcher, another engineer, or a maintenance foreman, to name a few.

The instructor sitting at the instructor workstation then initiates the simulation and begins a scenario. The engineer in the simulator then begins operating the train as if he or she were operating the train in real life. Over the course of the scenario run, a number of "events" may transpire, depending on how the scenario is programmed. For example, if an engineer were being trained on engine malfunctions, a number of equipment malfunctions can be simulated to familiarize the engineer with the equipment and the malfunctions, as well as to train him or her on the proper solutions to the equipment malfunctions. A simulated run can last for as little as a few minutes to over an hour.

5.2 Acela high speed rail simulator data collection

This section describes the data collection that currently exists and that which is currently possible. At the moment, data collection is primarily observation-based, since instructors are using the Acela simulator to familiarize Amtrak engineers with the new Acela equipment. The simulator is capable of generating a number of quantitative, performance-based data, however. These are discussed in greater detail in the following sections.

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[1] The oncoming train may violate a locomotive engineer's expectancies regarding the behavior of the oncoming train. However, if this is explained to engineers before the simulation, this violation of expectancies may be acceptable to engineers.

5.2.1 Current Acela high speed rail simulator data collection

Currently, Amtrak instructors primarily rely on direct observation of the engineer to monitor or evaluate his or her progress in becoming familiar with the new Acela trainset equipment. To accomplish this, there is one seat inside the cab where an instructor may sit and monitor the locomotive engineer's activity. In addition, there is a charge-coupled device (CCD) camera inside the simulator cab, to the right of the engineer's seat, through which an instructor sitting at the instructor workstation can monitor the engineer (see Figure 5). There is also a microphone located inside the simulator cab (as well as one located at the instructor workstation) that can be used for interaction between the engineer and the instructor. Video data from the camera, along with the audio from the verbal exchanges between the engineer and the operator can also be recorded on videotape.

5.2.2 Currently feasible Acela high speed rail simulator data collection

Although not extensively used by Amtrak instructors, the simulator can produce a limited number of quantitative performance data variables. They include the following:

1. The number of acknowledged CDU equipment fault alarms and the duration of each alarm.
2. The number of times the deceleration rate at stopping is above a predetermined threshold specified by the instructor, and the deceleration rate (mphps) of each occurrence.
3. The number of audible alerter alarms and the duration of each alerter alarm. The duration is from the time the audible alarm begins to the time the alarm is acknowledged or there is movement of a control device that causes the alarm acknowledgment to be "true."
4. The number of times that the brake pipe pressure is reduced below a predetermined threshold, and the duration of each occurrence.
5. Total power consumption over the run (measured in kilowatts per mile per ton).
6. The number of times that the rate of change of acceleration is above a predetermined threshold, and the rate of change (mphpsps) for each occurrence. This measure is called "jerk" and is a measure of ride smoothness.
7. The number of emergency brake applications, and the duration of each application.
8. The number of times that the train speed reaches a predetermined value above the cab signal speed (called "over speed"), and the duration of each occurrence.
9. The number of penalty brake applications (an automatic service application of the air brakes caused by overspeed control, ATC, ATS, or Safety Control), and the duration of each application.
10. The number of times that the train passes a positive stop (implemented in the Advanced Civil Speed Enforcement System, or ACSES).

Data are sampled and recorded about once per second (1 Hz). Most of the variables are simple frequency counts based on a value surpassing a pre-determined threshold established by the instructor before the simulation. An instructor can also establish multiple threshold values for a given variable. For example, an instructor can collect data on the number and duration of brake pipe pressure reductions greater than 10 psi and the number and duration of brake pipe pressure reductions greater than 25 psi. These would be recorded as separate data.

Currently, the data collection period starts at the beginning of a simulator run and stops at the end of the simulator run. No other data collection periods can be specified (i.e., it is not possible to divide a simulation into separate events).

5.2.3 Current Acela high speed rail simulator output

Currently, simulator data can be output into three different formats:

1. Graphical displays presented at the instructor's workstation.
2. An assessment report.
3. Video and audio data of an engineer's simulation run.

Some simulator performance variables can be graphically *displayed* at the instructor's workstation during a simulator run (i.e., in real-time). These data can be displayed over time or distance. However, these data are not currently recorded (i.e., saved); they are simply displayed in real-time. A number of variables can be displayed; some include brake pipe pressure reduction (psi); train speed (mph); train acceleration/deceleration (mphps); and total power consumption (kilowatts per mile per ton). The instructor can select which variables he or she wishes to monitor, as well as the number of variables to monitor. The only limitation is that the simulator system must already compute the variable in order to display it at the instructor's workstation.

A second form of data output is an ASCII-formatted data output file referred to as an "assessment report" (see Figure 8 for an example of an assessment report). It contains relevant information about an engineer's simulator run. The assessment report is divided into four parts:

1. <u>Identifying information</u>. This section contains the name of the student, the date of the simulation run, the train configuration used, and a file name for the run.
2. <u>Event log</u>. The event log records occurrences of the variables described in section 5.2.2. The log includes the time, location[2], and track name for each event, along with the variable type. These data are organized and presented temporally by the time the event occurred. Each row presents a different event occurrence.
3. <u>Event summary</u>. The event summary provides a frequency count for each variable that was recorded (e.g., three brake pipe pressure reductions greater than 25 psi occurred over the course of the simulation run).
4. <u>Instructor comments</u>. Lastly, there is a field where an instructor can enter comments.

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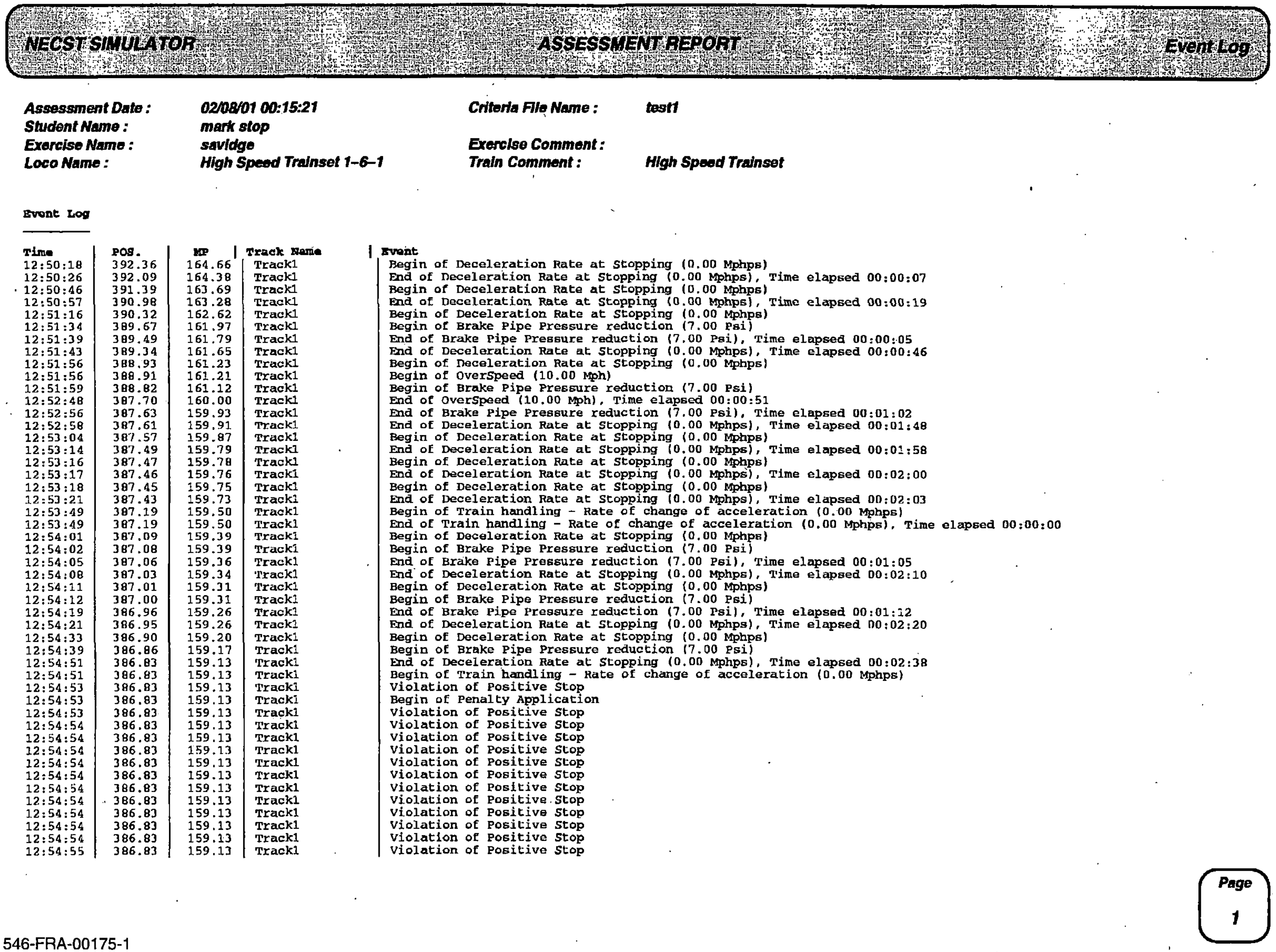
[2] The Acela simulator produces two variables associated with track location: "position" and "mile post." Position refers to the relative location within the NEC, starting with 0 on the southern end of the NEC and increasing as trains travel north toward Boston (approximately 600 miles). The second variable, milepost, is the actual milepost as would be found in the real NEC. The reason that there are two location variables is that frequently there may be two locations within the real NEC that contain the same milepost (e.g., there may be a milepost 210 located near Baltimore and one near Rhode Island), depending on which territory the train is operating on. So, both a true milepost and a relative location (position within the NEC virtual world) are used to determine exactly where the event occurred.



NECST SIMULATOR **ASSESSMENT REPORT** **Event Log**

Assessment Date : 02/08/01 00:15:21
Criteria File Name : test1
Student Name : mark stop
Exercise Name : savidge
Exercise Comment :
Loco Name : High Speed Trainset 1-6-1
Train Comment : High Speed Trainset

Event Log

```
Time      | POS.   | MP     | Track Name  | Event
12:50:18  | 392.36 | 164.66 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:50:26  | 392.09 | 164.38 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:00:07
12:50:46  | 391.39 | 163.69 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:50:57  | 390.98 | 163.28 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:00:19
12:51:16  | 390.32 | 162.62 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:51:34  | 389.67 | 161.97 | Track1      | Begin of Brake Pipe Pressure reduction (7.00 Psi)
12:51:39  | 389.49 | 161.79 | Track1      | End of Brake Pipe Pressure reduction (7.00 Psi), Time elapsed 00:00:05
12:51:43  | 389.34 | 161.65 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:00:46
12:51:56  | 388.93 | 161.23 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:51:56  | 388.91 | 161.21 | Track1      | Begin of OverSpeed (10.00 Mph)
12:51:59  | 388.82 | 161.12 | Track1      | Begin of Brake Pipe Pressure reduction (7.00 Psi)
12:52:48  | 387.70 | 160.00 | Track1      | End of OverSpeed (10.00 Mph), Time elapsed 00:00:51
12:52:56  | 387.63 | 159.93 | Track1      | End of Brake Pipe Pressure reduction (7.00 Psi), Time elapsed 00:01:02
12:52:58  | 387.61 | 159.91 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:01:48
12:53:04  | 387.57 | 159.87 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:53:14  | 387.49 | 159.79 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:01:58
12:53:16  | 387.47 | 159.78 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:53:17  | 387.46 | 159.76 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:02:00
12:53:18  | 387.45 | 159.75 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:53:21  | 387.43 | 159.73 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:02:03
12:53:49  | 387.19 | 159.50 | Track1      | Begin of Train handling - Rate of change of acceleration (0.00 Mphps)
12:53:49  | 387.19 | 159.50 | Track1      | End of Train handling - Rate of change of acceleration (0.00 Mphps), Time elapsed 00:00:00
12:54:01  | 387.09 | 159.39 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:54:02  | 387.08 | 159.39 | Track1      | Begin of Brake Pipe Pressure reduction (7.00 Psi)
12:54:05  | 387.06 | 159.36 | Track1      | End of Brake Pipe Pressure reduction (7.00 Psi), Time elapsed 00:01:05
12:54:08  | 387.03 | 159.34 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:02:10
12:54:11  | 387.01 | 159.31 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:54:12  | 387.00 | 159.31 | Track1      | Begin of Brake Pipe Pressure reduction (7.00 Psi)
12:54:19  | 386.96 | 159.26 | Track1      | End of Brake Pipe Pressure reduction (7.00 Psi), Time elapsed 00:01:12
12:54:21  | 386.95 | 159.26 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:02:20
12:54:33  | 386.90 | 159.20 | Track1      | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:54:39  | 386.86 | 159.17 | Track1      | Begin of Brake Pipe Pressure reduction (7.00 Psi)
12:54:51  | 386.83 | 159.13 | Track1      | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:02:38
12:54:51  | 386.83 | 159.13 | Track1      | Begin of Train handling - Rate of change of acceleration (0.00 Mphps)
12:54:53  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:53  | 386.83 | 159.13 | Track1      | Begin of Penalty Application
12:54:53  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:54  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
12:54:55  | 386.83 | 159.13 | Track1      | Violation of Positive Stop
```

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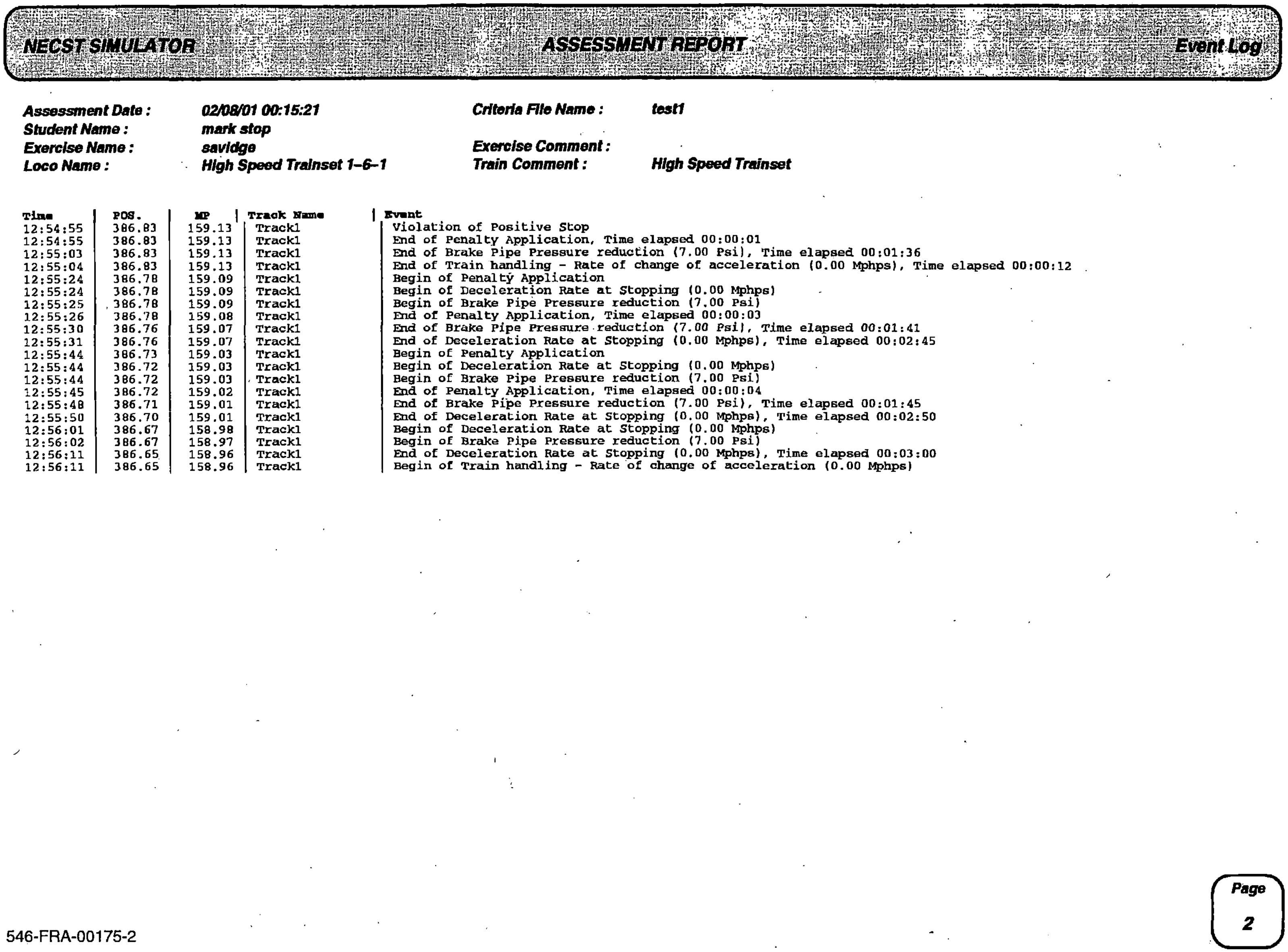
Figure 8. Acela simulator assessment report



