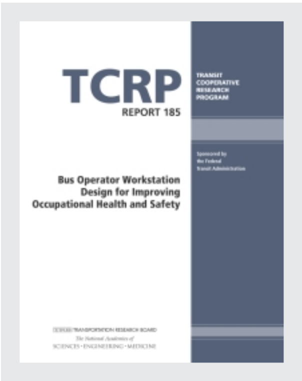

Bus Operator Workstation Design for Improving Occupational Health and Safety

DETAILS

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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 185

Bus Operator Workstation Design for Improving Occupational Health and Safety

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TRANSPORTATION RESEARCH BOARD

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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, adapt appropriate new technologies from other industries, and introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000,* also recognized the need for local, problem-solving research. TCRP, modeled after the successful National Cooperative Highway Research Program (NCHRP), undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes various transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA; the National Academies of Sciences, Engineering, and Medicine, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel appointed by TRB. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired effect if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

TCRP provides a forum where transit agencies can cooperatively address common operational problems. TCRP results support and complement other ongoing transit research and training programs.

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C O O P E R A T I V E R E S E A R C H P R O G R A M S

CRP STAFF FOR TCRP REPORT 185

TCRP PROJECT C-22 PANEL
Engineering of Vehicles and Equipment

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The authors wish to thank the participating bus manufacturer for their material support, which provided data that formed the foundation on which the bus operator workstation computer-aided design (CAD) model guidance was built. Furthermore, the human modeling simulation for validation of this model would not have been possible without the access to and support of the RAMSIS software provided by Andre Luebke and the Human Solutions of North America team.

Additionally, engineering and modeling development would not have been possible without the creative expertise of Chris Garguilo, Design Engineer, and Matthew Moeller, Research Associate, in the Center for Technology Development at the Virginia Tech Transportation Institute (VTTI). Furthermore, the expertise and keen eyes of Michael Buckley and Laura Krisch, VTTI Editing Team, were an ever-present help during all reporting activities. Casey Gin provided important research assistance for the interview planning and initial data analysis.

Finally, and most importantly, the authors wish to thank the participating industry experts and transit agency and union representatives from across North America who provided the ground-level knowledge of the procurement process and challenges and opportunities that stand before our transit industry.

FOREWORD

By Dianne S. Schwager
Staff Officer
Transportation Research Board

TCRP Report 185: Bus Operator Workstation Design for Improving Occupational Health and Safety was developed to support improved bus procurement by public transit agencies, focusing on the bus operator workstation component of a bus. The project was designed to assist transit agencies and bus manufacturers in integrating improved and emerging technologies into current procurement practices and improving bus operator workstation design across the transit industry. The research produced practical guidance documents and tools applicable to the procurement process and bus design, including (1) a recommended procurement process and strategies for transit agencies to develop, train, and support a bus procurement team that includes bus operators and representatives from operations, maintenance, safety, and procurement; (2) training recommendations for the procurement team, including an ergonomics training module for bus operators; (3) guidelines to update the *TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines* developed in 1997; and (4) a digital model of a bus operator workstation that can be used by designers and transit agencies to develop specifications.

Transit agencies and bus manufacturers face the task of integrating improved and emerging technologies into current procurement practices while improving bus operator workstation design across the industry. Led by Virginia Tech and including RMGillespie Consulting and Sound Science, Inc., the research team for this ambitious project captured input from bus manufacturers, transit agencies, labor unions, and transit organization staff in the United States and Canada to develop strategies for improving collaboration in the bus design and procurement process.

The final deliverables for this research include a report supplemented by six tools. The report provides an overview of the structure and content of the research, defines the role of each key stakeholder in the procurement process, and presents two types of training needed to support a well-prepared procurement team that includes bus operators trained in their ergonomic needs. The report also presents important computer-aided design (CAD) and human modeling simulation models, now integral to modern bus procurement. Six appendices present detailed research results that complement the research report.

The report is supplemented by three organizational tools and three design guidance tools that can be used by transit agencies during bus procurement. The organizational tools support the improvement of the bus procurement process and training for participants. These tools can be tailored to meet the specific needs of different transit agencies. The design guidance tools support current bus design technology. In updating the bus operator workstation guidelines, the research team sought to align the new tools, such as the Bus Operator Workstation Feature Guideline and the three-dimensional (3-D) Bus Operator Workstation Engineering

CAD Model, with processes and practices now common in the commercial bus and truck industry. To assist in the communication of bus operator workstation requirements with individuals who are not trained in expensive and difficult CAD software, a Bus Operator Workstation 3-D PDF Model also was created.

The six organizational and design guidance tools, including the 3-D PDF Model, can be accessed from the report webpage at www.trb.org by searching “TCRP Report 185”.

CONTENTS

SUMMARY

Bus Operator Workstation Design for Improving Occupational Health and Safety

Purpose and Products

Many bus operator workstation elements have changed in recent years, and many are evolving. Transit industry stakeholders—transit agencies, bus and equipment manufacturers, trade groups, and government agencies—all have an interest in enhancing the bus operator workstation design to improve bus operator health and safety. A well-designed bus operator workstation ensures safe driving while navigating busy streets and attending to unpredictable vehicles. It should maximize operator safety, health, and comfort; reduce cognitive and physical demands; and promote interaction with passengers.

Research Approach

To understand the challenges related to transit bus procurement and design specifications, the research team started by reviewing the literature available on bus operator health and safety, bus design guidelines, and bus technologies. Following the literature review, the research approach included:

- **Soliciting input from key stakeholders.** Bus manufacturers, transit agency staff, labor union officers, and industry experts in the United States and Canada were asked about their experiences with the bus design and procurement process to enhance bus operator health and safety. Data collection consisted of surveys and interviews focused on three components that are essential to continuous improvement: people, process, and technology. The intent was to understand the team structure, composition, and processes of bus procurement activities as they related to bus operator health and safety.
- **Combining this information to draft an improved procurement process for the bus operator workstation, with training recommendations for procurement teams and bus operators.** The investigation of bus procurement practices looked into who the critical bus operator workstation procurement stakeholders are; how transit agencies bring stakeholders together for problem-solving; and what tools, training, and skills the stakeholders need to effectively assess and design bus operator workstations.
- **Developing a CAD model for transit buses.** Physical measurements of buses were combined with data supplied by a transit bus manufacturer to develop the bus operator compartment for the workstation computer-aided design (CAD) model. Researchers drafted a suggested feature guideline and a CAD model guideline by combining known transit bus architecture with a matrix of international bus operator workstation design guides.