NECST SIMULATOR **ASSESSMENT REPORT** **Event Log**

Assessment Date : 02/08/01 00:15:21
Student Name : mark stop
Exercise Name : savidge
Loco Name : High Speed Trainset 1-6-1
Criteria File Name : test1
Exercise Comment :
Train Comment : High Speed Trainset

```
Time     | POS.   |  MP    | Track Name   | Event
12:54:55 | 386.83 | 159.13 | Track1       | Violation of Positive Stop
12:54:55 | 386.83 | 159.13 | Track1       | End of Penalty Application, Time elapsed 00:00:01
12:55:03 | 386.83 | 159.13 | Track1       | End of Brake Pipe Pressure reduction (7.00 Psi), Time elapsed 00:01:36
12:55:04 | 386.83 | 159.13 | Track1       | End of Train handling - Rate of change of acceleration (0.00 Mphps), Time elapsed 00:00:12
12:55:24 | 386.78 | 159.09 | Track1       | Begin of Penalty Application
12:55:24 | 386.78 | 159.09 | Track1       | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:55:25 | 386.78 | 159.09 | Track1       | Begin of Brake Pipe Pressure reduction (7.00 Psi)
12:55:26 | 386.78 | 159.08 | Track1       | End of Penalty Application, Time elapsed 00:00:03
12:55:30 | 386.76 | 159.07 | Track1       | End of Brake Pipe Pressure reduction (7.00 Psi), Time elapsed 00:01:41
12:55:31 | 386.76 | 159.07 | Track1       | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:02:45
12:55:44 | 386.73 | 159.03 | Track1       | Begin of Penalty Application
12:55:44 | 386.72 | 159.03 | Track1       | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:55:44 | 386.72 | 159.03 | Track1       | Begin of Brake Pipe Pressure reduction (7.00 Psi)
12:55:45 | 386.72 | 159.02 | Track1       | End of Penalty Application, Time elapsed 00:00:04
12:55:48 | 386.71 | 159.01 | Track1       | End of Brake Pipe Pressure reduction (7.00 Psi), Time elapsed 00:01:45
12:55:50 | 386.70 | 159.01 | Track1       | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:02:50
12:56:01 | 386.67 | 158.98 | Track1       | Begin of Deceleration Rate at Stopping (0.00 Mphps)
12:56:02 | 386.67 | 158.97 | Track1       | Begin of Brake Pipe Pressure reduction (7.00 Psi)
12:56:11 | 386.65 | 158.96 | Track1       | End of Deceleration Rate at Stopping (0.00 Mphps), Time elapsed 00:03:00
12:56:11 | 386.65 | 158.96 | Track1       | Begin of Train handling - Rate of change of acceleration (0.00 Mphps)
```

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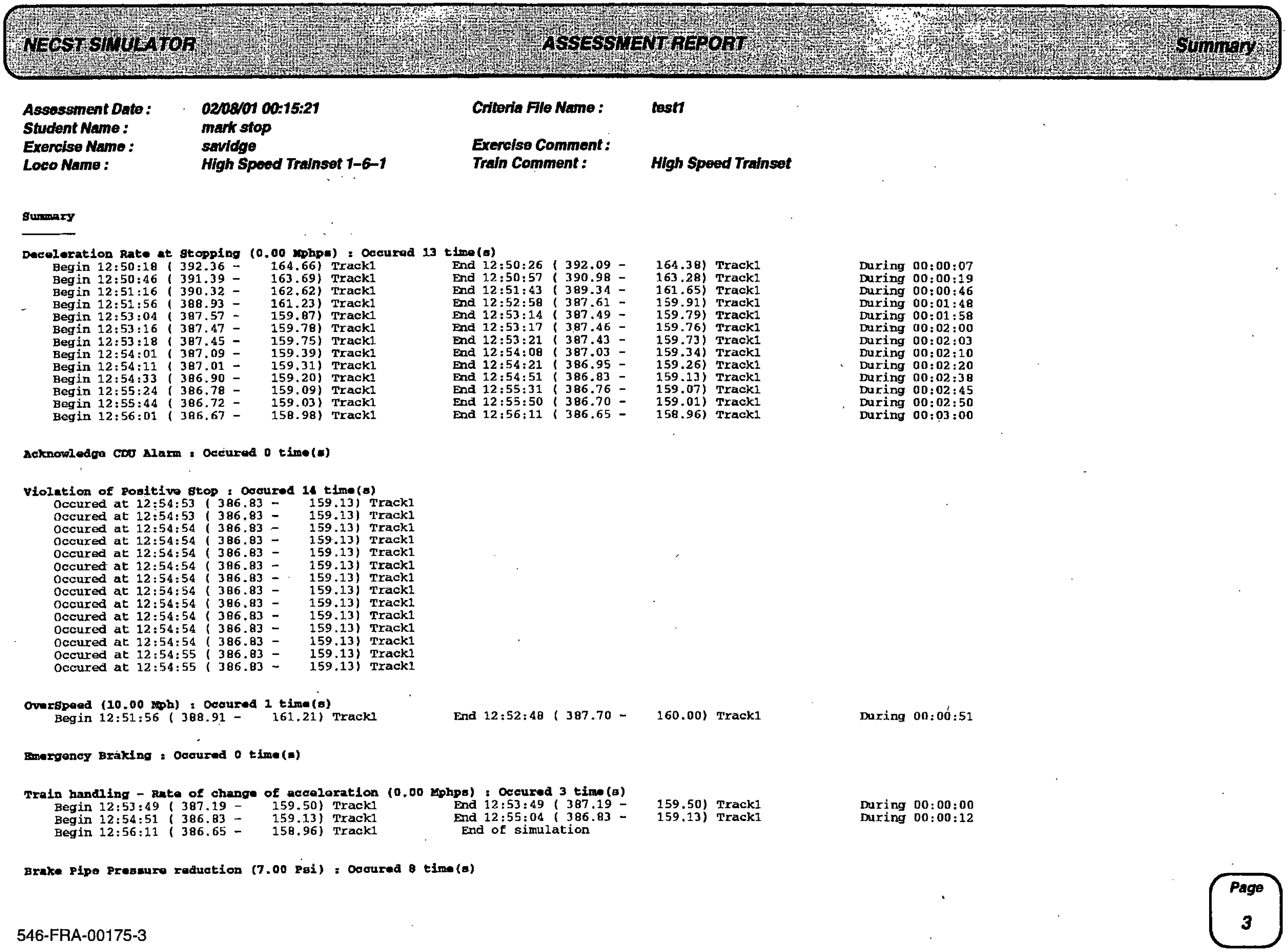
Figure 8. Acela simulator assessment report (continued)



NECST SIMULATOR **ASSESSMENT REPORT** **Summary**

Assessment Date :	02/08/01 00:15:21	**Criteria File Name :**	test1
Student Name :	mark stop		
Exercise Name :	savidge	**Exercise Comment :**	
Loco Name :	High Speed Trainset 1-6-1	**Train Comment :**	High Speed Trainset

```
Summary
_______

Deceleration Rate at Stopping (0.00 Mphps) : Occured 13 time(s)
    Begin 12:50:18 ( 392.36 -    164.66) Track1          End 12:50:26 ( 392.09 -    164.38) Track1              During 00:00:07
    Begin 12:50:46 ( 391.39 -    163.69) Track1          End 12:50:57 ( 390.98 -    163.28) Track1              During 00:00:19
    Begin 12:51:16 ( 390.32 -    162.62) Track1          End 12:51:43 ( 389.34 -    161.65) Track1              During 00:00:46
    Begin 12:51:56 ( 388.93 -    161.23) Track1          End 12:52:58 ( 387.61 -    159.91) Track1              During 00:01:48
    Begin 12:53:04 ( 387.57 -    159.87) Track1          End 12:53:14 ( 387.49 -    159.79) Track1              During 00:01:58
    Begin 12:53:16 ( 387.47 -    159.78) Track1          End 12:53:17 ( 387.46 -    159.76) Track1              During 00:02:00
    Begin 12:53:18 ( 387.45 -    159.75) Track1          End 12:53:21 ( 387.43 -    159.73) Track1              During 00:02:03
    Begin 12:54:01 ( 387.09 -    159.39) Track1          End 12:54:08 ( 387.03 -    159.34) Track1              During 00:02:10
    Begin 12:54:11 ( 387.01 -    159.31) Track1          End 12:54:21 ( 386.95 -    159.26) Track1              During 00:02:20
    Begin 12:54:33 ( 386.90 -    159.20) Track1          End 12:54:51 ( 386.83 -    159.13) Track1              During 00:02:38
    Begin 12:55:24 ( 386.78 -    159.09) Track1          End 12:55:31 ( 386.76 -    159.07) Track1              During 00:02:45
    Begin 12:55:44 ( 386.72 -    159.03) Track1          End 12:55:50 ( 386.70 -    159.01) Track1              During 00:02:50
    Begin 12:56:01 ( 386.67 -    158.98) Track1          End 12:56:11 ( 386.65 -    158.96) Track1              During 00:03:00

Acknowledge CDU Alarm : Occured 0 time(s)

Violation of Positive Stop : Occured 14 time(s)
    Occured at 12:54:53 ( 386.83 -    159.13) Track1
    Occured at 12:54:53 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:54 ( 386.83 -    159.13) Track1
    Occured at 12:54:55 ( 386.83 -    159.13) Track1
    Occured at 12:54:55 ( 386.83 -    159.13) Track1

OverSpeed (10.00 Mph) : Occured 1 time(s)
    Begin 12:51:56 ( 388.91 -    161.21) Track1          End 12:52:48 ( 387.70 -    160.00) Track1              During 00:00:51

Emergency Braking : Occured 0 time(s)

Train handling - Rate of change of acceleration (0.00 Mphps) : Occured 3 time(s)
    Begin 12:53:49 ( 387.19 -    159.50) Track1          End 12:53:49 ( 387.19 -    159.50) Track1              During 00:00:00
    Begin 12:54:51 ( 386.83 -    159.13) Track1          End 12:55:04 ( 386.83 -    159.13) Track1              During 00:00:12
    Begin 12:56:11 ( 386.65 -    158.96) Track1           End of simulation

Brake Pipe Pressure reduction (7.00 Psi) : Occured 8 time(s)
```

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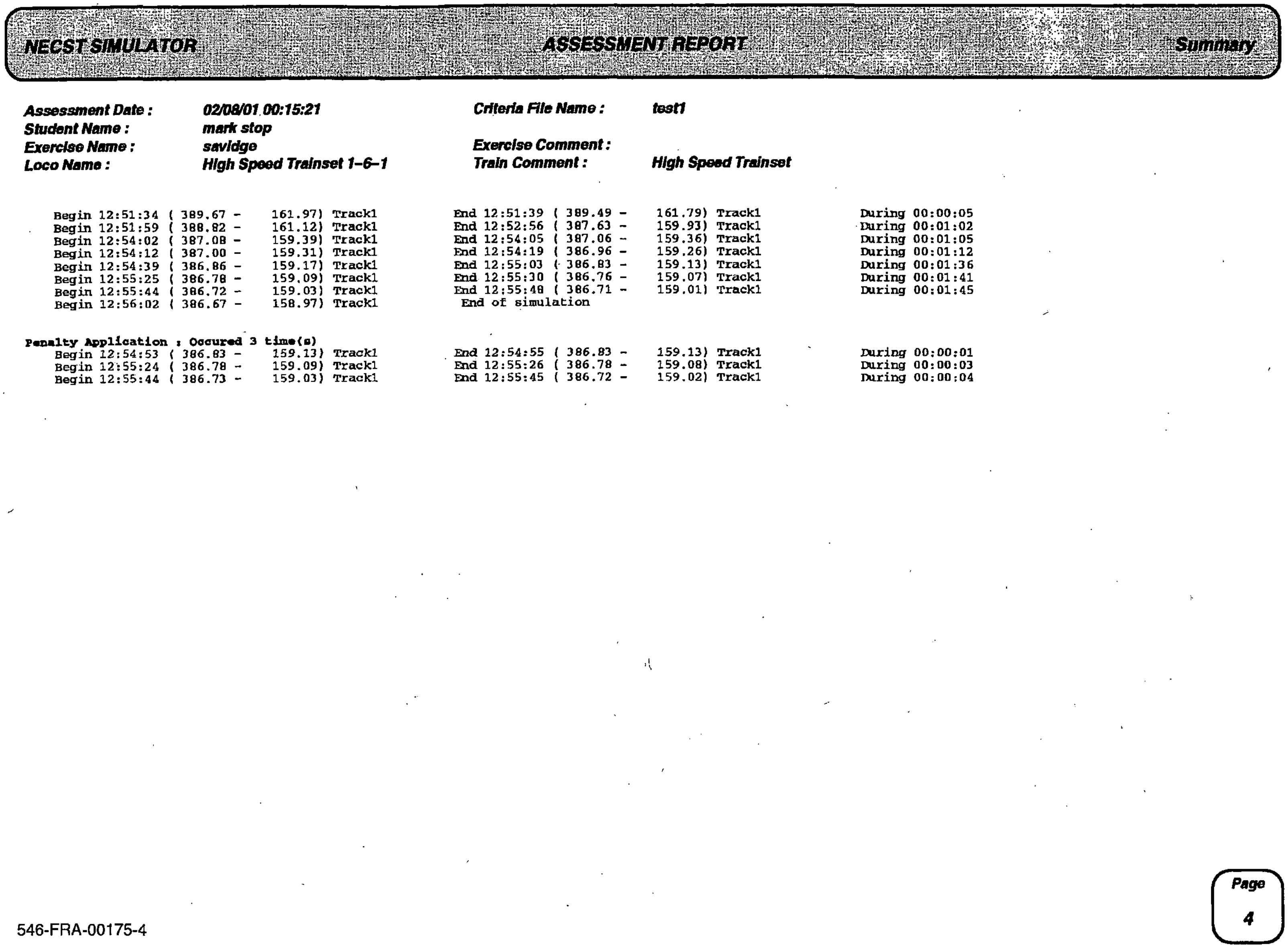
Figure 8. Acela simulator assessment report (continued)



NECST SIMULATOR **ASSESSMENT REPORT** **Summary**

Assessment Date :	02/08/01 00:15:21	**Criteria File Name :**	test1
Student Name :	mark stop		
Exercise Name :	savidge	**Exercise Comment :**	
Loco Name :	High Speed Trainset 1-6-1	**Train Comment :**	High Speed Trainset

```
    Begin 12:51:34 ( 389.67 -    161.97) Track1        End 12:51:39 ( 389.49 -    161.79) Track1          During 00:00:05
    Begin 12:51:59 ( 388.82 -    161.12) Track1        End 12:52:56 ( 387.63 -    159.93) Track1          During 00:01:02
    Begin 12:54:02 ( 387.08 -    159.39) Track1        End 12:54:05 ( 387.06 -    159.36) Track1          During 00:01:05
    Begin 12:54:12 ( 387.00 -    159.31) Track1        End 12:54:19 ( 386.96 -    159.26) Track1          During 00:01:12
    Begin 12:54:39 ( 386.86 -    159.17) Track1        End 12:55:03 ( 386.83 -    159.13) Track1          During 00:01:36
    Begin 12:55:25 ( 386.78 -    159.09) Track1        End 12:55:30 ( 386.76 -    159.07) Track1          During 00:01:41
    Begin 12:55:44 ( 386.72 -    159.03) Track1        End 12:55:48 ( 386.71 -    159.01) Track1          During 00:01:45
    Begin 12:56:02 ( 386.67 -    158.97) Track1         End of simulation

Penalty Application : Occured 3 time(s)
    Begin 12:54:53 ( 386.83 -    159.13) Track1        End 12:54:55 ( 386.83 -    159.13) Track1          During 00:00:01
    Begin 12:55:24 ( 386.78 -    159.09) Track1        End 12:55:26 ( 386.78 -    159.08) Track1          During 00:00:03
    Begin 12:55:44 ( 386.73 -    159.03) Track1        End 12:55:45 ( 386.72 -    159.02) Track1          During 00:00:04
```

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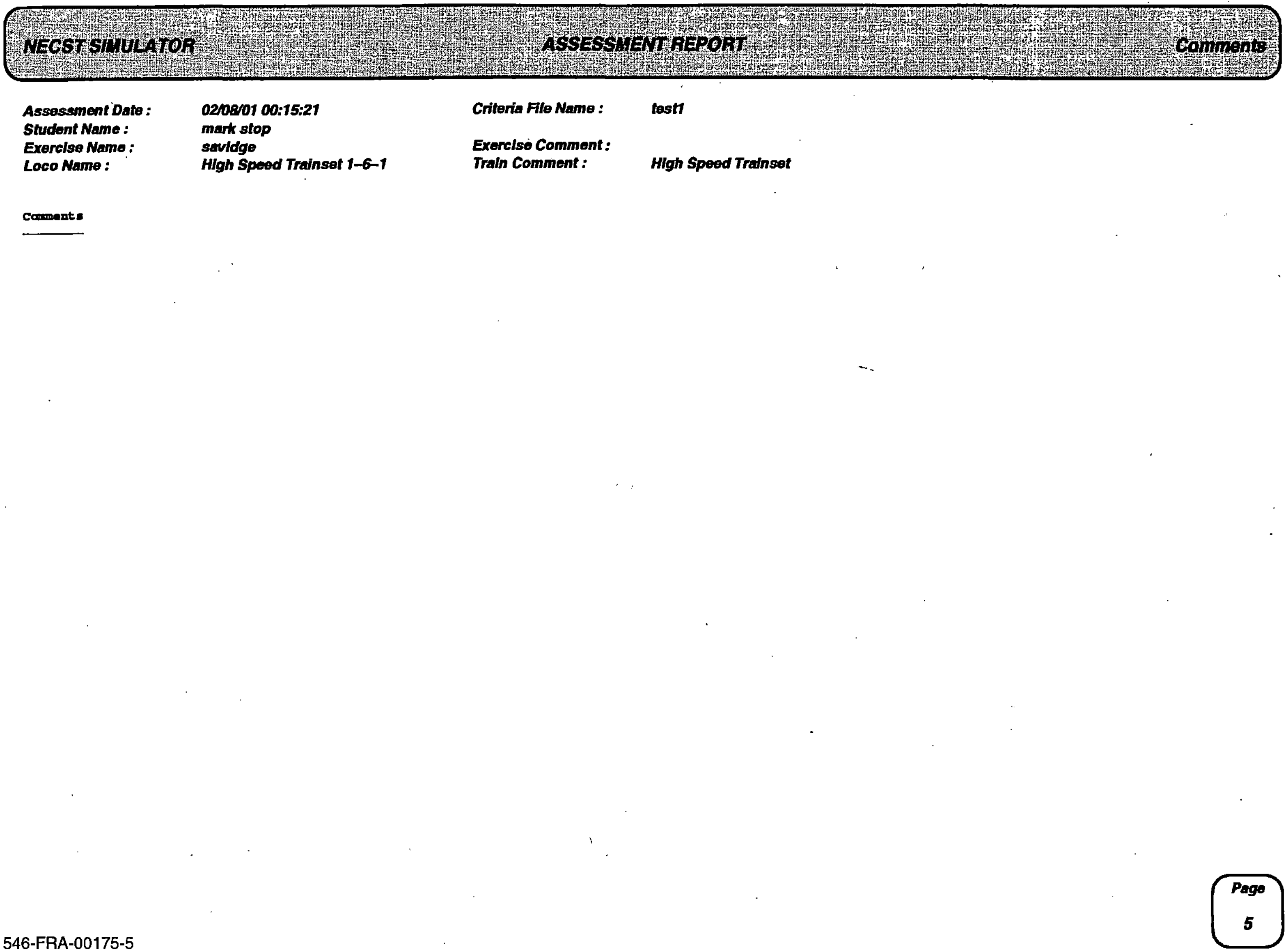
Figure 8. Acela simulator assessment report (continued)



NECST SIMULATOR **ASSESSMENT REPORT** **Comments**

Assessment Date :	02/08/01 00:15:21	**Criteria File Name :**	test1
Student Name :	mark stop		
Exercise Name :	savidge	**Exercise Comment :**	
Loco Name :	High Speed Trainset 1-6-1	**Train Comment :**	High Speed Trainset

Comments

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Figure 8. Acela simulator assessment report (continued)

Data can be saved after each simulator run, and thus multiple engineers can operate the simulator back-to-back. Data can be separated for each engineer using identifying information such as the engineer's name. To access or examine the data from a simulator run, however, it is necessary to shut down the simulator. Thus, immediate feedback is not feasible unless the simulator is shut down between runs.

Lastly, the audio and video segments of a simulator run can be recorded onto videotape. The audio and video data are not integrated with the simulator data, however.

6 Modifications to the Acela High Speed Rail Simulator

To use the Acela simulator as a research tool, there is a need for greater control over scenarios, simulation runs, and data collection, than currently exists. Thus, there is a need to expand the Acela simulator's capabilities. Section 6 addresses this need for expanded capabilities and is divided into two sections. Section 6.1 addresses simulator requirements to enable researchers to use the Acela simulator to collect human-centered research data, focusing on what is needed and what is feasible. Section 6.2 presents some specific recommendations regarding modifications to the Acela simulator. These recommendations are based on different (increasing) levels of funding, so that a range of options is available from which to choose. The advantages and disadvantages of each level of modification are discussed as part of section 6.2.

6.1 Desired Acela high speed rail simulator capabilities

Specifically, there is a need to expand the simulator's capabilities in the following three areas:

1. Scenario development and control
2. Data collection and reduction
3. Experimental control

Section 6.1 discusses this triad of desired capabilities in more detail.

6.1.1 Scenario development and control

For a research simulator, it is desirable to have precise and measurable control over the development and implementation of operating scenarios. Currently an instructor has some control over the operating scenario (see section 5.1.3). This control is limited to programming the operating scenario, however, and does not extend to the rest of the virtual environment, which was programmed specifically by Corys according to Amtrak specifications of the NEC, and which cannot be changed with the current simulator software and configuration.

Off-line scenario development

To develop (i.e., program) an operating scenario, an instructor must use the simulator's computer resources. Therefore, the simulator itself cannot be operated during scenario development. Ideally, an individual would be able to develop scenarios off-line so that the simulator itself is not tied up or otherwise occupied, thus freeing it for concurrent operation. Such an approach would increase the efficient use of the equipment by expanding access to the equipment. This may in turn reduce the cost of developing and/or using the simulator since both developing scenarios and operating the simulator could be carried out simultaneously. According to Corys, a scenario preparation station may be able to be created using some duplicated simulator components. This option would have to be explored in more detail with Corys.

Multiple configurations

A related issue is whether it is economically beneficial to either Amtrak or the FRA to have two versions of the simulator software: one version that Amtrak can use to train its locomotive engineers, and a second separate version of the simulator software that FRA researchers can use to conduct research that will not interfere or conflict with the Amtrak training configuration.

Depending on the specific use of the simulator for a given run, one or the other software configurations can be set-up and used. The reason for producing separate configurations is that researchers may want to implement changes that Amtrak does not want to implement, and instead of reprogramming the operating scenarios each time, it may be easier to set-up essentially two separate "logins" to the simulator. According to Corys, the simulator can support multiple configurations, and therefore may be able to accommodate a training configuration and a research configuration. Further discussions with both Amtrak and Corys would be necessary to explore this option in greater detail. It is critical that the research configuration does not interfere in any way with the Amtrak training configuration. One of the evaluation team members was skeptical of developing two simulator configurations, however, citing a concern over unforeseen complications and interference. Additional memory (i.e., disk space) and other hardware may be necessary to support multiple software configurations.

Corys suggested that a decision should be made only after the FRA specifies what type of scenario control is desirable, so that comparisons can be made regarding what differences there are between what the FRA wants and what currently exists, and whether it is cost-effective to maintain a single Amtrak/researcher configuration or two separate configurations. If there are two configurations, Corys noted that they would be able to be switched in 15 minutes or less, and a front-end interface could be developed to allow the operator to choose which configuration to use.

Access to previously developed operating scenarios

Access to older (previous) operating scenarios is also desirable to enable replication of experimental results. According to Corys, specific operating scenarios can be saved on disk and can be archived. Corys notes, however, that the software configuration at the time the operating scenario is developed (called a "release") must also be saved and cross-referenced because software configuration updates may affect the ability to run a previous operating scenario. Corys provides Amtrak with archives of each simulator software configuration "release" on tape, therefore, operating scenarios should be able to be archived and cross-referenced with the appropriate simulation configuration used at the time. For example, earlier simulator software configurations can be reinstalled any time. A limitation may be that hardware changes made at a later date may make previous software configurations incompatible unless the hardware is reconfigured to match the previous software configuration. Since updates to the simulation software can be done in a variety of ways (e.g., as an addition to a current configuration or as an entirely new configuration), specific changes to the simulator software or hardware should be discussed with Amtrak and Corys before their implementation to ensure that access to previous operating scenarios can be preserved.

Simulation of false negatives

A capability that the Acela simulator does not currently have but that was identified as being important by the evaluation team was the ability to simulate "false negatives," where the CDU indicates that all systems are functioning normally but there is an actual problem that may be indicated by some other simulated method, such as flat spots on the wheels of the HEP, that may produce a slightly "rougher" ride. According to Corys, the simulator software can be modified to simulate this type of malfunction.

Adding new features to the virtual environment

It is also desirable to be able to add new features to the virtual environment. The evaluation team suggested that the FRA may want to be able to introduce additional objects into the operating scenario, for example. It is possible now to introduce a vehicle at a grade-crossing or a stopped train ahead in the same or adjacent track. These and a few other objects have already been programmed into the simulator as options from which an instructor can select. Other objects (e.g., a cinder block falling from an overhead pass) likely can be added through Corys programming. Additional objects that are desired should be identified; Corys can then develop and introduce them as options in a new software release.

Corys can also develop a Track Builder Tool (TBT) for the Amtrak simulator. According to Corys, the TBT could enable researchers to develop new sections of track to be used in conjunction with the NEC. Alternatively, the TBT could be used to develop new, generic virtual environments and operating scenarios separate from the NEC. This latter option is discussed later in section 7.

Reconfigurable in-cab displays

The CDUs inside the cab are also programmable and therefore re-configurable to satisfy various potential research needs. However, the amount of additional displays and the types will be limited by the current CDU configuration. It may be possible to re-engineer the existing CDUs, or, for more flexibility, it may be possible to add more powerful hardware to support more complex displays, including touch screen LCDs. Corys has also developed a set of rapid prototyping tools that researchers could use to design and study new display concepts.

6.1.2 Data collection and reduction

This section addresses several issues regarding desired Acela high speed rail simulator data collection and reduction capabilities.

Locomotive engineer performance measures

One of the greatest challenges in studying locomotive engineers is that, because they are highly-trained professionals, they make very few errors (e.g., passing a positive stop), and are involved in even fewer, if any, incidents (e.g., collision). Thus, it is necessary to develop a battery of surrogate performance measures to replace the more traditional and straight-forward measures such as the number of collisions. Surrogate performance measures must be sensitive enough to be recorded and evaluated statistically and must be clearly related to larger measures or concepts, such as safety, speed control and operating efficiency. To assist the FRA and others in conducting human-centered locomotive engineer simulator research, a list of train and train handling performance measures was generated. The performance measures are organized by general activity type, or category. Five train handling categories were identified. They are:

1. Speed control
2. Efficiency/fuel consumption
3. Ride comfort/quality
4. Safety
5. Engineer behavior/performance

Table 5 presents the train handling performance measures, organized by general type of train handling activity. In addition to the five general categories, a sixth category, cab ergonomics, was included, since cab ergonomic factors can affect an engineer's performance in the simulator, and his or her ability to safely and efficiently operate a train. Some of these performance measures are based on measures that have been collected in other locomotive simulators, including the Research and Locomotive Evaluator/Simulator (RALES), the Volpe NTSC locomotive simulator, and several Amtrak locomotive simulators. The performance measures presented in Table 5 were reviewed by the evaluation team, several certified locomotive engineers, and a locomotive engineer instructor, to provide face validity to the train handling performance measures. Feedback from these reviewers was incorporated into the final set of performance measures presented in Table 5.

Table 5. Train and train handling performance measures

Conventional		HSR	
Pass	Freight	Pass	Variable
			Speed Control
x	x	x	Maximum speed
x	x	x	Variance of speed
x		x	Duration (elapsed time) of a run
x	x	x	Number of emergency brake applications
x	x		Number of dynamic brake applications
x	x		Number of running releases (failure to stop train when air brake reduction > X lbs. while traveling at or below Y mph)
x	x		their release)
x	x		Number of occurrences where auxiliary brake reservoir < X lbs.
x	x		application > Y lbs.)
	x		Number of excessive locomotive (independent) brake applications (locomotive brake pressure release > X lbs. while traveling greater than Y mph)
x	x	x	Number of penalty brake applications
x	x		Maximum brake pipe reduction
x	x		Variance of brake pipe reductions
	x		Number of brake pipe reductions above X lbs.
	x		Wheel slippage? Y/N
	x		Reaction time (RT) to wheel slippage
	x		Duration of wheel slippage
	x		Location (axleset) of wheel slippage
x	x	x	the track)
			Efficiency/fuel consumption
x	x		Gallons of fuel used
x	x		Kilowatts per mile per ton
x	x	x	Variance of throttle position
x		x	Schedule adherence (time-based)
x	x	x	Failure to make required stops
x	x	x	Centered reverser during idle time? Y/N
x	x	x	stop
			Ride Comfort/Quality
x		x	Max. longitudinal deceleration (g's)
x		x	Var. longitudinal deceleration
x		x	Longitudinal deceleration > predetermined threshold
x		x	Max. lateral acceleration (g's)
x		x	Var. lateral acceleration
x		x	Lateral acceleration > predetermined threshold
	x		Max. buff force
	x		Steady state buff force
	x		Max. draft force
	x		Steady state draft force
			Safety
x	x	x	Collisions
x	x	x	Near misses (TBD; e.g., minimal distance between 2 trains; time-to-impact)
x	x	x	Speed limit violations a.k.a. overspeed (e.g., violation of track speed, train order speed, bulletin speed or in-cab signal speed)

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Table 5. Train and train handling performance measures (continued)

Conventional Pass	Conventional Freight	HSR Pass	Variable
x	x	x	Degree of overspeed
x	x	x	Duration of overspeed
x	x	x	Distance traveled while overspeed
x	x	x	Stop past red signal (Y/N) a.k.a. overrun
x	x	x	Distance stopped in front of, or past, red signal
x	x	x	Horn blow activity
x	x	x	Bell activity
x	x	x	Sanding activity? (e.g., counts)
x	x	x	RT to need for sanding
x	x	x	Train speed when emergency brake applied
			Engineer Behavior/Performance
x	x	x	RT to internal alarm (e.g., locomotive/equipment malfunction)
x	x	x	Number of missed internal alarms
x	x	x	RT to alerter alarm
x	x	x	Number of missed alerter alarms
x	x	x	RT to in-cab signal change
x	x	x	Number of missed in-cab signal changes
x	x	x	RT to wayside signal change
x	x	x	Number of missed wayside signal changes
x	x	x	RT to wayside detector notification (e.g., notification of dragging equipment)
x	x	x	Number of missed wayside detector notifications
x	x	x	RT to audio communications with external RR personnel
x	x	x	Number of missed audio communications
x	x	x	Duration of audio communications
x	x	x	RT to a datalink/digital communications
x	x	x	Number of missed datalink/digital communications
x	x	x	Duration of datalink/digital communications
x	x	x	RT to external events (e.g., object in track, change in speed restriction)
x	x	x	Number of missed external events
x	x	x	Elapsed time between throttle changes
x	x	x	Situation awareness (e.g., SART, stop simulation followed by Q&A)
x	x	x	Readback/hearback and other communication protocol errors
x	x	x	Subjective workload
x	x	x	Subjective fatigue
x	x	x	Subjective stress
x	x	x	Physiological stress
x	x	x	Objective fatigue (e.g., perclos)
x	x	x	Distracter/secondary tasks
x	x	x	Taskload (counts of the number of discrete tasks)
x	x	x	Time-to-complete tasks
x	x	x	Sequence of loco engineer's physical activities in carrying out tasks
x	x	x	Eye glance data: sequence, duration, frequency (e.g., percent of time looking at a particular display, number of glances to a display)
			Cab Ergonomics
x	x	x	Loudness (dB)
x	x	x	Temperature
x	x	x	Vibration

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General approach to data collection

The recommended approach to data collection is to collect as much raw data as possible, as frequently as possible, then reduce and post-process the data afterward using pre-defined filters and calculations. All data related to engineer actions, simulated train state and performance, instructor inputs/actions, and scenario events (e.g., state of a signal as it is passed, information on when the train passes trackside objects of interest, etc.) should be collected. These include both continuous and discrete variables, and address both absolute and relative measures. The specific simulator operating scenario configuration should also be saved. Front-end user interfaces could be developed to allow researchers to select and post-process only the data of interest. The chief advantage of this method is that it enables a researcher to conduct any number of post-hoc analyses. For example, it would be possible to re-analyze an engineer's performance using different filters or scoring criteria. The alternative is to be limited by a subset of pre-defined variables that is specified prior to the simulation.

It is also desirable to be able to segment an operating scenario into a number of smaller "events" that can be treated as distinct units of analysis. Data could then be collected for each event. An event may be thought of as a simulation-within-a-simulation. A researcher may be interested in certain engineer behaviors or actions within each event, and events may be expected to vary (though this is not necessary). Preferably, a researcher would be able to define events in an experiment beforehand, based on some combination of event beginning and end "markers," such as distance (e.g., milepost 10 to milepost 14), time (0700 hours to 0710 hours), triggering action (e.g., a change in weather or the introduction of some other event), etc. Though not currently an option, according to Corys, it is feasible to introduce a function to the simulator that would allow a researcher to assign event markers prior to a simulation run. The specific functionality of this capability would have to be discussed further with Corys. The method of defining events should be flexible so that a researcher can define events a number of ways within an experiment, as well as across experiments.

The advantage of dividing a simulation into smaller events is to be able to focus analyses on a particular type of activity (e.g., an engineer detecting an unexpected signal "drop" while operating on a straight-away) or to be able to increase the power of a simulation by creating, in effect, a within-subjects, repeated-measures, design. This may be accomplished, for example, if one is interested in studying a locomotive engineer's performance as he or she negotiates two different types of interlockings. A simulation may be designed to contain 20 interlockings, 10 each of two different types. Each interlocking can be treated as a separate event. Thus, the one simulation has produced data for one engineer operating 10 interlockings of one type, and 10 of another type. A minimal number of participants are then needed to collect sufficient data to yield statistically significant results comparing performance between two different interlocking types.

Data management

Researchers will need to manage the data once it has been collected. Currently the Acela simulator has a relatively elementary data recording structure (called a "data logger") that is used to manage data from the simulator. Data logging is a software function that can be expanded, through Corys intervention, to incorporate new variables of interest. Filtering tools could be developed to enable researchers to filter and reduce the data according to their specifications for the particular experiment. The filtering tools could contain easy-to-use front-end interfaces, and among other options, the tools could enable users to select the events of interest as well as the variables of interest. Since some variables will have a lot of associated noise, filtering will be critical. Raw data will take up a lot of storage "space," but given the low cost of storage media, the ability to conduct post-hoc analyses on the data more than outweighs the associated cost of buying additional storage space to store the raw data. The tool(s) should be capable of producing an ASCII file containing the reduced data so that the data can be read and analyzed by standard statistical software packages such as SAS, SPSS and Microsoft Excel.

One possible data logging structure that was discussed by the evaluation team and Corys is to log continuous and discrete variables in separate files, at separate frequencies. Continuous variables could be regularly recorded or logged to one file at a certain frequency, while discrete, infrequent data could be recorded in a separate log, at a lower frequency. This would save disk space. An example of a less frequent, discrete event might be the occurrence of the simulated train passing a red signal. These types of activities occur irregularly and are discrete, and thus would not need to be recorded continuously and at a high frequency. Instead, a special record could be written when they occur, along with a timestamp that would allow the discrete data to be integrated with the continuous data. The specific data to be recorded under each format would have to be determined by the FRA and discussed with Corys.