The suggested procurement process practices, training, and CAD tools from this research are designed for use by transit agencies to coordinate with their workforce, vehicle manufacturers, and suppliers. This procurement and design guide also is intended to enhance communications among transit agencies, manufacturers, researchers, and industry groups.

Research Products

TCRP Project C-22, "Bus Operator Workstation Design for Improving Occupational Health and Safety," produced a set of guidance documents and tools to help transit agencies and manufacturers integrate the suggested procurement practices and emerging technologies into bus operator workstation design and procurement.

The products of this research include:

1. **A suggested procurement process and strategies for transit agencies** to develop, train, and support a bus procurement team that includes bus operators as well as representatives from operations, maintenance, safety, and procurement to effectively participate in the development of specifications for the bus operator workstation;
2. **Training recommendations** for the procurement team to support the bus operator workstation procurement process and an ergonomics training module for bus operators designed to improve their contributions to procurement and improve their health, safety, and job performance;
3. **Guidelines** to update *TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines*, developed in 1997; and
4. **A digital CAD model** of an operator workstation that can be used by designers and transit agencies to develop specifications for the bus operator workstation. (A 3-D PDF Model also was created to facilitate use of the digital model by individuals who do not have CAD training or access to CAD software).

The tools and suggested practices support an active procurement team that includes stakeholders throughout the procurement process. Bus operators are pivotal members of the team, especially during current bus evaluation, bus operator workstation specification, and new bus testing. The procurement process relies on communication and sharing of resources within the transit agency. Transit agencies are key stakeholders in the development and availability of technology, and can use the design guidance tools to find, request, or design equipment that suits their needs.

Improved technology also strongly depends on communication among transit agencies, with manufacturers and suppliers, and across government, research, and transit industry trade organizations. Bus operators and their unions have a great deal to contribute to—and gain from—workstation design improvements. Trade groups and academic researchers in transit, vehicle design, and ergonomics can support innovation and accelerate design changes, as can government agencies with influence on procurement standards and equipment design expectations. This research report illustrates a network for information exchange and resource sharing that involves all of the interests needed to contribute to the development of safer and more affordable equipment.

Toolkit Overview

The tools discussed in this section are available for download from the webpage for *TCRP Report 185*, which can be accessed from www.trb.org by searching "TCRP Report 185".

Organization Guidance Tools

The suggested procurement practices for bus operator health and safety are based on the understanding that bus operator health and safety will be optimized in an ongoing process of planning, data collection, evaluation, and decision-making that includes all relevant stakeholders. The procurement training template and the bus operator ergonomics training framework will help procurement teams to understand the process before and during procurement. Carrying out the outlined training between procurement cycles is also important; it will prepare stakeholders, including bus operators, to observe, document, and correct issues during the bus life cycle and record them for future reference.

Suggested Procurement Practice for Bus Operator Health and Safety

The suggested procurement process is organized into four phases. Each phase includes varying degrees of training, data collection, evaluation and testing, and communication both internal and with outside stakeholders. **Organization Tool 1: Bus Operator Workstation Procurement Practice** (listed online as "Suggested Procurement Practice for Bus Operator Health and Safety") consists of essential steps and suggested practices that were generated from the range of activities described by the research subjects. The process is explained in detail in Chapter 2 of this research report and is summarized in the following discussion.

Phase I: Build and Support the Procurement Team

Step 1: Define procurement process and recruit stakeholders.

Suggested Practice: The transit agency procurement process engages stakeholders to address bus operator workstation health and safety.

Step 2: Prepare and train procurement team and stakeholders.

Suggested Practice: Stakeholders contributing to the procurement process are provided with training to understand, analyze, and support bus operator health and safety.

Step 3: Maintain internal communications.

Suggested Practice: Throughout the procurement process, effective communication about bus operator workstation and operator health and safety is maintained between the procurement team and executive, management, and line-level employees and their representatives.

Phase II: Prepare for Procurement

Step 4: Review past procurements.

Suggested Practice: Stakeholders systematically review past procurements for all items affecting workstation design and operator health and safety, engaging safety teams and operators.

Step 5: Request information—internally and externally.

Suggested Practice: The procurement team collects relevant internal and external information about bus operator workstation design and its impact on bus operators. The focus is on identifying bus operator health and safety (BOHS) concerns and impacts.

Step 6: Investigate new technology.

Suggested Practice: The transit agency maintains and refers to an information base of existing and developing technologies and their impacts on operator health and safety.

Step 7: Test or mock up changes.

Suggested Practice: Potential changes are assessed for their impacts on operator health, safety, and comfort through mock-ups and loaner equipment.

Phase III: Specification, Request for Proposals (RFP), and Award

Step 8: Define options with all manufacturers.

Suggested Practice: The procurement team engages manufacturers in active exchanges that help identify and resolve concerns related to health and safety before final specifications.

Step 9: Draft specifications and RFP.

Suggested Practice: The procurement draft and RFP reflect stakeholder input to explicitly address the areas affecting bus operator health and safety.

Step 10: Review changes proposed internally or by manufacturers.

Suggested Practice: Changes proposed at any upper level, later changes, and manufacturers' requests for deviations are assessed on the same terms as the procurement draft and RFP.

Phase IV: Complete the Build and Roll-out.

Step 11: Monitor bus build process and test pilot buses.

Suggested Practice: The procurement team continues to oversee the build process, test pilot buses, and systematically address changes needed to meet the ergonomic demands of the bus operator workstation to improve any impact on the health and safety of operators and others.

Step 12: Evaluate and correct problems (ongoing).

Suggested Practice: Throughout the bus life cycle, the safety department and bus operators contribute to the evaluation of the fleet for issues that affect health and safety. In-warranty and fleet defects and refit and retrofit solutions are identified and implemented on existing buses and documented for future procurements.