According to Corys, the number and frequency of variables for which data are collected directly affects the CPU power available for other simulator functions. Thus, the more data that are saved and the more frequently the data are saved, the greater the draw on the simulator CPU. This draw may negatively affect the simulator's performance at some point. It may be possible to upgrade the simulator's CPU, or to add an additional CPU to enable multiple processing, but this will depend on what upgrades are available by the CPU's manufacturer and the operating systems that are compatible with the hardware upgrades. Both the CPU and the operating system must be compatible with the rest of the simulator system. The CPU upgrade, if feasible, would enable more and more frequent data collection without negatively impacting the simulator's performance.

Currently, the Acela simulator collects or "logs" data about once per second, or 1 Hz. The evaluation team recommends that continuous data should be captured at least 30 times per second (i.e., 30 Hz), if not more frequently. In addition to producing more precise data, the 30 Hz frequency rate matches the frame rate of normal VHS video data. Thus, each 1/30th of a second of simulator data will correspond to one frame of video data. Data collection at 30 Hz, thus, facilitates matching video data with (continuous) simulator data. These data can then be sampled at a lower frequency during data reduction and filtering, if desired. Of course, different variables may be associated with different frequencies (e.g., discrete events such as the time the train passed a specific switch), and therefore not all variables may be able to be collected at 30 Hz. As a rule of thumb, higher sampling rates reduce the impact of sampling errors, but increase the noise associated with the data.

Collecting communication-based data

Currently there is no clear indication for which character or role the instructor plays when communicating to the engineer inside the cab. It would be beneficial to be able to easily determine whether the instructor was role-playing a dispatcher, a MOW foreman, or an engineer from another train. One possibility is to develop a panel of simple buttons that the instructor can press. Each button could correspond to a different character. The panel could be connected to the data collection system so that a unique marker is placed in the data to indicate which voice is being conveyed. This marker would accompany the actual audio transmission data.

According to Corys, it is also possible to add microphones to the instructor workstation to simplify communications when multiple external parties (e.g., a dispatcher, a MOW flagman and a conductor) participate in the simulation. It may be possible, for example, to have one microphone for each character that must be role-played. The advantage of this set-up is that if several confederates are used to provide the voices of the parties external to the simulator cab, they will not be on top of each other trying to get in position to use the one existing microphone at the instructor's workstation. Each microphone would have to be integrated into the audio recording and could transmit a unique identifier to signal which microphone is being used (and thus, which character is speaking).

Separately, locomotive engineers occasionally must change radio channels to communicate with external parties. Researchers may be interested in collecting this information; that is, in determining which channels the locomotive engineer selects inside the simulator cab, as they might in a real cab. With respect to aural communication in general, a researcher may want to know (1) to whom the engineer is talking, (2) when they are talking (start and stop times and duration), and (3) the content of the communication. Currently the engineer can select radio channels in the simulator as he or she would do in a real cab. These selections are currently not logged, but according to Corys, they can be added to the data log if desired.

Data collection using auxiliary devices

It is also desirable for researchers to be able to plug auxiliary devices into the simulator, from which data can be collected and synchronized with simulator data (i.e., data are sent to the simulator's data log), or which serve to capture certain data of interest (i.e., capture certain data elements from the simulator and record them on the auxiliary device). Examples of possible auxiliary devices include a Peripheral Vigilance Test, or PVT, device; a personal digital assistant such as a Palm that could be used as an "electronic grip" analogous to aircraft pilots' "electronic flight bag," or as an electronic means of collecting subjective ratings; and a laptop computer. Subjective workload ratings could be collected on a PDA connected to the simulator computer system via wireless communication. The subjective rating data would then be automatically integrated with the operator performance (i.e., simulator) data. An additional Ethernet port connected to the Acela computer system may be able to be introduced into the simulator cab so that multiple auxiliary devices could be used concurrently. Though serial connections may be available, an Ethernet connection is much faster and allows greater expansion for the future (i.e., an Ethernet port is more likely to be compatible with hardware in 5-10 years, while serial ports are already being phased out in favor of Universal Serial Bus, or USB, ports). A PVT can either be a separate device or integrated into the simulator through the introduction of simple hardware and some "permanent" lights introduced inside the cab[3]. PVT devices have been used as a measure of operator alertness in over-the-road trucking field studies while drivers are engaged in driving.

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[3] The alerter may be considered a form of PVT. However, a drawback is that some locomotive engineers respond to the alerter automatically out of habit (i.e., years and years of experience), thus this may not be a good indication of the locomotive engineer's alertness.

Physiological data, such as from an electroencephalograph[4], or EEG, may be used in conjunction with operator performance and subjective data. However, these types of data may be difficult to collect in a locomotive simulator due to the confounding effects of the simulator motion and the electrical interference from the simulator's electrical equipment. Physiological data may be more easily collected if the simulation is run without motion, however.

It may also be desirable to collect data on cab temperature and sound level. The reasons for collecting these data are to (1) ensure that the in-cab temperature is suitable to reduce the probability of inducing simulator sickness, and (2) ensure that noise and temperature levels remain the same across experimental conditions and simulations. Noise may be able to be used as an independent variable, too. For example, one could measure the effect of new sound-dampening headphones on locomotive engineer performance in a very loud operating environment. Temperature is not recommended as an independent variable since there is likely a relationship between temperature and simulator sickness.

Electronic data collection

If desired, Corys could program the Acela simulator to generate electronic (i.e., computer-based) "forms" to collect a variety of possible data from both the instructor and the engineer inside the cab. For example, during a simulation, a "form" could appear on a laptop computer or personal digital assistant (PDA) plugged into the simulator requesting that the engineer provide a subjective workload rating. These forms could be used to collect a host of data that are currently collected on paper.

Collecting data on simulator subsystems

Lastly, it is desirable for researchers to be able to measure and modify the performance of all of the simulator subsystems (e.g., visual, motion, sound, etc.). This capability would enable researchers to validate simulator performance and determine, for example, if a piece of simulator equipment has "drifted" or is malfunctioning.

6.1.3 Experimental control

One of the greatest advantages of conducting experimental research is the control that it affords the researcher. This section discusses some of the specific experimental control issues that were raised at the evaluation team meeting. These control issues make up the last of the triad of desired capabilities discussed in section 6.1.

There are several motion-related experimental controls that may be of interest to researchers. One capability is to move the simulator into its starting point (including the associated sounds, referred to as "klaxon") at the beginning of a simulation, but when the simulation begins, no motion is used. This may combat expectancies that the participant may have regarding motion, or would enable researchers to study simulator participant expectancies regarding simulator motion. Research has shown that simulator participants' expectancies related to motion may affect their subjective ratings of the simulator. The effect that motion has on fidelity and participant responses is discussed in greater detail in section 7.7.

It may also be desirable to be able to pause the simulator in the middle of a simulation run

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[4] EEGs have been used to measure an individual's state of alertness.

without lowering the simulator to its resting state (the legs on which the simulator is situated will probably be extended during the simulation, as this is what provides the vestibular cues and is part of the simulator's motion system). This would help to eliminate external cues (e.g., the klaxon associated with the motion system settling) that indicate to the participant that the scenario has stopped. This brief interruption can be used to collect additional data (e.g., to assess situation awareness or collect subjective workload and stress data). The purpose of not settling the entire simulator system is to maintain the realism of the simulation while, and immediately after, collecting these data. It is also desirable to be able to "blank out" the scenario visuals (i.e., forward out-the-cab view) and the CDU displays in the cab at any time during the simulation to permit the study of locomotive engineers' situation awareness. According to Corys, each of these motion-based controls can be accomplished with various software modifications.

If desired, Corys could also create a simple randomization program to include in the instructor/researcher interface so that pre-programmed operating scenarios are randomly selected for an experiment. This would reduce the potential influence of researchers' expectancies on research participants' behaviors and responses during the simulation (i.e., the experiment would be double-blind in that neither the research participant nor the experimenter/operator would know which particular operating scenario is being run).

6.2 Recommended modifications to the Acela high speed rail simulator

Two approaches are taken to recommending possible modifications to the Acela high speed rail simulator. The first approach is based on the number of experiments that the FRA expects to conduct using the Acela simulator. This approach is discussed in greater detail in section 6.2.1. The number of experiments that are expected to be conducted may be the biggest factor that will affect the approach taken to modifying the Acela simulator. Given that this is not an easy question to answer, if it is even possible to answer, a second approach is taken based on five different levels of effort required to make the modifications. This approach is discussed in greater detail in section 6.2.2. The five levels of effort address a range of modifications, depending on the amount of time and resources that can be spent on the modifications. Both approaches address the modifications discussed in section 6.1. The specific modifications that are recommended and the number of modifications recommended in each approach will vary. As a general rule of thumb, the more time and resources that are committed, the more modifications that can be made to the simulator to better accommodate the FRA's research needs.

6.2.1 Approach # 1 to Acela simulator modifications

The first approach is based on the number of experiments that the FRA expects to conduct using the Acela simulator. When considering how many studies may be conducted using the Acela high speed rail simulator, the following factors should be explored:

- The number of issues related to high speed passenger rail that are of interest to the FRA. The evaluation team estimated that high speed passenger rail makes up around 1% of all railroad operations in the US. Based on this estimate, it is conceivable that high speed rail operations will make up only a fraction of the FRA's research program.
- The circumstances in which the Acela simulator is the best research tool. The FRA has several data collection methods that are available to them, including field studies and a

locomotive simulator operated and maintained by the Volpe NTSC. One of the evaluation team members noted that the level of fidelity that the Acela simulator provides may not be necessary for many studies.

The number of studies that the FRA plans to conduct using the Acela simulator will influence whether (1) many substantial, up-front modifications should be made to expand the simulator's general capabilities and increase the flexibility of the simulator to accommodate a number of research experiments or (2) specific modifications should be made to the simulator one experiment at a time, where the modifications address the particular needs of the given experiment and research design. The former approach will be expensive and time-consuming at first, but ultimately, will be less expensive *if* the simulator is used frequently to conduct research. This approach will also increase flexibility in conducting research using the simulator and will facilitate standardization across experiments. If only a few experiments will be conducted, however, the numerous up-front modifications may result in higher costs per experiment. In this case, the latter, "one experiment at a time," approach will be less time-consuming up-front and may be less expensive in the end. In addition, the FRA may be able to control much of the scenario and experimental protocol due to specific modifications that can be requested for the particular experiment. Table 6 summarizes the advantages and disadvantages of each approach.

Table 6. Advantages and disadvantages of the two approaches to the modification of the Acela high speed rail simulator

	Option	Advantages	Disadvantages
1	Substantial up-front modifications to expand simulator's general capabilities	• Flexibility in research designs over time • Standardization across experiments • Lower cumulative cost if simulation used frequently • Less inter-experiment time due to minimal adjustments and programming to simulator	• High up-front costs • Potential waste in spending if simulator is used infrequently • Substantial up-front time required
2	Experiment-to-experiment modifications	• Ability to specify precise requirements for each experiment • Lower cumulative cost if simulation used infrequently	• Potential for little standardization across experiments • Higher cumulative cost if simulator used frequently • Greater inter-experiment time due to programming the simulator for each experiment

Given the FRA's expected research needs (based on results from the structured interview), and a small estimated percentage of high speed passenger rail operations that exist in the U.S., the consensus among evaluation team members was that the FRA should fund simulator research projects one experiment at a time, costing out the simulator requirements for each experiment as needed. An advantage of this approach is that after the experiment, the FRA will not be responsible for any other simulator-related costs. This approach assumes that the FRA would use the simulator only a couple of times altogether. If the FRA plans to use the simulator frequently, however, then up-front modifications may be more economical in the long run to develop tools to use in building scenarios and collecting data for a number of experiments.

If the FRA chooses to make modifications to the simulator one experiment at a time, the Acela simulator facility could be viewed as a turnkey operation, providing all areas of support for a simulator experiment. For example, the FRA could give Amtrak a set of specifications for a simulator experiment. Amtrak could work with Corys to develop and configure the simulator and to get it prepared to conduct the experiment. The FRA could then run the experiment. The FRA could then be provided with a copy of the raw data, which could be processed (i.e., filtered and reduced) using customized filtering software programs written by Corys. The reduced data set would then be ready to be imported into a statistical software package such as SAS or SPSS for analysis by the FRA.

6.2.2 Approach # 2 to Acela simulator modifications

While the question of how many experiments will be conducted must be considered, ultimately, decisions will focus on (1) how many modifications should be made, (2) what modifications should be made, and (3) when should they be made. It is difficult and complicated to calculate a specific number of experiments (a "break-point") where it is more economical to make more modifications in the beginning than to make the modifications one experiment at a time. Further, it may not be feasible to know, or even approximate, the number of experiments that would be conducted over the course of the next 5-10 years due to the large number of factors that can influence a decision to fund a research study (these include, but are not limited to, Congressional mandates, FRA goals, changes in government policy, and Office of Safety requests).

Consequently, a second approach is provided. The second approach addresses simulator modifications based on the amount of time and monetary resources necessary to make modifications to the Acela simulator. Five levels of effort are identified; each level is associated with increased capabilities along with increased implementation time and costs (see Figure 9). Each of the five levels is discussed below, along with the advantages and disadvantages associated with each level. Specific costs associated with technologies or levels of effort are not provided, as these values will change over time. More important to the study is the delineation of the resources, technologies and systems that are associated with each level of effort. This approach provides the FRA with a tool that can be used to support future decisions regarding the use of the Acela simulator.

When deciding on modifications, one of the most important considerations is enhancing the simulator's flexibility in accommodating future needs. It is simply too difficult now to anticipate all of the possible research needs over the life of the simulator, so as much as possible, flexibility should be a focal point in selecting modifications to the simulator to accommodate FRA research needs.

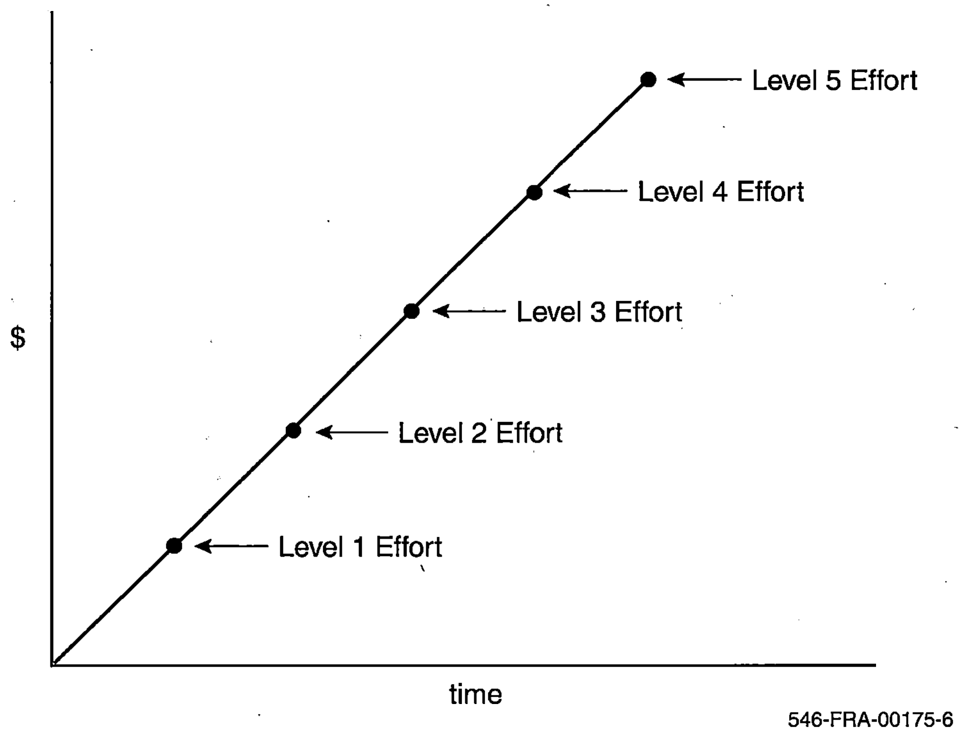

Figure 9. Conceptual diagram of the five different effort levels

Level 1 effort

This level of effort involves the fewest modifications to the simulator and consequently it is the least costly of the five levels of effort to implement. However, this level of effort is still capable of producing much useful human-centered locomotive engineer performance data. Level 1 effort relies on the same visual database as the Amtrak training configuration. Researchers would use the scenario development tool that currently exists, and which Amtrak instructors currently use, to build an operational scenario for the experiment. A separate video system would be built to collect video and audio data from the simulator. A personal computer would be supplied to plug into the simulator's Ethernet hub to collect basic simulator data through the use of a "packet sniffer" to obtain time, train position, and other simple data. Motion-related data would also be collected, as would ambient temperature using a simple thermometer. Lastly, any additional (i.e., add-on) behavioral, cognitive or physiological data collection systems that are desirable would be introduced. Each type of modification is described below in more detail.

There are several advantages of this level of effort. The primary advantage is that it is the least costly of the five levels of effort discussed. Depending on the particular research need, modifications described here can yield a lot of meaningful data without requiring a lot of investment in time and money. A second advantage is the simplicity with which this level of effort can be implemented. And related to this second advantage, this level of effort would involve a minimal amount of time to make the modifications. Lastly, since the high fidelity NEC virtual environment would be used, a locomotive engineer's performance in the simulator could be compared to real-world performance of an engineer operating the Acela train along the NEC.

Naturally, there are some disadvantages of this level of effort as well. One disadvantage is that this approach results in minimal researcher control over many aspects of the simulation, including simulator component performance. Another disadvantage is that a researcher is constrained by the types and amount of data that are collected. Lastly, this level of effort does not afford experimental controls such as event markers to break down a simulation into smaller units of analysis.

Video data collection system. Several cameras would be used to collect video data. One camera could directly face the locomotive engineer to capture engineer behaviors and control stand-related actions, a second camera (which currently exists) can provide a side view of the locomotive engineer, and a third camera could provide a forward out-the-cab view, as seen by the locomotive engineer. Video data should include the frame number, a time stamp, the current train speed and train position, as well as other simple train-related variables of interest. These data can be taken from the simulator computer system via a "packet sniffer" connected to the simulator system. A packet sniffer could be set up to detect and record (copies of) specific types of data that are passed through the simulator's computer system and network, and can be stored in a separate FRA-furnished PC. A multiplexer can be used along with the PC to integrate the video and train-related data. An individual watching (i.e., coding) the video would then be able to see both the video and the simulated train-related data on-screen. These data can be saved on either a videotape or, preferably, directly onto some type of computer storage media such as a hard disk. A computer storage medium is recommended because it allows the researcher to synchronize the video data with the simulator data using a computer rather than a video, which would facilitate immediate access and retrieval of the video data. If the lights are turned off in the simulator cab during an experiment, a near-infrared (IR) camera and lights are recommended to enable the cameras to "see" the locomotive engineer during the low-light condition. Such a system was successfully used in many driving simulator experiments using the Iowa Driving Simulator.

Audio data collection system. Two sources of audio are desired: (1) communication between the locomotive engineer and external parties (e.g., operator, "dispatcher," "MOW foreman," etc.), and (2) simulator vehicle sounds. A microphone inside the cab should be adequate to pick up all engineer communications, and simulator sound data should be able to be collected directly from the simulator's sound system output. If multiple external parties are used, such as a "dispatcher," a "MOW foreman," and/or another "train crew member," multiple microphones can be used (e.g., one for each confederate). Of course, recorded voices may be used instead of live voices. Regardless, the audio data should be recorded. These data should be integrated into the video data collection system, and preferably stored on some type of computer storage media, though these data can be recorded onto videotape if necessary.

Accelerometer/gyro pack. To collect basic simulator motion data such as lateral, longitudinal and vertical accelerations, accelerometers or gyros can be installed relatively inexpensively. A stand-alone accelerometer/gyro pack can be used, or data can be taken directly from the simulator motion system, which controls the simulator motion. The separate PC could collect and manage these data in addition to the other data.

Thermometer to measure cab temperature. To ensure that the temperature inside the cab is optimal to minimize the likelihood of simulator sickness, a thermometer can be placed inside the cab and data could be collected regularly during simulations to monitor the temperature inside the cab. Warmer temperatures may negatively affect a participant's performance in the simulator. A simple dry-bulb thermometer can be used and does not need to be connected to the simulator computer system.

Activity, behavioral and physiological sensor measurement systems. Activity, behavioral and physiological sensor technologies should be able to be integrated into the data collection. For example, it may be desirable to use a PVT to collect alertness-related data. Though simple to implement, a PVT can provide meaningful, complimentary data to that already being collected. These technologies may be connected directly to the simulator computer system or to the separate PC that is provided. There are also some controls that are a part of the simulator cab that are not used. These controls can be "re-directed," or assigned, to correspond to a new task, such as a reaction time test, and data could then be easily collected. For example, if the sander is not going to be used in an experiment, the sander switch could be "re-directed" to serve as a reaction time switch for a task introduced by the experiment. The re-direction of the sander would have to be performed by Corys prior to the experiment.

The simulator-based data could be processed by the simulator's computer system or by a physically separate post-processor. These data would be limited to the current data that the simulator can produce (i.e., no modifications to the simulator data output would be made). The PC described above could be used to collect these data from the simulator as well as to post-process these data. This computer could also manage the motion-based data and the activity, behavioral and physiological sensor data. Video and audio data could be stored on the PC or separately on videotape. Thermometer data can simply be collected by hand.

Level 2 effort

Level 2 effort builds on the modifications made in the level 1 effort described above. The major difference is that additional researcher-requested data would be collected from the simulator. This is expected to entail some programming by Corys to re-configure the simulator software in order to produce the desired data and send it to a researcher-supplied personal computer for post-processing and storage. Any filtering and reduction that may be necessary would also be included or involved. This is a more active system and would include additional locomotive engineer performance variables. Consultation with Corys would be necessary to determine exactly how variables of interest would be computed, collected and filtered/reduced. In all other ways, this level of effort resembles the first level. The focus of the first two levels of effort is on data collection. Scenario development and control will be addressed beginning in level 3.

Advantages of this level of effort are that it is still relatively low-cost and still relatively simple and straight-forward to implement. As with level 1 effort, a locomotive engineer's performance in the simulator can be compared to the engineer's performance operating the Acela train along the NEC.

Disadvantages of this level of effort are the same as those in level 1; chiefly, the researcher has minimal control over many aspects of the simulation, including no experimental control such as the use of event markers to break down a simulation into smaller units of analysis.

Level 3 effort

This level of effort, like levels 1 and 2, uses the existing, highly realistic NEC virtual environment as the backdrop or context in which the simulated train operates. It also uses a similar data collection system as that described in the level 2 effort, though it may be extended beyond level 2 if desired (data should still be stored in a separate computer). The primary difference between level 3 effort and the first two levels of effort is in the introduction of a researcher logon configuration (separate from the current "training" scenario used by Amtrak) to increase scenario and experimental control. This separate, researcher configuration would enable researchers to make changes to the operating scenario and would increase experimental control beyond that which is available through the current Amtrak configuration. For example, a researcher could reconfigure a CDU, introduce event markers that divide up a simulation into smaller events for analysis, or introduce new placeable objects along the track. Corys would be moderately to heavily involved in this level of effort, primarily to develop a researcher configuration according to FRA specifications. Level 3, thus, not only has a significant degree of data collection capabilities but also increased scenario and experimental control.

Advantages of this approach include some control over the operational scenarios and experimental factors, and the potential for enhanced data collection over the first two levels. The primary disadvantage of this level of effort is the increased cost due to the moderate involvement of Corys in developing the researcher configuration and enhanced data collection capabilities.

Level 4 effort

Level 4 effort substantially deviates from the first three levels. Level 4 involves the introduction of completely new virtual environments beyond the NEC. Level 4 distinguishes itself based on the use of a virtual environment and scenario-building tool that Corys would develop called a Track Builder Tool. While the first three effort levels all use the NEC as the basis for the simulator scenario, this custom-designed tool would enable a researcher to construct an entire virtual environment from the ground-up, using libraries of objects specified by the FRA. Both the background and foreground could be created, as could the specific track/right-of-way configuration, signals, interlockings, etc. The FRA could then develop, or program, generic scenarios that can be used with the Acela simulator, and would not be limited to the NEC operating environment. Since equipment and territory familiarization is so important to operating a train, researchers must ensure that research participants are familiar and comfortable with the simulated environment and equipment before proceeding with the simulation and data collection. This will involve additional training in the simulator before data are collected.

An advantage of this approach is that there is a great deal of flexibility and control in scenario development and experimental design. A researcher can develop a number of different virtual environments, an a number of different operating scenarios that can be used to study FRA human-centered research questions.

A disadvantage of this approach is that training locomotive engineers on the new territory would require additional time. Another disadvantage is that it may not be easy to validate the results using real-world data since the scenario that is created may not represent any particular (i.e., real) territory in great detail. A concern with respect to the development of new, generic operating scenarios is the scenarios and environment will not be familiar to locomotive engineer participants. Since territory familiarization is so critical to train handling, an engineer's lack of familiarity with the territory has the potential to confound the results of the study unless ample training is provided before the experiment.

Corys would be heavily involved at this level of effort. A significant amount of time and monetary resources would be devoted to Corys' development of the Track Builder Tool. The tool would be developed according to FRA requirements. Some of the Track Builder Tool's features should be based on real-world analogues, such as signage that is specific to a railroad but that the FRA or researcher can place along the track in any configuration.

Thus, at some level, the Track Builder Tool will enable researchers to replicate some aspects of a real territory in the simulator. The details will not be as fine as if Corys were custom-developing the virtual environment, of course. Level 5 effort addresses the need for another highly-realistic virtual environment similar to the NEC.

Level 5 effort

Level 5 involves the greatest amount of time and money. It is similar to level 4 except that, instead of having a tool to develop a generic virtual environment, in level 5, Corys would develop a virtual environment according to specification, similar to how the NEC environment was developed. This virtual environment would be highly detailed, and would have very few, if any, limitations to its development. In addition, a Track Builder Tool would be developed for use here, to enable researchers to modify parts of the environment, add desired features/events, and create operating scenarios.

A major difference between level 4 effort and level 5 effort is that, whereas with level 4 effort a researcher could develop a generic virtual environment (one that had many of the desired features that a researcher wants but that does not specifically match any true environment), in level 5, a real environment can be replicated, similar to how Amtrak has replicated the NEC in the Acela simulator.

An advantage of this approach is that the virtual environment would be very detailed and thus its face validity would be high. However, where the detailed environment gains in face validity, it loses in the generalizability of the results. A disadvantage is that there would be minimal flexibility once the virtual environment was developed, since Corys would have to make the changes (similar to the current NEC set-up). Further, the locomotive cab and control stand may be limited to those of the current Acela simulator (i.e., the Acela trainset or high speed locomotive). This may be incompatible with certain simulations. Thus, it may be necessary to develop a cab and control stand that are compatible with the new virtual environment and operating scenarios produced. This possibility would have to be discussed with Corys and Amtrak first, however.

Another improvement that may be made at this level of effort involves the upgrade of the visual system to increase the visual resolution. Currently a CRT screen is used in the Acela simulator. A liquid-crystal display, or LCD, screen with at least 1280x1024 resolution, would substantially enhance the visual resolution. Further, it is possible to increase the visual resolution by increasing the number of visual channels (i.e., increasing the amount of visual information that is displayed in the same amount of space). In addition, separate computers are recommended for each visual channel to enhance the capability of each.

6.3 Acela high speed rail simulator modification conclusions

The Acela high speed rail simulator is a training simulator whose primary mission is to familiarize Amtrak locomotive engineers with the new Acela equipment to be used on the NEC. The Acela simulator was designed for this purpose. As a research tool, however, there are limited scenario and experimental controls and limited data collection capabilities. The FRA, therefore, will have to make some modifications to the simulator to suit their research needs. The number and degree of simulator modifications that are "necessary" depends on how many experiments the FRA expects it will conduct using the Acela simulator. Section 6.2.1 provides some guidance with respect to the number and type of modifications based on the number of expected experiments. However, it may not be possible to know exactly how many experiments the FRA will want to conduct. Thus, a second decision aid was produced, based on increasing time and monetary investments by the FRA. In general, the more time and money invested, the greater the simulator capabilities and the more control that the FRA will have over scenario and environmental development, and data collection. However, minimal modifications can still potentially produce very high-quality research results, and these minimal modifications (e.g., level 1 effort) should be seriously considered. Section 6.2.2 describes five levels of effort and what modifications each level would involve. Ultimately, the FRA will have to work closely with Amtrak and Corys to implement any of the recommended modifications, and conduct experiments using the Acela high speed rail simulator.

7 Recommendations for the Design of a Conventional Locomotive Research Simulator

Section 7 provides suggestions for the design and development of a locomotive simulator to accommodate conventional passenger and freight operations where travel speeds are less than 125 mph. The following suggestions are based on the opinions and expertise of the evaluation team members, and are not intended to be exhaustive. Rather, these recommendations should be considered a first step in more fully specifying the requirements for a locomotive simulator. As specific research needs are elucidated and formalized by the FRA, the requirements for a locomotive simulator will become more extensive and complete.

Potential benefits of a locomotive simulator include:

- Cost savings compared to field studies
- Time savings compared to field studies
- The ability to duplicate any portion of a situation or environment safely
- Control over all aspects of the situation and environment.

The recommendations discussed in this section are based on one “cornerstone” recommendation made by the evaluation team: a simulator research facility should be built to house several locomotive simulators. The simulator facility envisioned would be interdisciplinary, and would be capable of conducting a number of different types of railroad-related research, including railroad dispatcher research, track and structures research, and train dynamics modeling. Figure 10 illustrates the type of facility envisioned by the evaluation team. The facility would have a full-time staff to support the facility, and its organization would include specialized departments to address each of the different simulation areas, such as visual databases and scenarios, train dynamics modeling, and human factors. Such a facility could be supported by both federal and industry-funded research.

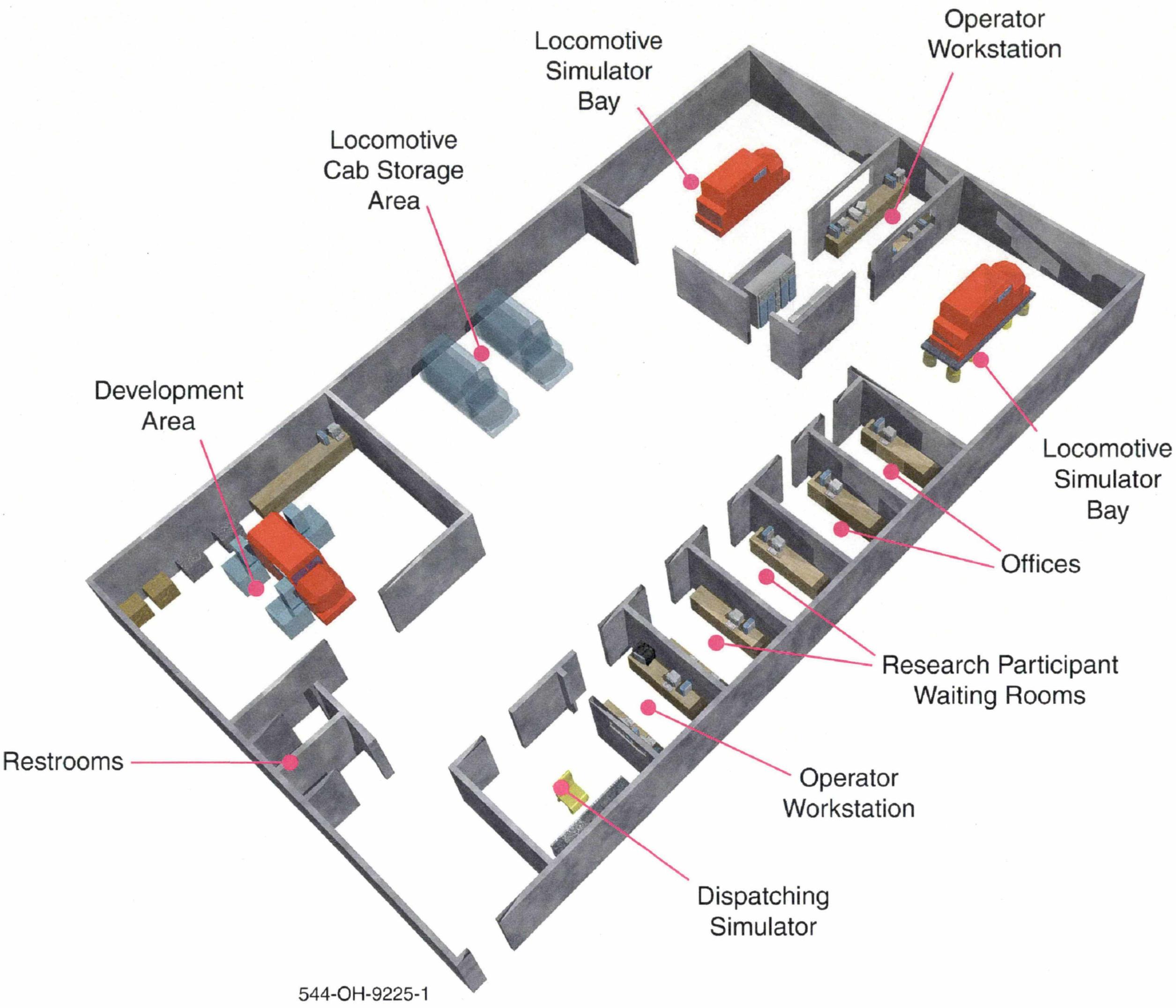

Figure 10. Locomotive simulator research facility

Each locomotive simulator at the facility would have a different level of capability (and thus, a different cost to build and operate). Raw simulator data would be reduced through a suite of computer-based tools programmed by staff programmers and subject matter experts (SMEs).

A basic simulator research facility (as discussed by the evaluation team) might contain the following components or elements:

- Three locomotive "bays": one motion-based simulator, one static simulator, and one developmental area where simulator components can be maintained and developed off-line.
- Multiple interchangeable cabs that can be moved to any of the three "bays."
- Multiple locomotive engineer control stands that represent different types of equipment.
- Multiple train dynamic models to represent different types of equipment, different types and amounts of loads, etc.
- A range of operating scenarios.

Ideally, facility staff would be able to switch out a locomotive cab or a control stand from one "bay" to another within a few hours.

The remainder of this section provides recommendations toward the development of a locomotive simulator facility such as the one described above. However, these recommendations are equally appropriate for the design and development of a single conventional locomotive simulator and facility. Section 7.1 describes the functional areas that a simulator facility, and a locomotive simulator in particular, might support. Section 7.2 introduces some top-level system architecture recommendations for a locomotive simulator. Section 7.3 presents some recommended system requirements for a locomotive simulator. Section 7.4 discusses operational requirements for the simulator. Section 7.5 describes data collection requirements to facilitate human-centered research. Section 7.6 presents a set of physical/experiential requirements that will increase the fidelity of the simulator. Lastly, section 7.7 discusses the issue of simulator fidelity in greater detail, since simulator fidelity is critical to all human-in-the-loop simulations.

7.1 Functional areas

The evaluation team identified four research functional areas that could be supported by an interdisciplinary simulator facility. These functional areas use both human-in-the-loop simulation as well as other types of simulation, modeling and computer-aided design. The four broad functional areas are:

1. Human factors and operations safety. A simulator facility could support research into the safety, usability, user acceptance and efficiency of a number of railroad operations technologies, training methods and procedures. Human-in-the-loop simulators afford numerous benefits, including the ability to control the environment and the ability to study human performance in a safe environment without risk of injury or property damage. Some examples of the types of research questions that may be addressed using a locomotive simulator are presented in

Table 4, along with the general human factors-related research areas that these questions address.