Organization Tool 1 presents these steps sequentially, but in the real world they overlap. In particular, evaluation of the impact of the workstation on bus operator health and safety continues throughout the bus life cycle. Similarly, it is suggested that training precede the procurement phase and also be continued or repeated as needed.

Procurement Team Training

Comprehensive procurement team training to enhance bus operator health and safety covers three areas:

1. The transit agency's procurement practices,
2. Core knowledge and technical skills concerning the bus operator workstation, and
3. Engineering and design skills and knowledge.

Training modules that focus on how the procurement process works and how it will address bus operator health and safety are suggested for all procurement team participants working on issues affecting bus operator health and safety. Additional training topic areas include bus operator ergonomics and biomechanics, relevant design and engineering concepts, and regulations concerning operator health and safety.

Chapter 3 of this research report details the content that will help the procurement team to understand how the workstation configuration affects the bus operator and to identify and evaluate potential improvements. **Organization Tool 2: Bus Operator Workstation Procurement Team Training** (listed online as "Procurement Team Training") is a presentation template that lays out the training module objectives, suggested content, and support materials to be developed and modified to suit each transit agency's needs. The template includes slides that summarize the steps and suggested practices defined in Organization

Tool 1. The training could be developed and carried out by a consortium at a regional or national level.

Ergonomics Training for Bus Operators

The goal of the procurement process is to limit the physical challenges presented by the bus operator workstation. Additionally, bus operators need training to use the equipment provided to work as comfortably and safely as possible, and to contribute to the selection of improved workstation elements. Comprehensive ergonomics training teaches workers to understand and to ameliorate their work demands. For this section of the research, the research team collected information from transit agency and industry experts through interviews, and reviewed training examples produced by transit organizations and other industries.

Organization Tool 3: Ergonomics Training for Bus Operators (listed online as "Ergonomics for Bus Operators Training Template") provides a complete presentation template for transit agencies to modify with their own information and images. This tool can also be used to train the procurement team on ergonomics and the demands of bus operators' work.

Design Guidance Tools

The research team sought to develop the updated bus operator workstation guidelines by including tools, such as **Design Tool 1: Bus Operator Workstation Feature Guideline** (listed online as "Bus Operator Workstation Feature Guideline") and the three-dimensional (3-D) **Design Tool 2: Bus Operator Workstation Engineering CAD Model** (listed online as "Bus Operator Workstation Engineering CAD Model" and available as either an IGS file or a STEP file), in products that align with the processes and practices that are common within the rest of the commercial bus and truck industry. To help communicate bus operator workstation requirements with individuals who do not have access to or are not trained in CAD software, the Bus Operator Workstation Engineering CAD Model was exported into a lightweight 3-D universal file format to create **Design Tool 3: Bus Operator Workstation 3-D PDF Model** (available online from the *TCRP Report 185* webpage, along with a 3-D PDF user guide)

Bus Operator Workstation Feature Guideline

The feature guideline is a tool for comparing pre-existing or new bus operator workstation dimensions to suggested feature dimensions. The research team used information from industry, existing transit bus vehicle design, and other international bus operator workstation guidelines to construct a stand-alone, updated feature guideline document. The research team gathered transit industry bus operator workstation guidelines from the United States and Europe and compiled comparative specifications from these publicly available sources, including *TCRP Report 25*, to illustrate similarities and differences in one International Bus Operator Workstation Design Matrix, which is appended to Design Tool 1.

The feature guideline document is intended to provide design guidance for transit bus manufacturers and transit bus agencies procuring buses. The primary scope of this document is limited to the key elements of operator workstation design that impact the health and well-being of the bus operator. Each feature guideline uses the following format:

- **Definition:** Provides a description of each individual operator workstation feature;
- **Figure:** Where possible, provides an illustration of each specific feature;
- **Design Guideline:** Provides suggested design objectives based on ergonomic principles and vehicle design literature; and
- **Need for Design Guideline:** Provides the reasoning for the design criteria as well as the factors that need to be considered when designing the operator workstation feature.

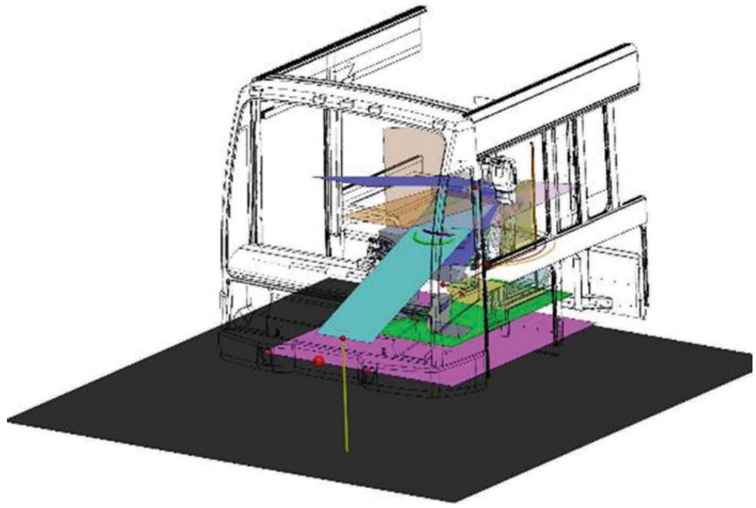

Figure S-1. Bus Operator Workstation Engineering CAD Model guideline data (solid-body colored envelopes only) superimposed over the transit bus operator workstation reference system with wireframe bus—contextual demonstration only.

Bus Operator Workstation Engineering CAD Model

The research team applied 2-D and 3-D data from a current production transit bus to establish the basic architecture of a transit bus operator workstation. The modeling of components was accomplished using solid-modeling CAD. SAE International's recommended practices (RPs) were applied to develop the operating packaging references and envelopes of Design Tool 2: Bus Operator Workstation Engineering CAD Model (Engineering CAD Model). Additional guidelines were applied that might enhance the Engineering CAD Model to meet the needs of the transit bus operators. The model has been exported in universal solid-body CAD modeling formats including Initial Graphics Exchange Specification (IGES) and Standard for the Exchange of Product (STEP), which are available online for download from the *TCRP Report 185* webpage.