2. Track structures, materials and configurations. Using a locomotive simulator along with computer-aided design (CAD) software and supporting technologies (e.g., finite element analysis and modeling), various track structures, materials and configurations could be designed and tested in a simulator facility. Such research could focus on the efficacy and acceptance of competing track designs and materials, including rail, ties, fasteners and ballast. By enabling researchers to design and visualize the end result before any ground is moved or track is laid, this type of research could enable safe and cost-effective design and analyses to be conducted.
3. Train dynamics. A locomotive simulator facility could be used to study and model the train dynamics involved in different train consists, draft/coupling technologies, and in-train forces. Train dynamics research could also be conducted with locomotive engineers to understand the effects that different train dynamics models have on train crews and their performance. Research on modeling train dynamics would lead to safer equipment and specifications.
4. Advanced technologies. Using a state-of-the-art simulator facility, researchers could examine safety issues related to introducing new in-cab and wayside technologies such as positive train control, or PTC. Two types of research are envisioned: one based on modeling and testing complex communications logic and circuitry using computer-aided design and desktop simulation tools, and another using human-in-the-loop simulation to examine the safety and usability of these devices and technologies.

7.2 System architecture

Changes in computer, simulation, and networking technologies are occurring very rapidly, and these rapid changes can be expected to continue. Therefore, it is advantageous to design a simulator to be as flexible as possible in order to be compatible with new technologies and to expand the useful life and functionality of the simulator facility. To this end, the simulator design should be (1) modular and (2) supported by an "open" architecture.

Modular architecture

A modular architecture is one that will enable multiple independent simulator components to work together as a whole. Yet, the removal, addition or modification of one component will not affect the performance of the other components. For example, a simulator might consist of two major components: a central backbone and "add-on" components. The central backbone might contain hardware and software systems that are required to operate the simulator at a bare minimum. This might include a central processor and network, a simple visual and audio system, basic data collection capabilities, etc. Add-on components could then plug-in to the simulator to add functionality and capability to the simulator as needed or desired, in such a way so as the addition or removal of any add-on components or subsystems will not affect the overall operation of the simulator. Motion might be an example of such an add-on system component. Custom-designed data reduction and analysis tools are another example of an add-on component.

The advantages of a modular architecture are that (1) it can accommodate the addition and use of a range of different equipment; (2) these components can be updated separately without affecting the overall system; (3) the usefulness of the simulator can be extended by enabling future components to be “plugged in” relatively seamlessly and inexpensively without requiring an overhaul of the entire simulator system. Consequently, the central backbone simulation software and network should be able to interface with a variety of hardware and control mechanisms, ranging from desktop computer inputs and ancillary data collection equipment, to basic cab control inputs.

Open architecture

An “open” architecture is one that is independent of a particular operating system or hardware. This will enable the simulator software to be ported to different operating systems and different hardware configurations (e.g., from Windows98/NT to UNIX or a UNIX variation such as Linux). Personal computers may be an ideal choice to run the simulator software, since they can support numerous operating system platforms, are sufficiently powerful and flexible, and are inexpensive.

7.3 System requirements

This section presents some of the system requirements that were recommended by the evaluation team. These “requirements” are based on a simulator facility that has multiple simulators; however, they can be applied to the design and development of a single locomotive simulator. The recommended requirements are presented below.

- Multiple levels of fidelity. Fidelity, here, refers to the amount or degree that a simulator accurately represents a real locomotive in operation. The simulator facility should be capable of generating multiple levels of simulator fidelity. The simulator facility should be capable of both part-task simulations and full-mission simulations. Regardless of the type of simulation and the degree of fidelity, however, each simulator should have the same data collection capabilities. Based on the requirements of an experiment, a researcher could select the appropriate amount of fidelity that is needed. As a general rule of thumb, the more fidelity (for example, the use of motion), the more expensive it will be to operate a simulator. Section 7.7 discusses the issues around general simulator fidelity in greater detail, including definitions of simulator fidelity and distinctions between part-task and full-mission simulations.

- Expandability. Each of the simulators must have the ability to accommodate auxiliary devices that could connect directly to the simulator’s computer system, the control stand, or somewhere inside the cab. One example of an auxiliary device is the introduction of a PVT into the simulated cab control stand to examine engineer alertness during a simulated task or experiment.

- Interchangeable control stands and cabs. One should be able to mix and match (within what can be reasonably expected to be found in the real world) a number of different cabs and control stands in any of the three “bays.” This will increase the range of locomotive cab/control stand combinations that are possible to simulate and will, therefore, increase the efficiency of the facility.

- Artificially intelligent core network. Each simulator should utilize an artificially intelligent, fully interactive, network as its backbone. This type of network would enable simulated vehicles (i.e., virtual vehicles within the simulation such as an oncoming train in an adjacent track) to have their own dynamics and operational logic. Consequently, these vehicles would be able to interact with the virtual communications and signaling (C&S) system in a highly realistic manner, resulting in greater simulation fidelity.

- Multiple-channel, high fidelity visual system. Each simulator should have a multiple-channel, high fidelity visual system. The Acela simulator's field of view is currently about 45 degrees. It is recommended that a conventional locomotive simulator's field of view be greater than 45 degrees, to the extent that this is cost-effective. This can be done through the addition of visual channels. Visual channels can also be overlapped to increase resolution. Further, to enhance the performance of the visual system, each visual channel should be driven by its own computer and hardware to maximize the computing power associated with the entire visual system. Current high-fidelity visual displays include a range of plasma displays, LCDs, CRT monitors and CRT projectors, among others. Each type of display has advantages and disadvantages that should be considered before a decision to settle on a particular type of display is made.
- User management system for simulator physical and software configuration. The simulator system must be able to output simulator configuration data (i.e., the performance of the simulator systems) so that researchers can compare the current performance of the simulator to previous simulation performances or to a calibration file containing acceptable values for various simulator components. A simulator is made up of pieces of hardware that may "drift" (i.e., become uncalibrated) over time. Drift may occur when the translation from a computer algorithm to the actual actuation of the physical simulator component is incorrect. Another form of drift occurs in some visual systems, where projectors and CRT monitors may dim over time. Drift may occur due to regular equipment wear-and-tear or due to an equipment malfunction/break. Since this is a possibility, and because drift may not otherwise be detected, it is important to be able to monitor and measure drift. The purpose of configuration management is to be able to diagnose drift and other simulator system problems, verify and validate simulator system performance, and calibrate simulator settings. Users should be able to easily manage both the simulator's physical and software configurations. A calibration file containing lookup tables of theoretical system hardware component values could be created, and/or a calibration program could be developed. Drift measurement is especially critical for the simulator to perform as specified so that experimental results are valid. The performance of major system components (e.g., the latency of movement or washout algorithms for the motion system) should also be routinely calibrated. For example, accelerometers in the simulator could record motion-based data, which could be compared to theoretical motion values (i.e., a look-up table) or a previous simulator performance to determine whether drift has occurred in the motion system.

7.4 Operational requirements

The following requirements are recommended to enable a broad range of simulator operations to be carried out in a multiple simulator facility such as the one described at the beginning of section 7. These operational requirements enhance the capabilities of the simulators with regard to the needs of a researcher or simulator user. For example, some of the requirements provide more control to the researcher regarding what can be studied and what can be manipulated experimentally. Operational requirements are presented below.

- The simulator must enable researchers to study interactions and communications between the experimental locomotive engineer and other parties, including dispatchers, MOW foremen, or other locomotive engineers and conductors. This may be accomplished by recording the live communication between the locomotive engineer and experimental confederates (e.g. the experimenter plays the role of a dispatcher) or between the locomotive engineer and a set of pre-recorded communications. This may also be accomplished through the use of a dispatching simulator, where a dispatcher sitting at a railroad dispatching simulator could interact, in real-time, with a locomotive engineer in a locomotive simulator.

- Each simulator should be able to interact, in real-time, with other simulators in the facility. Interaction among multiple simulators in a "virtual world" would enable more complex issues to be researched and more complex scenarios to be developed. Interaction among simulators would also increase the facility's capability by enabling individual simulators to be operated singly or together. For example, if a research facility has three locomotive simulators, two of the simulators could interact with each other in one virtual world to study a meet or pass. Or, as mentioned above, a dispatcher at a dispatching simulator could interact with a locomotive engineer in a locomotive simulator.
- The simulation should convey a realistic and accurate virtual world and on-track events. The simulated environment in which the locomotive engineer will operate, and the events that he or she will encounter, must be consistent with his or her expectations. This includes an accurate portrayal of the physical characteristics of a territory if a specific territory is going to be replicated (this will not apply if a generic virtual environment is developed) as well as accurate on-track events such as the performance of other simulated on-track vehicles. These vehicles should act as they would in the real world. For example, if tracks are typically used for unidirectional traffic, then other simulated trains that operate on that track should typically operate in the usual direction.
- Simulations should contain realistic autonomous vehicles. Other vehicles that share and operate the same virtual environment should be autonomous in addition to behaving realistically. Autonomous vehicles are rules-based vehicles that respond to state changes (e.g., a change in signal indication) in a predetermined and logical fashion according to accepted operating rules and procedures for a particular railroad. The autonomous vehicles should also be programmed to correspond to the performance or ability of a number of different operators, for example a fatigued locomotive engineer or a novice engineer.
- The simulator should be able to simulate oncoming glare from sun, the headlamp of an oncoming locomotive, or other sources. It should be possible to simulate glare using CGI technology. Another means of simulating oncoming glare could be to point a flashlight at the experimental locomotive engineer, in a position that is similar to where the headlamp of an oncoming locomotive would be located.
- A variety of different operating scenarios, locations and track configurations must be able to be reproduced.
- The simulator must be able to be stopped and re-started part-way through a simulation run. The advantage of this requirement is that if the simulator must be stopped, then an experiment can continue relatively seamlessly rather than having to re-start the simulation at the beginning. The longer the scenario, the greater the benefit of being able to re-start part-way through the scenario.

- The simulator must be able to duplicate a number of different train dynamics models to simulate different train types and consists/configurations. This will broaden the simulator's capabilities and will increase its utility.

7.5 Data collection requirements

The following requirements will assist researchers in collecting and analyzing relevant and meaningful simulator data such as the performance measures presented in Table 5.

- The simulator should be able to collect locomotive engineer performance/activity data, and simulation state data. Locomotive engineer performance and activity data includes locomotive engineer actions and computer inputs such as acknowledging an alerter or calling the dispatcher, as well as train behaviors that result from engineer actions (e.g., train speed, lateral accelerations, etc.) All actions or activities in which the engineer communicates or interacts with the simulator operator should also be recorded and collected (e.g., communication with a "dispatcher"). Simulation state data includes the time and state of switches and signals when passed, as well as mileposts and other roadside furniture. The specific data to be collected, of course, will depend on the particular needs of each experiment.
- The simulator should record all raw simulator data on computer storage media. The simulator facility should allow a researcher to collect and save all of the simulator raw data onto some type of computer storage media (e.g., CD-ROM or portable hard drive). Given the inexpensive cost of storing data on various computer storage media, this is a very practical method of storing simulator data for later reduction and analysis.
- The simulator should record all video and audio data on computer storage media. Given the low cost of computer storage media, video and audio data should also be recorded onto storage media rather than videotape. Digital cameras may be used to this end.
- The simulator facility should be able to produce and support researcher-driven data specification, reduction, management and analytical tools to interface with the simulator and the simulator data. These data specification and reduction tools would assist a researcher in selecting and specifying the variables of interest for a particular experiment, as well as the data collection periods. The analytical tools could be used to verify data and perform simple, top-level checks on the data, as well as other analytical or statistical functions that may be desired. The tools should contain a front-end user (researcher) interface (UI) that is easy to use and that enables a researcher to collect all variables of interest. The UI should be specified at the beginning of the simulator facility development, and the specific tools that are developed should be based on the FRA's research needs.

  The following requirements can all be met through the development of tools such as those described above:

  1. A user should be able to save the reduced data as an ASCII file so the data can be exported to a spreadsheet (e.g., Microsoft Excel) or statistical program (e.g., SPSS or SAS) for further analyses.
  2. The simulator should be able to accommodate conditional events to facilitate data analyses. A conditional event might take the form of, "If X occurs, then do Y." For example, if a research participant passes a red light (the conditional event), then a flag

should be placed in the data two minutes before the event occurred and two minutes after the event occurred to enable a researcher to easily examine this period of data afterward.

3. A user should be able to specify data collection periods and performance measures to be collected by the simulator. Simulator users should be able to divide a simulation run into a number of smaller units of analysis. The benefits of this approach are discussed in section 6.1.2. In addition, the researcher should be able to specify which variables he or she wishes to analyze for each analytical unit. The variables that are selected for analysis will naturally be driven by the research question(s) that need to be answered.
4. A tool should be developed to convert locomotive engineer and train handling performance measures into monetary equivalents. Some human performance-related variables, such as fuel consumption and large brake applications, can be converted to into monetary values to provide an understanding of how new technologies, procedures and training affect the "bottom line." For example, unnecessarily high wear of the brakes due to large brake applications reduces the brakes' service life. This decrease in service life results in sooner-than-expected replacement of the brake shoes, which can be translated into increased cost over a period of time, such as a year.
5. A user should be able to match simulator performance data with corresponding video and audio data. Digital video cameras can be used to record and save video and audio data onto a computer-accessible media. These data should be time-stamped in a similar fashion as the simulator performance data. Digitizing the video and audio data would enable a researcher to use a computer to precisely and efficiently analyze the video, audio and/or corresponding simulator performance data. Digitization of these data would eliminate or reduce the need to manually code the video and audio data. Further, digitization is less prone to errors and faster to perform than manually coding these data. Programs could be developed to pick-out flagged events within the data for faster analysis. Some analyses may be able to be automated using custom-developed software tools.

In addition to these general data collection requirements, Appendix B discusses a number of behavioral and physiological sensor technologies that may be used in a locomotive simulator to collect additional human-centered performance measure data.

7.6 Physical and experiential requirements

The following requirements address the need for the correct "look and feel" of the simulator to resemble a real locomotive simulator.

- The physical characteristics of the track, the track bed, and the configuration of the physical environment must all accurately represent the physical characteristics of the environment being emulated (if applicable). These physical characteristics are critical to an engineer's ability to operate a train safely and efficiently, and therefore this quality must be carried over to any locomotive simulator, to convey a sense of realism. The physical characteristics may include such fine details as the lateral motion and sound that a train makes when entering a certain interlocking, accurate placement of grade-crossings and buildings, and the location and type of "road furniture" along the tracks. According to an Amtrak instructor, "You feel where you are," indicating that an engineer uses vestibular cues as much as visual cues. For example, occasionally an engineer is unable to see the appropriate "brake point" along a route due to inclement weather such as heavy rain or fog. The brake point may be used by an engineer to make a smooth and efficient stop at a passenger station. If the engineer can not see the brake point (usually a landmark such as overhead wires or a mile marker), he or she may use his or her sense of feeling to determine approximately where he or she is in order to brake at the appropriate location. The simulator must accurately portray the important physical characteristics of the virtual territory through correct visuals (accurate out-the-cab view, correct physical layout), audio (3-D) and motion (side to side movement) cues. With a freight train in particular, a locomotive engineer uses all of his or her sensory systems to sense and perceive the motion of the train (e.g., to determine slack action), the sounds in and around the train, and even the smells associated with a run. All are important to running a freight train properly. And while buff and draft forces and coupling issues are not relevant in the Acela simulator, they provide very important cues to freight locomotive engineers.

- The combination of cab and control stand should be accurate and correct relative to what the locomotive engineers are familiar with. Different locomotives (and thus, the cabs) have different control stands. Interchangeable control stands will enable researchers to combine control stands and cabs in a realistic fashion to represent a number of different locomotive styles.
- The visual system must replicate, or approximate, the correct line-of-sight based on an out-the-cab view. The evaluation team speculated that a locomotive engineer's line-of-sight in a clear day, assuming 20/20 or similar vision, is about two miles. As much as possible, this line-of-sight should be replicated in the simulator. Line-of-sight can be determined empirically using field studies, of course. These data could then be used to produce a realistic line-of-sight in the simulator.

7.7 Simulator fidelity

Simulator fidelity is a multidimensional construct that has received renewed attention recently due to advances in simulator technology and decreasing computer costs. Whereas it used to be that a simulator would be developed to contain the state-of-the-art in simulator equipment to most closely approximate the target equipment and operational environment, today it is possible to over-design a simulator relative to a researcher's goals (Rehmann, Mitman, and Reynolds, 1995). That is, the advances in simulator technology coupled with decreased computer costs have set up a situation in which it is possible to have too much fidelity relative to one's experimental needs, resulting in unnecessary costs. Consequently, there has been a recent effort to more precisely define simulator fidelity in order to make decisions about the appropriate amount of fidelity that is needed for a given training or experimental simulation.

Section 7.7.1 begins with some broad definitions of simulator fidelity. Section 7.7.2 follows with a brief discussion of some of the issues that are involved in defining and evaluating simulator fidelity. Lastly, section 7.7.3 presents and discusses some fidelity-related considerations with respect to the possible development and operation of a conventional locomotive simulator.

7.7.1 Simulator fidelity defined

Simulator fidelity can be broadly defined as the degree to which a simulator accurately or faithfully reproduces the real world that is being emulated. Some different types of simulator fidelity that have been identified or defined by researchers include *perceptual fidelity*, *psychological fidelity*, *equipment fidelity*, *task fidelity*, *environmental fidelity*, *functional fidelity* and *physical fidelity* (Rehmann et al., 1995). According to Rehmann et al., who cite definitions produced by the Advisory Group for Aerospace Research and Design (AGARD) in 1980, though definitions may vary, all have two common dimensions that distinguish a simulator from the true equipment being replicated: *equipment cues* and *environmental cues.*

Equipment cues attempt to replicate the controls and displays of the equipment being emulated as well as their physical layout. Thus, for example, the Acela simulator may be said to have high equipment fidelity because the simulator cab is an exact replication of the actual equipment, including the types of controls and displays located in the cab as well as their respective locations in the cab. Environmental cues attempt to duplicate the environment in which the true equipment operates. These include motion cues (e.g., the flow of the external environment—the trees, houses, etc.—sweeping by as the train "moves" forward), visual cues (e.g., the field of view from the cab) and audio cues (e.g., the sound of the alerter going off). According to Rehmann et al., "Fidelity is then a function of the degree to which the equipment and environmental cues relate to those of the real... [operational equipment and environment]" (Rehmann et al., 1995, p. viii).