An example image from the Engineering CAD Model is shown in Figure S-1.

Bus Operator Workstation 3-D PDF Model and User Guide

To increase awareness of the bus operator's needs and the process by which those needs can be met through appropriate communication among the stakeholders in the procurement process, it was deemed appropriate to make a 3-D tool accessible to a wider audience than just engineers with CAD experience. To accomplish this purpose, the Bus Operator Workstation Engineering CAD Model was exported into a lightweight 3-D universal file format (i.e., PDF) as Design Tool 3: Bus Operator Workstation 3-D PDF Model. An image from this model is shown in Figure S-2. For users not familiar with Adobe 3-D PDF applications, a user guide was also developed and formatted into a PDF file. The user guide explains how to open the model, navigate, and capture rough dimensions.

Both Design Tool 3 and the 3-D PDF user guide can be accessed online from the *TCRP Report 185* webpage.

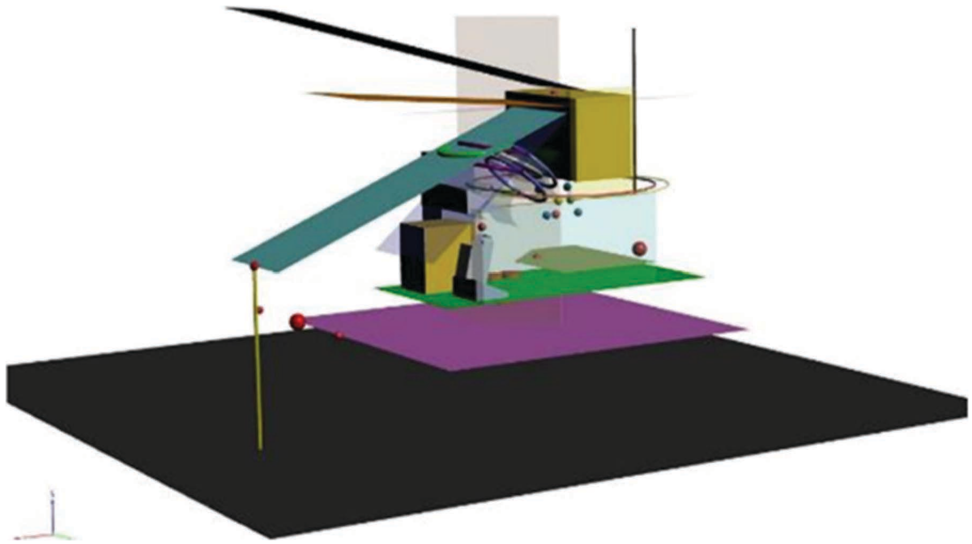

Figure S-2. A front, isometric view of the Bus Operator Workstation 3-D PDF Model. Ground and bus platform, vehicle references, clearance envelopes, reach envelopes, visibility planes, seat access, and seat/steering wheel/pedal packaging references are demonstrated.

CHAPTER 1

Project Overview

Problem Statement

In 1997, TRB published *TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines.* The report served as a reference for transit agencies seeking to evaluate and procure buses based on ergonomic considerations affecting musculoskeletal demands and human factors considerations for bus operators.

Since the publication of *TCRP Report 25*, significant progress has been made in bus operator workstation design and its impact on bus operator health and safety. TCRP recognized the importance of producing an up-to-date document covering available options for bus operator workstation evaluation and design to improve bus operator health and safety and reduce costs associated with liability, time loss, and disability. TCRP Project C-22 called for research proposals to do the following:

- Better assess the bus operator workstation in the context of occupational health and safety;
- Examine how bus operator workstation design guidelines can best be used in the bus design and procurement processes;
- Produce user-friendly guidelines for improving bus operator workstation design, including but not limited to the physical, cognitive, and perceptual environments; and
- Develop a planning and decision-making tool that improves future bus procurements to benefit bus operator health and wellness and transit system safety performance.

The research was expected to help transit industry stakeholders, especially transit agencies and manufacturers, integrate suggested procurement practices and improved technologies into bus operator workstation design, and to address operational and economic demands.

Project Objectives

The initial objectives of TCRP Project C-22 were to produce the following:

1. Potential strategies, practices, and policies for reducing bus operator injury and illness, public liability, and property damage attributable to bus operator workstation design in the U.S. public transit industry;
2. Guidelines to update the *TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines;*
3. A digital CAD model of a bus operator workstation that can be used by designers and transit agencies in bus specifications;
4. A proposal for developing a benefit/cost analysis of implementing an ergonomically designed bus operator workstation that considers (a) life-cycle costs of the workstation; (b) bus

operator turnover, illness, absenteeism, and injury costs; and (c) public liability and property damage costs;
5. Strategies for transit agencies to train and support a bus procurement team that includes bus operators to effectively participate in the development of specifications for the bus operator workstation; and
6. Training material in ergonomics for bus operators to improve their health, safety, and job performance.

This project was designed to assist transit agencies and bus manufacturers to integrate improved and emerging technologies into current procurement practices and improve bus operator workstation design across the transit industry. The research team captured input from bus manufacturers, transit agencies, labor unions, and transit organization staff in the United States and Canada to develop strategies for improving effective collaboration in the bus design and procurement process.

The research team identified and analyzed advances in ergonomics considerations as demonstrated in research and transit industry literature and transit bus practices. The team applied these findings to musculoskeletal demands and human factors concerns for transit bus operators in the context of several existing design guidelines. The research team used digital human modeling to produce a CAD model for vehicle engineers and designers. A universal three-dimensional (3-D) model that can be accessed by anyone with PDF computer software was exported for wider dissemination of information to improve transit bus operator workstation design. The research and practice background related to procurement and to ergonomics are described in the following sections.

Bus Operator Health and Safety Background

The public transit bus operator's job is complex and demanding. Compared to the U.S. workforce overall, public transit workers have higher instances of low back pain, shoulder problems, carpal tunnel syndrome, and lower leg vascular problems (Bushnell et al. 2011 and personal communication). Bus operators in particular are exposed to a wide range of physical demands that can contribute to the observed health problems. The most commonly recognized demands are extended sitting; stressful postures affecting the back and joints; glare; and force demands including, for example, using double interlock brakes or assisting wheelchair passengers. Bus operators experience whole-body vibration and impact forces transmitted via the seat, and higher frequency vibration from the steering wheel.

Navigating the road environment creates challenges and at times psychosocial stresses, such as staying aware of pedestrians, dealing with high volumes of traffic and construction, or driving through poor weather conditions. In addition, bus operators face attentional and cognitive demands related to bus alerts and controls, schedule stress, and sometimes abuse or assault by passengers. These stressors can increase the negative impact of the job's physical demands.

Visual and cognitive overload from displays and auditory inputs can also lead to stress that aggravates the impact of the biomechanical demands. Besides negative effects on the bus operator's health and well-being, these factors can combine to increase bus operator mental and physical fatigue, which may reduce awareness of potential vehicle or pedestrian road incidents. The complexity of the informational demands on bus operators continues to increase in today's transit buses.

Workstation Design and Bus Operator Work Demands

Workstation layout and design determine the biomechanical challenges that can result in cumulative or acute strain. These challenges include reaching for manual door mechanisms, manipulating the steering wheel in repeated 90° turn maneuvers, moving the legs and feet forcefully or awkwardly operating foot controls, repeatedly adjusting the torso to ensure safe visibility, and absorbing vibration through the seat, floor, or steering wheel.

Vehicle architecture may amplify biomechanical strains; for example, there is a trade-off between the comfort of the operator workstation compartment and optimization of the design of other areas, such as the passenger walkway, passenger seating and storage, and access to the fare box. The bus needs to be big enough to maximize passenger capacity while remaining maneuverable through city streets. Flat-front vehicle architecture tends to restrict the pedal and instrument panel space between a flat dash wall, which impedes pedal travel, steering column shaft location, and the operator's compartment barrier.

A minimized bus operator workstation typically results in a limited path to and from the seat. Typically, there is no exterior door access for the operator on the left side, and the pass-through is slim between the seat, fare box, passenger grab handles, and workstation compartment barrier in the rear of the operator seat. Variations in bus operators' anthropometric dimensions can result in a poor fit to seat, steering wheel, mirrors, and pedals. These restrictions may be complicated by the presence of protective barriers.

Workstation Impacts on Bus Operator Health and Safety

These stresses and cumulative strains can take a toll not only on bus operators but also on the transportation system and the riding public in the form of absenteeism and missed bus runs. Early studies indicated that the absenteeism rate of transit bus operators was as much as three times the average rate for other blue-collar workers (Evans 1991; Winkleby et al. 1988). A recent news story (Elinson 2012) reported that at the San Francisco Municipal Transport Agency the unscheduled absence rate was 12.2% on a daily basis. In contrast, in 2014 only 2.9% of the general U.S. working population reported working less than their regular hours in the previous week, for a total of 1.5% of regular hours missed (Bureau of Labor Statistics 2015).

A range of health factors, including chronic disease and stress, contribute to absenteeism (Evans 1994); but musculoskeletal disorders in particular have been shown to be higher among bus operators than in many other occupations (Alperovitch-Najenson et al. 2010a and 2010b; Gobel et al. 1998; Greiner and Krause 2006; Szeto and Lam 2007; Westgaard and Winkel 2011). The biomechanical and cognitive demands related to the design and layout of the bus operator's workstation have been suggested as a major contributor (Tse et al. 2006; Bhatt and Seema 2012). Improving workstation design will contribute to a reduction in the prevalence of musculoskeletal strains and other health problems faced by operators, and may limit related absenteeism.

Bus Operator Workstation Design: Literature Review

A growing body of research indicates the importance of bus operator comfort and safety in the success of public transit service delivery (e.g., Brunoro 2012), but the bus operator workstation has often been considered only after other concerns, including passenger seating (Grosbrink 1998). Grosbrink emphasized the bus operators' role in identifying workstation problems: "Finally, the assessment of the driver's area by the drivers, whose personal interests should be taken into account, is of great importance. Supposedly minor details, such as placement of the driver's bag or storage lockers for personal effects, are important for driver satisfaction." Bus design elements such as engine placement and floor height can affect key areas of personal interaction on the bus, especially between bus operators and passengers (Napper 2009).

Comfort, in addition to safety, was an area of concern to transit agency staff, industry experts, and bus operator union officers participating in the current research. They agreed that bus operators should play a central role with their transit agencies in defining how the bus operator workstations should be designed. These requirements and guidelines should be communicated to the manufacturers.

Bus Operator Participation in Bus Design Within Transit Agencies

The research literature supports the importance of the bus operator in assessing and improving the workstation, as the following examples show:

- An early study (Jabs 1988) used qualitative interviews of transit agency managers, driver surveys, and records review methods to identify the bus operator workstation elements that contribute to operator injuries. The concerns—seats, controls, stress, and lack of breaks—mirrored those described in the current research. Jabs remarked on the wide range of opinions on the same buses among transit agencies (and even within one location), and suggested the need for systematic data collection that is still flexible enough to incorporate opinions and qualitative assessments. Examples of research in this area include the following:
  - Carrier et al. (1992) assessed the bus operator workstation for the Canadian Public Transit Association. They interviewed and observed bus operators across Canada to diagram the many elements that contribute to the demands of the bus operator tasks (p.12). Carrier et al. also drafted a design priorities tree based first on health and safety concerns, then on efficiency and comfort.
  - Salmon (2011) defined a framework of ergonomics methods for assessing bus driver distraction (p. 609) that is based in existing and naturalistic data, rather than lab methods or simulators. This framework begins with data collection consisting of documentation review, subject matter expert interviews, bus driver focus groups, observational study, and ergonomic assessment of the bus operator workstation. Multiple, overlapping methods of analysis led to a definition of the sources and effects of distraction. The structure of the framework can also be applied to musculoskeletal, cognitive, and other demands of the bus operator workstation.

Communicating Bus Operator Insight to Vehicle Manufacturers

It is not enough just to generate good ideas in a vehicle assessment process. The findings need to influence what equipment is on the market. Research describing participatory ergonomics in varied work environments, including transportation, demonstrated that workers' recommendations may not be implemented; the reasons for this need to be investigated (Driessen 2010). In addition to bus operators' limited input within the transit agency, workstation design is hampered by lack of communication between bus operators and manufacturers. Both groups cited this as a barrier as early as a 1982 report (Transport and General Workers Union 1982).