Different simulators may emphasize different types of cues, depending on their primary function. Training simulators, for example, may emphasize equipment cues to increase transfer of training from the simulator to the real equipment. Research simulators may emphasize environmental cues to increase the likelihood that participants' performance in the simulator will more closely match the performance that would be expected in the real world due to the increased realism afforded by the environmental cues (Rehmann et al., 1995).

AGARD (1980) also defined two categories of fidelity: *objective fidelity* and *perceptual fidelity*. Objective fidelity involves the degree of similarity between the objective performance of a simulator and the true (objective) performance of the equipment that the simulator is trying to replicate. This may include motion-based and time-based characteristics (e.g., the elapsed time between a control input and equipment actuation). Perceptual fidelity involves the degree to which a participant perceives that the simulated vehicle performs like the equipment that is being replicated.

Simulations can also be divided into two categories based on the activity/ies for which they will be used. The two categories are *full-mission* and *part-task* simulations. A full-mission simulation replicates the entire operating environment, and is used to study complex operator behaviors and cognitive processes during all aspects of an operation. The term full-mission likely derives from the aviation industry (pilots fly "missions"). A full-mission simulation in the context of a locomotive simulator refers to an entire train "run," for example, from Penn Station in New York City to South Station in Boston. It would include all job-related tasks such as making accurate en route station stops, fielding calls to and from the dispatcher, and strict adherence to all signal indications. Part-task simulations typically replicate one, or a few, aspects of the original piece of equipment and only part of a complete operation or mission. The function of a part-task simulation is to enable a researcher to inexpensively and efficiently study participants operating one component or one piece of equipment (e.g., an operator's use of a new communication device), or executing one job procedure/task (e.g., proper readback/hearback procedure when receiving a movement authority). Where part-task simulation may lack in fully immersing participants, it gains in increased control over the experiment and cost-savings, compared to a full-mission simulation. Based on their different functions, then, full-mission and part-task simulations differ in the amount of fidelity that is required; generally, full-mission simulations will require a greater number of environmental and equipment cues, and therefore they will contain a greater level of fidelity, than part-task simulations.

Rehmann et al. (1995), citing earlier work by Orlady, Hennessy, Obermayer, Vreuls and Murphy (1988), present four occasions when full-mission simulation may be desired: (1) when a researcher desires to address multiple research questions (as it may be more cost-effective to run a full-mission simulation rather than several part-task simulations); (2) when the experimental design requires extended time periods or infrequent events; (3) when participants' behaviors can be elicited only in a fully-immersive environment; and (4) when it is important to study transitional periods between two or more tasks or phases of an operation.

Part-task simulations, in contrast, range from cardboard mock-ups to desktop PC-based systems with some representative controls and displays. Part-task simulations are particularly appropriate when a researcher is interested in studying one aspect of operating a piece of equipment or system (e.g., an engineer's interaction with an experimental PTC display), or is interested in examining an isolated task (e.g., an engineer's readback-hearback skills).

A simulator is made up of a number of subsystems. Rehmann et al. (1995), citing a Prasad, Schrage, Lewis, and Wolfe (1991) study, present ten different simulation subsystems. Though these subsystems are described in the context of a flight deck simulator, locomotive simulator analogues can be generated. The 10 flight deck subsystems presented by Rehmann et al. (1995) and the 10 corresponding locomotive simulator analogues are presented in Table 7. According to Rehmann et al., it is possible to define a range of levels of objective fidelity for each simulator subsystem. It is also likely that one can define a range of levels of perceptual fidelity for each simulator subsystem.

Table 7. Comparison of flight deck and locomotive simulator subsystems

Flight deck simulator subsystem (Rehmann et al., 1995)		**Locomotive simulator subsystem**
Cockpit	→	Cab*
Audio	→	Audio
Motion	→	Motion
Control system	→	Control system
Math model	→	Math model
Environment	→	Environment
Ground handling	→	Wheel-rail interaction*
Mission equipment	→	Operating equipment*
System latency	→	System latency
Visual	→	Visual
* Indicates a new analogue		

7.7.2 Simulator fidelity technical issues

There are a number of unresolved simulator fidelity technical issues, as suggested by the myriad definitions discussed in section 7.7.1. To begin, there is no clear definition of simulator fidelity. There are also no specific guidelines regarding how much fidelity is sufficient for a particular research or training simulation. Some of the major technical issues that are discussed in this section include:

- How much fidelity is necessary and sufficient?
- Is motion necessary? If so, how much motion is necessary?
- How much face validity is necessary?
- What are the downsides to having a lot of fidelity?

How much fidelity is necessary?

It is difficult to define simulator fidelity, as suggested by the large number of research studies and articles on the subject. Not only has it been difficult for researchers and trainers to define simulator fidelity, but there is no consensus regarding how much fidelity is needed for a given application. The need for a certain degree of simulator fidelity depends on a number of factors. Citing Orlady et al. (1988), Rehmann et al. (1995), suggest that there are two "principal factors" that affect the appropriate choice of fidelity level: the type of research to be conducted, and the psychological and behavioral processes that are of interest. The type of research dictates whether the experiment will use a part-task or full-mission scenario. The psychological and behavioral processes elicited by, and measured in, the experiment or training procedure determine the amount of realism that is required of the simulator.

Noble (2000), reviewing a number of simulator studies, asserts that the appropriate level of simulator fidelity for operator assessment may depend on the operator's skill level. The relationship that Noble hypothesizes is positive: as operator skill increases, so does the level of fidelity that is required to properly assess the operator's performance. This hypothesis is based on the theory that an operator's skill level affects his or her expectations and reliance on various real-world cues, which in turn affects the need to provide a certain amount of fidelity in the simulation. As operator skill increases, greater reliance is placed on real-world cues (due, perhaps, to greater familiarity and interaction with the real environment and equipment based on experience), which in turn results in a greater need for the simulator to faithfully reproduce the real operating environment and equipment. Noble also suggests that, as a practical matter, there may be a point of "diminished rate of practical assessment" (p.1) when increasing simulator fidelity beyond a certain level for non-expert operators. That is, it may be possible to have "too much" fidelity relative to the assessment of some (less experienced) operators.

According to Rehmann et al. (1995), the amount of fidelity that is needed also depends on the type of simulation. With full-mission simulations, the simulation must accurately and very closely replicate the entire range of operational scenarios and environmental cues one would expect in the real world in order for pilots to accept the simulation[5]. This suggests that there is a greater need for accurate environmental and equipment cues when running full-mission simulations, as discussed in section 7.7.1.

Rehmann et al. (1995) provide some basic guidelines for selecting particular levels of simulator fidelity, but ultimately, it depends on the goals of the research and the resources available to cover the costs of building the simulator and operating/maintaining it.

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[5] Unless pilots' expectations are modified by instructing them on the differences between the simulation and the real world before the simulation begins.

Is motion necessary? If so, how much motion is necessary?

Perhaps the most significant unresolved technical area within simulation, and the one that has been examined the most by researchers recently, is whether motion is necessary, and if so, how much is necessary. Conveying the sense or feel of motion (related to perceptual fidelity) is essential for a transportation simulator. However, motion can be conveyed through a number of cues, including visual cues (e.g., visual flow, visual resolution, and field-of-view all affect the sense of motion) and vestibular cues (e.g., the number of degrees-of-freedom and the amount of displacement). Recent research has focused on how much, and what types of, visual and vestibular cues are necessary to convey a realistic sense of motion to simulator participants.

Some research has indicated that participants' experiences with the equipment to be simulated (e.g., a train or aircraft) may have an effect on the desire for physical simulator motion. Bürki-Cohen, Soja and Longridge (1998) cite a study by Reid and Nahon (1988) that showed that, although pilots' simulator performance did not differ whether they were exposed to true motion or not, pilots had a strong preference for true simulator motion, as indicated on a number of subjective rating scales. Bürki-Cohen et al. suggest that pilots' preferences for true motion may be a function of their expectation that motion is better to have than not to have in a simulator.

Given the situation in which motion may be preferred but may not affect operator performance, a question that arises is, "Is some motion, rather than no motion or a lot of motion, adequate?" Lee and Bussolari (1989) compared the performance and subjective ratings of pilots in three simulator conditions—minimal motion cues, two degrees-of-freedom motion, and six degrees-of-freedom motion. The authors found no differences in performance and subjective ratings of workload, overall realism and other scales, among the three scenarios, suggesting that it may not be necessary or even advantageous to include full motion in a simulator.

In their analysis of the need for motion in flight simulators, however, Bürki-Cohen et al. (1998) suggest that some motion may be necessary to provide certain critical feedback cues in some experimental conditions. In other words, the value of motion may depend on the function it serves. Bürki-Cohen et al. (1998) note that if motion plays an alerting or critical role or function, or is a primary cue, then motion may be important to include in a simulator. They caution, however, that it may be possible to (eventually) overcome reliance on vestibular cues altogether with advances in visual system technologies.

Bürki-Cohen, Boothe, Soja, DiSario, Go, and Longridge (2000) conducted a more recent study in which some pilots trained in a static simulator, while others trained in a motion-based simulator. All pilots were then tested in the motion-based simulator. No significant differences in performance or subjective ratings (e.g., workload and comfort) were found between those who trained in the motion-based simulator and those who trained in the static simulator, providing further evidence that motion may not be necessary.

If motion is used, the motion system must be synchronized with the visual system. Poor synchronization between a simulator's visual system and its motion system, called lag or asynchronization, may be worse than having no motion at all (Bürki-Cohen et al., 1998). Asynchronization between the visual and motion systems likely contributes to simulator sickness, which in turn, can negatively affect an operator's performance in the simulator. Bürki-Cohen et al. (1998) suggest that experienced operators may be particularly prone to simulator sickness, and that this may be due to their reliance on motion-based cues. Such reliance on motion cues may increase experienced pilots' sensitivity to asynchronization between a simulator's visual and motion systems, thereby increasing their susceptibility to becoming simulator sick when a simulator's motion and visual systems are not synchronized. Reliance on motion cues may also increase susceptibility to simulator sickness in the absence of motion cues.

Simulator face validity

Another technical issue related to the degree of simulator fidelity is the simulator's face validity. Face validity refers to user "buy-in" or acceptance that the simulator accurately and faithfully replicates the actual equipment being simulated. The greater the "buy-in," the more closely a simulator participant's performance will likely represent his or her performance as if he or she was operating a real piece of equipment. Face validity also refers to the acceptance of the simulator results by those who will "use" the results. Generally speaking, face validity is a function of simulator fidelity. That is, as simulator fidelity increases, so does its face validity.

Potential disadvantages of high fidelity simulation

A disadvantage of developing a high fidelity simulator is that a simulator can be over-designed relative to one's needs, resulting in unnecessary costs. Another potential drawback to having a high level of fidelity is that it may result in "unwanted variance associated… [with] the behavior being examined" and may "reduce the sensitivity of the performance measures as well as the reliability of their values" (Rehmann et al., 1995). However, a well-designed high fidelity simulator may be able to overcome these concerns to some degree.

7.7.3 Locomotive simulator fidelity considerations

Simulator fidelity is a multi-faceted construct. Consequently, an important first step in considering the development of a locomotive simulator is to establish an acceptable or adequate definition of locomotive simulator fidelity. Based on an acceptable definition, the next logical step is to decide how much fidelity will be needed for a locomotive research simulator. This will depend primarily on research goals and the cost to develop and operate/maintain the simulator. The specific types of research that the locomotive simulator will be used for should be considered. For example, will the simulator be used mostly for full-mission simulations or part-task simulations? Or will it be used for an equal number of each? Full-mission simulations are particularly appropriate for examining complex cognitive tasks (e.g., decision-making) and behaviors. If full-mission simulations will be run, and/or if complex cognitive processes are expected to be studied, a high-fidelity simulator may be warranted.

A high-fidelity simulator capable of full-mission simulations can be expected to cost more to develop and operate/maintain than a lower fidelity/part-task simulator. However, a simulator capable of running full missions can also be used for part-task simulations (and thus, can accommodate a range of simulations and experimental designs), while a part-task simulator can not be used for full-mission simulations. If both full-mission and part-task simulations will be conducted frequently, then it may be most cost-effective to develop both a high-fidelity simulator capable of full-mission (and part-task) simulations and a low-fidelity simulator capable of part-task simulations, both of which can be operated concurrently. If only individual tasks will be examined (e.g., reaction time to a new alerter display), then a part-task simulator may be adequate.

Another issue to consider is whether a large number of experienced locomotive engineers will be participating in the simulations, since this may impact a decision regarding the amount of fidelity necessary or sufficient for a locomotive simulator. When running experienced locomotive engineers, it may be necessary to include a high level of fidelity since they are likely to expect certain cues to be present in a locomotive simulator, just like they would expect to experience these cues in the real world.

The implementation of motion in a simulator is one of the most significant technical issues related to simulator fidelity, due in part to the costs and additional complexity introduced by a motion system. Several questions must be addressed. First, is motion needed in a locomotive research simulator? If so, what kind of motion is necessary? And lastly, how much motion is necessary? Among the benefits of using motion is the fact that it will likely increase the simulator's face validity, which will result in (1) greater participant "buy-in" that the simulator is faithfully reproducing the equipment it is designed to simulate, and (2) greater railroad industry acceptance of research results. However, implementing motion will increase the overall cost of developing the simulator and its maintenance costs.

Some motion-based questions that will need to be addressed if motion is desired in a locomotive simulator include the following:

- What is an acceptable/tolerable delay between the visual and motion systems?
- How many degrees of freedom are necessary and sufficient?
- How much range of motion is necessary?
- Which vestibular cues must be reproduced? In other words, what vestibular cues do locomotive engineers rely on, and how do they "use" them? Under what circumstances are vestibular cues particularly important to a locomotive engineer?
- Can the sensation of any of the vestibular cues be replaced by the use of enhanced visual cues such as a large field-of-view?
- What aspects of territory familiarity can be translated into vestibular cues?
- Does a locomotive engineer's reliance on vestibular cues make him or her more susceptible to simulator sickness in the absence of motion?

As was discussed earlier, the value of motion may depend on the function it serves (Bürki-Cohen et al., 1998). Based on (1) research showing that pilots' performances and subjective ratings were no different under a small displacement condition than under two full motion conditions (Lee and Bussolari, 1989), (2) the possible need for at least some displacement to provide feedback cues (Bürki-Cohen et al., 1998), and (3) pilots' preference for motion, designing a simulator to contain a little motion or displacement may be an ideal solution since it may increase participant acceptance, it provides some vestibular cues, and it would be less costly to build than a full-motion simulator. Partial motion, thus, may provide an economical solution to the question of how much motion is necessary to include in a locomotive simulator.

Another issue that must be examined with respect to any human-in-the-loop simulation is the possibility of inducing simulator sickness in participants. The likelihood of inducing simulator sickness in a locomotive simulator will depend on a number of factors, including the types (and extent) of motion involved in a locomotive simulator, the amount of lag between the motion system and the visual system, and how experienced locomotive engineers use vestibular cues. Steps should be taken in the development of a locomotive simulator to minimize or eliminate the likelihood of simulator sickness.

Another component of simulator fidelity that needs to be explored is the quality of the visual system, including, but not limited to, screen resolution and field-of-view. A decision will have to be made with respect to how much horizontal and vertical field-of-view is necessary and sufficient in a locomotive simulator. Fields-of-view can vary from a single 17-inch computer monitor or screen located a few feet in front of an operator, to a full "out-the-cab" view. Further, due to advances in visual system technology and decreasing costs, it is important to explore whether increasing the field-of-view or other visual system modifications can be used to replace some or all of the vestibular cues that may be desired. In fact, there may be an optimal combination of field-of-view and vestibular cues. Screen resolution depends on the computing power and number of visual channels used, as well as the visual screen/projection technology used.

An experienced locomotive engineer's extensive familiarity with the physical characteristics of a territory is one of the most important types of knowledge that an engineer can possess, and faithfully replicating these cues may be one of the greatest challenges in designing a locomotive simulator. Locomotive engineers use all of their senses to safely and efficiently operate a train. For example, an engineer of a passenger train may use a visual landmark such as an overhead wire or mile marker sign, to indicate when he or she should begin to slow the train down in order to make a smooth stop at an upcoming passenger station. When visibility is limited, using a visual landmark may not be feasible. Thus, engineers learn to use their other senses to determine where they are along a route. For example, the train may enter a tunnel shortly before the "brake point" (the overhead wire or mile marker sign), at which point the engineer typically begins to brake the train. In the absence of visual cues, the engineer can use the change in sound as the train enters the tunnel (external train sounds are louder due to the reverberation and confined space in the tunnel) to indicate where the train is, and can use this information to brake at the appropriate place. An important step in the development of a locomotive simulator, then, will be to identify the visual, vestibular and aural cues that a locomotive engineer uses in the daily operation of his or her train, in order to replicate some or all of these cues in a locomotive simulator.

8 Key Findings and Recommendations

This section summarizes the key findings from the technical memorandum, and presents some recommendations to the FRA regarding next steps. Key findings and recommendations regarding the possible use of the Acela high speed rail simulator are presented in section 8.1, while section 8.2 presents key findings and recommendations for the possible development of a conventional locomotive simulator.

8.1 Acela high speed rail simulator

The Acela high speed rail simulator is a high fidelity training simulator with high face validity, due to the realism of both the simulator equipment and the virtual environment. The simulator was designed as a training tool, and as such, it has some operational, data collection and scenario development limitations. These research limitations are discussed in section 5. At the same time, however, the simulator has several advantages. Some of the advantages and limitations of the Acela high speed rail simulator are presented below.