In contrast, there are examples of successful execution of procurement based on the identification of design issues by users and interaction with manufacturers.

- Bellemare et al. (2005) described a method for overcoming the mistrust and inefficiencies that may result from top-down analysis and design of a subway train cab. A team of stakeholders (operators, maintenance workers, engineers, operations management, and ergonomists) developed a simulated workstation (model) that allowed the research team to address the experience of operators with regard to the constraints of the workstation. The researchers felt that a trained procurement team that included operators could apply the simulated computer model to carry out assessment and testing more efficiently than if the process were done solely by engineers and designers.

- Participatory ergonomics is especially important when the initial concern of the vehicle purchaser may not be the most important issue. In an ergonomics assessment of a subway operator's cab, Stevenson et al. (2000, 502) found that "[a]s with many ergonomic projects, the problem initially identified by the client, viz. the detailed design of the handle of the master controller, turned out to be a less significant issue than several other factors. The questionnaire and design studies indicated that the most important issues were the knee space and the ease of use of the foot pedal."
- Frieling (2012, 59) quoted a Dutch transit agency and manufacturers describing their joint, practical approach: "The use of a low-level mock-up and the input of future drivers at an early stage of the design process were essential for the successful development of this driver's cabin for Amsterdam's metro. The combination of experts, real drivers, and virtual manikins has resulted in a driver's workplace in accordance with the principals of human factors." The researchers acknowledged that some aspects of needed design were not possible to mock up and would need to be assessed in pilot phases of production.

In summary, the research literature on the impact of workstation design on bus operator health illustrates a range of naturalistic, qualitative, and technical approaches to data collection and analysis. It also supports increasing the role of the bus operator, along with other stakeholders, in analyzing the workstation and designing solutions.

Updated Bus Operator Workstation Design Guidelines

Overview of Previous Guidelines: *TCRP Report 25*

TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines was developed through TCRP Project F-4 by Pennsylvania State University in the late 1990s (You et al. 1997). The project consisted of an analysis of bus operator workstation demands and the modeling, mock-up, and testing of an improved design. The guidelines involved products and suggestions for specifications, including the following:

- Bus operator workstation mock-up user evaluation;
- Bus operator workstation designation of component reference points [e.g., seat reference point (SRP), right instrument panel reference point (RIPRP)], vehicle design variables, and anthropometric body variables, which were organized into a hierarchy and fit into design function relationship equations;
- A bus operator workstation checklist of approximate design values and adjustment ranges to nominally accommodate a 5th percentile female through a 95th percentile male; and
- Demonstration of suggested workstation design on a drivable prototype to a sample of bus operators.

In reviewing *TCRP Report 25*, the research team identified two important areas for consideration in TCRP Project C-22:

1. The workstation design approach in the earlier study was based on a neutral seat reference point (NSRP) rather than neutral pedal references, and
2. The anthropometric data set of the earlier study was based on univariate linear body lengths and posture angles or range of motion.

The authors of *TCRP Report 25* concluded that the NSRP approach would require adjustable floors and pedals; however, the adjustable floor was not attempted in dynamic or static evaluations of the workstation because of its potential impact on safe ingress/egress from the workstation. The authors of *TCRP Report 25* also decided not to pursue adjustable pedals due to concerns about reliability. Without either adjustable floors or adjustable pedals, the assumptions of a fixed NSRP and optimized visibility were not supported for bus operators of various sizes.

Current Approach

The methodology chosen to develop the updated bus operator workstation design guidelines improves upon the approach applied in *TCRP Report 25*. The approach presented in *TCRP Report 185* allows the inclusion of design requirements from multiple international guidelines, as well as common vehicle architecture dimension characteristics (e.g., SAE J1100). Industry feedback was collected from transit agencies that would be future guidelines users. SAE Class B vehicle packaging RPs were applied to the location and positioning of the bus operator workstation seat, controls, and components. In order to place boundaries on the arrangement of the workstation elements, the research team obtained current production vehicle data. A recent survey of a North American population of commercial vehicle drivers was applied to develop multivariate manikins that became the basis for validation of the suggested bus operator workstation.

International Transit Bus Operator Workstation Guideline Matrix

As part of the literature synthesis, the research team gathered transit industry bus operator workstation guidelines from the United States and Europe.

- U.S. Sources:
  - *TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines*
  - Standard Bus Procurement Guidelines (APTA 2013), developed as a tool to assist with the RFP process
- International Sources:
  - European Bus System of the Future (EBSF) Recommendation for a Code of Practice of Driver's Cabin in Line-Service Buses (European Commission 2011)
  - International Organization for Standardization (ISO) document ISO 16121-1:2012(en): Road Vehicles—Ergonomic Requirements for the Driver's Workplace in Line-Service Buses, Part 1: General Description, Basic Requirements (ISO 2012)

The research team compiled comparative specifications from these publicly available sources to illustrate similarities and differences in one International Bus Operator Workstation Design Matrix. The result of the bus operator workstation guideline matrix was a feature guideline.

Bus Operator Workstation Feature Guideline

Design Tool 1: Bus Operator Workstation Feature Guideline is useful for determining how pre-existing or new bus operator workstations' dimensions compare to the suggested feature dimensions. The research team used industry feedback, existing transit bus vehicle data, and the matrix of international transit bus operator workstation guidelines to construct the tool as a stand-alone guideline document with updated features. The document is intended to provide design guidance for transit bus manufacturers and transit bus agencies procuring buses. The primary scope of the document is limited to the key elements of operator workstation design that impact the health and well-being of the bus operator.

Bus Operator Workstation Engineering CAD Model

For **Design Tool 2: Bus Operator Workstation Engineering CAD Model** (listed online as "Bus Operator Workstation Engineering CAD Model"), the research team applied 2-D drawing and 3-D model data from a current production transit bus to establish the basic architecture of a transit bus operator workstation. The modeling of components was accomplished using solid-modeling CAD. Gaps in the CAD data were filled by reverse engineering components from physical measurements of transit buses. When the vehicle CAD model was completed, the research team had a detailed benchmark upon which to build the suggested Engineering CAD Model. SAE RPs were applied to develop the operating packaging references and envelopes. Additional guidelines were applied that might enhance the Engineering CAD Model in meeting the needs of today's procurement practices and ultimately meeting the needs of the transit bus operators.

Bus Operator Workstation 3-D PDF Model and User Guide

To increase awareness of the bus operator's needs and the process by which those needs can be met through appropriate communication between the stakeholders in the procurement process, it was deemed appropriate to make a 3-D tool accessible to a wider audience than just engineers with CAD experience. To accomplish this purpose, the Bus Operator Workstation Engineering CAD Model was exported into a lightweight 3-D universal file format (i.e., PDF), creating **Design Tool 3: Bus Operator Workstation 3-D PDF Model** (available online from the *TCRP Report 185* webpage, together with a 3-D PDF user guide).

The design tools and suggested procurement team practices from TCRP Project C-22 are designed for use by each transit agency to coordinate with its workforce, vehicles, and suppliers. The intent of *TCRP Report 185* is also to enhance communications among transit agencies, manufacturers, researchers, and industry groups.

Report and Tools Roadmap

The chapters of this report define and explain the tools produced through the TCRP Project C-22 research and how they can be used to support effective bus procurement and help transit operators provide safe, efficient, and economical service.

Chapter Guide

- **Chapter 2: Bus Workstation Design and Procurement Process to Protect Operator Health and Safety** defines the steps and practices derived from the research interviews and surveys. It provides a background summary of the research for each phase of procurement, and illustrates the important roles played by stakeholders outside the transit agency.
- **Chapter 3: Training to Support the Procurement Team and Bus Operator Ergonomics** lays out suggested areas of training and shows how these can enhance the procurement process.
- **Chapter 4: Development of Bus Operator Workstation Design Guidelines** establishes the bus operator workstation packaging assumptions and steps used to develop the feature guideline document, CAD model, and associated 3-D PDF model.
- **Chapter 5: Human Modeling Validation of Bus Operator Workstation Design Guidelines** describes the process of human modeling simulation that was used to test the prescribed seat/steering-wheel/pedal arrangement to determine if it would accommodate a population of U.S. commercial vehicle operators comfortably while meeting requirements for visibility and floor/pedal reach.
- **Chapter 6: Conclusions** summarizes the processes, communication paths, and tools that, when applied during and between procurement periods, will support and deliver improvements in bus operator health and safety.
- **Appendix A: Bus Operator Considerations for Purchase Price** consists of a proposal for developing a benefit/cost analysis of implementing an ergonomically designed bus operator workstation that considers all costs and the benefits to impacted social groups, and a discussion of a return on investment (ROI) analysis approach.

- **Appendix B: Bus Operator Workstation Engineering CAD Model Specifications** demonstrate the steps and specifications that were applied to the creation of the Bus Operator Workstation Engineering CAD Model and Bus Operator Workstation 3-D PDF Model tools.
- **Appendix C: Construction of Multivariate Manikins in Human Modeling Software** demonstrates the steps and body dimensions applied to develop a group of simulation manikins representative of a recent U.S. population of commercial vehicle operators in a high fidelity human modeling software (RAMSIS).
- The **Annex to Appendices** summarizes information from appendices D, E, and F regarding data collection and the methodology used during the research. Complete, unedited copies of appendices D, E, and F can be found on the TCRP Project C-22 webpage.

Tools

The following organization and design tools are available for download from the *TCRP Report 185* webpage. To access the correct page, go to www.trb.org and search for "TCRP Report 185".

- **Organization Tool 1: Bus Operator Workstation Procurement Process** (listed online as "Suggested Procurement Practice for Bus Operator Health and Safety") defines the phases, steps, and suggested practices for procurement teams to enhance bus operator health and safety. This tool is explained in detail in Chapter 2 and summarized in the online tool.
- **Organization Tool 2: Bus Operator Workstation Procurement Team Training** (listed online as "Procurement Team Training") is a presentation template outlining the training that supports the bus procurement process described in Chapter 2. This tool is described in Chapter 3.
- **Organization Tool 3: Ergonomics Training for Bus Operators** (listed online as "Ergonomics for Bus Operators Training Template") provides a training plan and presentation that can be adapted by transit agencies and unions to help bus operators understand the ergonomics demands of their work, protect their health, and contribute to safer bus operation. This tool is described in Chapter 3.
- **Design Tool 1: Bus Operator Workstation Feature Guideline** (listed online as "Bus Operator Workstation Feature Guideline") is intended for use in determining how pre-existing or new bus operator workstations dimensions compare in 2-D to the suggested feature dimensions. It has been organized by workstation component categories. A comparison matrix of international transit bus guidelines is appended to the guideline document. The development of this tool is described in Chapter 4.
- **Design Tool 2: Bus Operator Workstation Engineering CAD Model** (listed online as "Bus Operator Workstation Engineering CAD Model" and available as either an IGS file or a STEP file) is a 3-D engineering level spatial representation of the visibility, seating, and control criteria supplied in the 2-D feature guideline. The development and validation of this tool are described in Chapters 4 and 5, respectively.
- **Design Tool 3: Bus Operator Workstation 3-D PDF Model** (listed online as "Bus Operator Workstation 3-D PDF Model" and provided with a 3-D PDF user guide) provides a model for procurement team members and stakeholders who do not have access to complicated and expensive engineering CAD programs. The development of this tool is described in Chapter 4 and the validation of this tool is described in Chapter 5.

CHAPTER 2

Bus Workstation Design and Procurement Process to Protect Operator Health and Safety

Introduction

The purpose of this project was to develop tools, strategies, and practices for improving bus operator workstation design and procurement in the U.S. public transit industry. The current APTA bus procurement guidelines acknowledge workstation ergonomics in the proposal rating considerations for vehicle structure, including "layout of the operator's compartment . . . available ergonomic information, and functional enhancements, including integration of electronic controls and minimizing the number of gauges and switches" (APTA 2013, 287). However, these guidelines do not address how to select the components that affect operator and vehicle safety into the whole of the physical workstation layout and how to integrate stakeholders during all procurement phases and throughout the bus life cycle.