Acela simulator advantages:

- High fidelity.
- High face validity.
- Already constructed and operational.
- Accessible pool of research participants (Amtrak locomotive engineers)[6].
- Amtrak and Corys are interested in and enthusiastic about working with the FRA.

Acela simulator limitations:

- Data collection capabilities are limited.
- The FRA may have to share simulator time with Amtrak
- The operating scenario currently is limited to the NEC.
- FRA modifications must not interfere with Amtrak simulator usage.

The recommended modifications in this technical memorandum are based on the expertise and opinions of the evaluation team. Recommended modifications are based on two approaches. The first approach is based on the number of experiments that are expected to be conducted using the Acela high speed rail simulator. Since this may be difficult to determine, a second approach was taken. The second approach is based on the time and fiscal resources necessary to make the recommended modifications. Five different levels of effort are proposed, ranging from minimal modifications to the maximum recommended modifications. Each level of effort is associated with increased time and costs, as well as increased capabilities. However, these costs do not include any potential fees imposed by Amtrak for the usage of their simulator, simulator

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[6] Amtrak is likely to release its locomotive engineers from work to participate in simulator studies since FRA's usage of the Amtrak simulator will directly benefit Amtrak. Further, the BLE likely will be supportive of the FRA's research efforts, given the FRA's interest in increasing the safety of train handling and operation.

facility or personnel/staff.

The recommended next step is for the FRA to decide what it wants to use the simulator for, what kinds of data it wants to collect, and the number of experiments it may be run on the simulator. To assist the FRA, the following steps are proposed:

5. Identify and prioritize locomotive engineer research and data needs.
6. Determine available budget and time considerations.
7. Determine (and prioritize if necessary) desired modifications.
8. Discuss research and data needs, and desired modifications, with Amtrak and Corys, as appropriate.

Ultimately, the FRA will have to work with Amtrak and Corys to implement modifications to, and use, the Acela high speed rail simulator.

8.2 Possible development of a conventional locomotive simulator

The recommendations presented in this memorandum regarding a conventional locomotive simulator focus on the development of a multi-simulator, multi-function simulator facility. However, most recommendations can be applied to a single locomotive simulator.

The overall theme for the development of a locomotive simulator is to build as much flexibility into the simulator (facility) design as possible, from the very outset of the design process. This design goal will expand the simulator's functionality, it will reduce the cost of future modifications, and it will increase the operating life of the simulator through enabling the simulator to be as compatible as possible with future I/O devices. Examples of this flexibility include designing the simulator to be operated across multiple platforms, to host multiple device I/O types, to provide a range of data collection capabilities and researcher controls, and to enable the simulator to be compatible with future technologies.

Possible next steps that the FRA might take include the following:

7. Determine the FRA's need for a conventional locomotive simulator facility.
8. Determine how much fidelity would be needed or desired (e.g., the quality of the visual system, whether to have motion, and if so, how much?).
9. Calculate the approximate cost of the desired simulator facility.
10. Determine the FRA's budget.
11. Match the budget to the desired simulator facility.
12. If necessary, change aspects of the desired simulator facility to align with the FRA's fiscal budget.

If the FRA would like to further explore whether motion is necessary in locomotive simulation, an experiment could be designed to study locomotive engineers' performances in the Acela simulator either with or without motion, and then participants' performances could be compared to their performance operating the real Acela on the actual NEC. This would indicate whether there are differences between performances in the simulator with and without motion. It would also provide a validation of the Acela simulator.

If the FRA is interested in determining which visual, auditory and vestibular cues a locomotive simulator should provide, a second project could focus on deconstructing an engineer's territory knowledge in terms of the visual, vestibular and aural cues that the environment provides to the engineer and that the engineer uses in operating the train safely and efficiently. These cues could be prioritized or weighted to indicate their relative importance to the engineer. A locomotive simulator could then be designed to produce these cues, focusing first on the most important ones to ensure that they are included in the simulation.

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Appendix A: Evaluation Team Member Biographies

This appendix contains a brief biography of each evaluation team member who participated in the study.

Mr. Stephen Reinach, Foster-Miller, Inc.

Mr. Stephen Reinach is a Senior Engineer at Foster-Miller, and the principal investigator of this research project. He has over six years of human-in-the-loop simulation and railroad operations safety experience. Most recently, Mr. Reinach has been involved in a number of railroad human factors and safety research projects sponsored by the FRA OR&D. These have ranged from railroad yard safety to train dispatcher training. Mr. Reinach has also aided in the design, development, implementation and data analysis of multiple driving simulator experiments to assess driver performance, understanding, and preferences for a number of intelligent transportation system and medical applications.

Mr. Michael Bartelme, KQ Corporation

Mr. Michael Bartelme is currently Research Products Marketing Manager for KQ Corporation. Prior to this appointment, from 1997-2001, Mr. Bartelme was Chief Operating Officer, Secretary, and Treasurer of Hyperion Technologies, Inc., which merged with KQ Corporation in 2001. While at Hyperion, Mr. Bartelme held additional technical responsibilities in the areas of Systems Engineering, Visual System Design, Database Engineering, and Customer Support. From 1991 to 1997, Mr. Bartelme was employed by the National Science Foundation's Center for Computer Aided Design with Positions as Database Modeler, Senior Database Modeler, Virtual Environments Group Leader, Research and Development Project Leader, and Human Factors R&D Project Leader. Mr. Bartelme was also a Federal Procurement Officer for the National Advanced Driving Simulator Project with duties that involved review, analysis, and recommendations to the NHTSA during the competitive bidding process for the prime contractor to build the device and facility. Mr. Bartelme has Bachelors and Masters degrees in Design from the University of Iowa as well as a Masters degree in Human Factors Engineering from Iowa. Mr. Bartelme also completed his Masters of Fine Arts in Industrial Design in May of 1999 at the University of Iowa. His emphases have been in human-machine interaction, three dimensional environments, product design, and human visual system performance.

Dr. Judith Bürki-Cohen, Volpe National Transportation Systems Center

Dr. Judith Bürki-Cohen is the Principal Investigator (PI) of the Flight Deck Human Factors Program at the Operator Performance and Safety Analysis Division of the U.S. Department of Transportation's Volpe NTSC. Her research program includes two main areas: one aimed at improving pilot training and evaluation by investigating flight simulation fidelity requirements, and another aimed at supporting pilot performance by determining information display and interface design requirements for flight deck technologies. During her nine years at the Volpe Center, she has initiated and served as PI in human factors research programs and projects spanning several transportation modes, including air traffic control communications and automation and high speed rail human factors. Although most of her studies required simulators as a research tool, for the past five years she has been examining the effect of the fidelity of simulation on transfer of operator performance and behavior between simulator and simulated vehicle. Her current simulator fidelity requirements research focuses on two aspects of flight simulation: the need to provide pilots with physical motion stimulation in a simulator with a high-quality visual system, and the need to simulate a realistic radio communications environment to accurately represent in-air workload. Although both of these questions elicit strong subject matter expert opinions, scientific data on either of these questions are still lacking.

Dr. Jordan Multer, Volpe National Transportation Systems Center

Dr. Jordan Multer is a human factors engineer with the Operator Performance and Safety Division of the Volpe NTSC. He is currently the principal investigator of the Railroad Human Factors Program. This research program supports the FRA's efforts to create safer rail transportation systems. This program covers three areas: train control system design, railroad operating practices, and highway-railroad grade crossings. For the FRA, he supervised several projects evaluating warning devices for use at highway-railroad grade crossings. These projects include: an evaluation of alerting devices for making locomotives more conspicuous, investigating the use of retro-reflective markings for making rail cars more visible, and an evaluation of a wayside audible horn. He also managed a project to develop human factors guidelines for the evaluation of the locomotive cab and supervised several projects examining the role of automation and communication technology on safety in train control. As part of evaluating the role of automation and communication in train control, he supervised the development of a locomotive simulator and the experiments that use this simulator.

Dr. June Pilcher, Bradley University

Dr. June Pilcher is an Associate Professor in the Department of Psychology at Bradley University in Peoria, Illinois. Dr. Pilcher has been involved in sleep-related research for over 15 years and has published over 25 articles and abstracts on sleep and fatigue. Dr. Pilcher earned her Ph.D. in biopsychology from the University of Chicago in 1989. She began working on simulators when she started collaborating with the FRA in 1997. One of Dr. Pilcher's current projects involves analyses of simulator data from an FRA-sponsored research study on locomotive engineer fatigue conducted in the mid-1990's using the RALES locomotive simulator.

Mr. Dave Muller, Riverside Technical Design

Mr. Dave Muller began his career as an electronics technician and audio engineer. From 1984 to 1990, he was an engineer at the University of Iowa School of Music, where he developed software and hardware for synthesizing and recording digital audio. From 1990 to 1994, he was an electronics design engineer at the University of Iowa Department of Physics and Astronomy, where he designed circuitry and software for a spacecraft imaging instrument. From 1994 to 1997, he worked for the University of Iowa's Iowa Driving Simulator, where he designed and maintained simulator hardware and software, and led the simulator's Hardware group. Mr. Muller's simulator expertise lies in the areas of visual display systems, data collection, audio and video systems, real-time software design, and human controls interfaces. In 1997, he started his own company, Riverside Technical Design, where he and his staff have designed and constructed equipment and software for diverse areas of scientific research, including driving simulators and instrumented test vehicles.

Appendix B: Physiological and Behavioral Sensor Technologies

Recent advancements in science and technology have led to a number of devices that can be used to collect a variety of data to support human-centered research goals. Two areas where there have been particular advancements include physiological and behavioral measurement technologies. These may be used, for example, to measure an engineer's fatigue, state of alertness, stress, or eye movements. Appendix B presents functional summaries of different data collection technologies that are currently available and that can be used to collect human-centered physiological and/or behavioral (i.e., observable) data. These technologies can be used in either the Acela high speed rail simulator or a conventional locomotive simulator, such as the one described in section 7. Technologies are organized into two major categories: Physiological sensors and behavioral sensors. Functional summaries for each technology include the following information:

- A description of the basic function of the technology- what it is and how it works
- The range of device types and capabilities of the technology
- A basic delineation of the advantages and disadvantages of the technology in the context of use in a locomotive simulator

Sections B.1 addresses physiological sensor technologies, while section B.2 addresses behavioral sensor technologies.

B.1 Physiological sensor technologies

Several physiological sensor technologies may be used in a locomotive simulator. They are described below.

Neurological/brain monitoring devices

Neurological monitoring devices, or electroencephalography (EEG), provide data on the brain's electrical activity using electrodes attached to an individual's scalp. In lieu of electrodes, a net-like headpiece that has the correct spacing of the electrode contacts but does not involve the use of paste or collodion to adhere the electrodes to the scalp, can be worn by the research participant. EEG is non-intrusive to administer, and can provide information on levels of operator alertness, sleep and arousal.

Heart monitoring devices/electrocardiography

Electrocardiography (EKG or ECG) measures the electrical activity of the heart (specifically, the electric potential that causes the heart to beat). EKGs are used to measure the rate and regularity of heartbeats, as well as the size and position of the heart chambers. Among other uses, EKGs can be used to monitor an individual's activity levels and the effect that these physical activities have on heart activity. EKGs can also be used to measure stress in an operator. Stressful situations may cause a release of certain hormones such as cortisol, which cause an individual's heart rate to increase. This change in heart rate can be measured by the EKG. Similar to an EEG, an EKG uses electrodes affixed to an individual's arms, legs, and chest. Each of these connections is called a "lead." The number of leads for an EKG may range from 3-15; the more leads, the more precise the measurements.

Electrodermal Response

Also referred to as a galvanic skin response (GSR), electrodermal response involves the measurement of the skin's electrical conductance (i.e., how well electricity flows through the skin). This can be measured exosomatically (external to the body) or endosomatically (internal to the body). GSR is a measurement of skin conductivity from the fingers and palm of a hand due to the autonomic response of the central nervous system. The skin's electrical conductivity is correlated with levels of emotional or physical arousal or stress; the greater the response, the higher the skin conductance.

Measurement of GSR is similar to the EEG and EKG methods described above in that leads are used for the measurement. Leads are attached to an individual's fingers or palm. An electronic device then sends a small amount of electrical current between electrodes. The GSR device records the electrical conductivity (the autonomic response) between electrodes.

There are several potential problems associated with EEG, EKG and GSR measurement in a simulator that should be noted. The electromagnetic noise due to the simulator's electrical components is expected to, at least minimally, interfere with and confound EEG, EKG and GSR measurement. Further, if motion is used in the simulator, it will likely affect the results of all three measurement technologies. Any such technologies, therefore, must be sufficiently robust to withstand the movement induced by the simulator, as well as the potential electrical interference imposed by the simulator equipment.

Cortisol Testing

Cortisol is a hormone that is associated with a human's level of stress or arousal. The human body (specifically, the adrenal glands) releases cortisol in a regular and cyclical manner throughout the course of a 24 hour period. However, cortisol is also released by the body in response to stressful conditions or situations. Cortisol is released into the blood stream, and can be measured in an individual's blood, urine and saliva. Increases in cortisol may be found in the body about 15-20 minutes after a stressful situation has occurred or been experienced. Typically, cortisol is collected through saliva, since it is the least intrusive means of data collection. The inside of the mouth can be swiped with a Q-tip or an individual can suck on gauze for a few minutes (enough time so that the gauze can absorb a sufficient amount of saliva). Alternatively, a urine or blood sample can be taken. Blood and urine provide a much more accurate measurement of cortisol levels in the body, however, their collection is more intrusive than the collection of saliva. Regardless of the method used to collect the samples, baseline values should be measured before the experiment begins due to individual variation and cyclical changes throughout the day.

Body and skin temperature

Skin and body temperature naturally fluctuate according to the time-of-day and ambient temperature (e.g., skin temperature will likely be higher in August than in February, though the range is limited due to humans' warm-blooded nature). However, skin and body temperature may also change in response to stressful situations. Specifically, stressful situations (both mental and physical) can cause an increase in blood flow, which in turn increases body and skin temperature. Skin temperature can be measured with a small patch on the skin, while core body temperature measurement, which is more invasive, requires a lead into a body cavity (e.g., rectum, vagina, or throat).

Ambient light exposure

Exposure to light affects the body's circadian rhythms. Measurement of ambient light exposure is often paired with other measures of operator fatigue or alertness. Ambient light exposure can be used as in independent measure if one is interested in light exposure as a fatigue intervention, or it can be used as a covariate when collecting other fatigue-related measures. A small device worn on a wrist can collect light exposure data. Frequently, actigraphy devices package ambient light exposure measurement in some of their higher-end devices.

B.2 Behavioral sensor technologies

In addition to the physiological sensor technologies described above, there are several behavioral sensor technologies that may also be used in a locomotive simulator. They are described here.

Actigraphy/activity monitoring devices

Activity monitoring devices, also known as actigraphy, record an individual's limb or trunk movements. Specifically, activity monitors, typically worn on the wrist, ankle or waist, measure the amount of activity (frequency) and the intensity of the activity using omnidirectional accelerometers or bi-axle motion sensors, depending on the specific product. Researchers can infer wakefulness and sleep based on the amount and intensity of the activity. Periods of non-activity, coupled with a corroborating sleep log completed by a research participant, usually indicate sleep activity, while active periods typically indicate periods of wakefulness. These devices provide an objective measure of an individual's wakefulness and sleep, and complement other tools and measures of human fatigue, such as sleep logs, subjective sleepiness ratings and work schedule data. As more research emphasis has been placed on operator fatigue in the 1990s, these devices have become very popular in transportation research. Activity monitors are typically packaged in small, watch-like encasements that are relatively small, lightweight and non-intrusive. The watch-sized activity monitor collects activity data and stores it until it can be downloaded to a personal computer using a custom-designed manufacturer's interface. The downloaded data can then be analyzed using the manufacturer's software.

In addition to recording activity data, certain models can record ambient light data, skin temperature and heart rate. Extra memory and remote download ability are also available in some models.

Eye-tracking instruments

Eye-tracking instruments track an individual's eye movements to determine the location of an individual's gaze. Eye-tracking data can provide information on eye glance durations (e.g., how long is an engineer looking at a particular display?), sequences (e.g., in what order does an engineer visually scan the control stand of a locomotive?) and frequencies (e.g., how many times does the individual look ahead during a critical period of time?). Eye-tracking devices typically account for, and/or measure, head position and orientation, eye-gaze direction, eye closure and/or blink rate. This information can be correlated with simulator data.

Video cameras

Video cameras, including standard video recorders and digital cameras, can be used to record the durations, sequences and frequencies of research participant activities. Any activity that someone can be seen *doing* (e.g., tapping an alerter or adjusting the train's throttle) can be recorded on a video camera. Information that is recorded ranges from very broad activities such as an individual carrying out experimental tasks, to very specific activities, such as an individual's response to a specific display or alarm, or his/her posture(s) while executing specific activities. Video camera data are very versatile, and can be used to study a large range of human-centered activities. Video camera data can be used to measure eye-tracking behavior, too, albeit it is much cruder than using an eye-tracking device. Video camera data can be used to compute reaction times, and can be used to calculate a research participants actions, either in part or in whole. Video cameras also tend to be very inexpensive relative to the range of data they produce.

Using multiplexers, computers and other available technologies, video camera data can be integrated with simulator or other types of data collected during a simulation or other experiment. Digital cameras are especially suitable for integrating with other simulator data, since these data are already digital and thus are already stored in a computer-accessible format. Video camera data can also be analyzed separately from simulator data, and in fact, simulator data can be ported over to the video data. Train speed and train location data can be used to facilitate the coding of the video data by providing reference information that can be used as benchmarks or markers in the video data.

An examination of Amtrak's Acela High Speed Rail Simulator for FRA Research Purposes, 2001, S. Reinach, Foster-Miller 11-Advanced Systems