The transit agency employees and industry experts interviewed in this research felt that the procurement process needed to do more to incorporate bus operator workstation health and safety considerations. This chapter of *TCRP Report 185* answers that need, defining an effective bus procurement process to enhance bus operator health and safety. The suggestions given in this chapter are based on current transit agency practice, industry expert insight, and the research and practice literature. The accompanying tools were produced to support the process described and improve bus operator workstation design through better industry-wide coordination.

The research into the procurement process consisted of the following:

- **Interviews with transit agency managers and union officers.** Interviews with representatives from 10 transit agencies addressed the structure, team make-up, and typical steps of their bus procurement activities as they related to bus operator health and safety. Respondents also provided examples of decision matrixes. A total of 17 people participated, with transit agency managers and union officers participating in five locations, managers participating in four locations, and the union officer participating in one location.
- **Interviews with industry experts.** Interviews with four industry experts with experience in procurement, bus operator design and ergonomics, and worker-centered design addressed current and ideal practices for collaborative bus procurement.
- **A survey of transit unions.** Local union officers representing bus operators at 26 transit agencies returned surveys about their members' roles in bus procurement.

Chapter 3 covers training for the bus operator workstation procurement team and targeted training for bus operators in ergonomics and workstation health and safety. The material presented in Chapters 2 and 3 is supplemented by detailed appendices and tools as described in Chapter 1, including Appendix D: Transit Agency Procurement and Bus Operator Workstation Considerations: Research Methods and Results; Appendix E: Industry Experts' Perspectives on Improving Bus Operator Workstation Design; Organization Tool 2: Bus Operator

Workstation Procurement Team Training; and Organization Tool 3: Ergonomics Training for Bus Operators. Appendices D, E, and F are summarized in the Annex to Appendices published with this report. Complete, unedited content for these appendices is available from the TCRP Project C-22 webpage.

Improving Bus Operator Workstation Design and Procurement

Bus operator health and safety are not always considered as a distinct procurement issue. Moreover, workstation demands and safety concerns are ongoing and evolving. This occurs in part because ergonomic and health-related information comes in at all phases of the bus life cycle. Solving problems often demands an immediate response rather than one that can wait for new bus procurement. Concerns may arise after formal testing of the pilot buses is completed, as equipment is stressed to failure or as bus operator discomfort surfaces over time. For these reasons, the equipment changes that affect bus operator health and safety may not be well integrated into the procurement process. An unsystematic approach can make it harder to define improvements or identify the limitations of the vehicle in the next procurement cycle.

This chapter integrates the information provided by transit agency, union, and industry expert sources to lay out steps for a systematic bus procurement process to improve bus operator health and safety. The most effective procurement team will encompass representation from a range of roles and experiences at the transit agency: maintenance staff, operations, engineering, safety, purchasing and procurement, upper management, and—at times—the board and the riding public. The size and purchasing needs of the transit agency will determine whether stakeholders are ongoing team members or targeted contributors. Most critically, the procurement process depends on the input and participation of bus operators.

The suggested steps are consistent with other models for design and procurement, including those used by FHWA, the Centers for Disease Control and Prevention (CDC), and APTA. Transit agency engineers are likely to be familiar with the FHWA Traditional Transportation Project Development Process, which defines systematic phases of project initiation; preliminary engineering; plans, specifications, and estimates; construction; and project closeout (FHWA 2007).

Similarly, the industry experts' recommendations correspond closely to the comprehensive product testing and selection stepwise process published by the CDC, shown in Figure 1 (CDC n.d.).

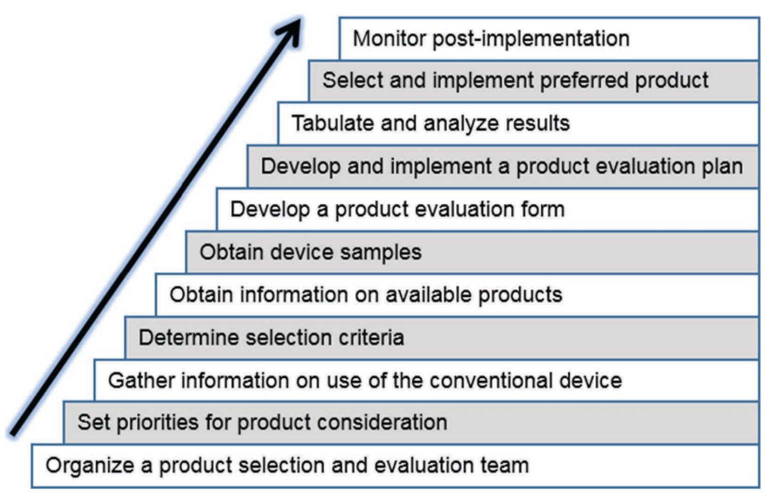

Figure 1. Key steps in the CDC product evaluation process.

Coordinating Industry-wide Action

Strong transit agency procurement proposals reflect stakeholder input. The bus procurement process is also supported by broader industry-wide interaction, before, during, and after active procurement. Within the transit agency, hourly and management staff from maintenance, engineering, and operations understand how past procurement decisions affect day-to-day service delivery and the bottom line. They form the core of the procurement team. Their important roles are discussed in greater detail later in this chapter.

Some of these transit agency stakeholders participate in an ongoing way, gathering information and communicating with counterparts in other transit agencies, with vendors, or with researchers. They may be members of the procurement team or provide the team with needed information. As illustrated in Figure 2, various people and organizations contribute to the development and procurement of the bus operator workstation through their interactions with the transit agency. Effective bus design and specification engages bus and parts manufacturers (A), other transit agencies (B), professional groups and government resources (C), and academic and government research partners (D). Communication goes both ways between the transit agency and the other partners.

Many industry partners are already taking steps to improve bus procurement and can incorporate the tools and recommendations of this report in their work. In particular, APTA has influenced industry practice, continually updating bus procurement guidelines and other support materials as knowledge, policy, and technologies have developed. FTA also is coordinating efforts to improve bus procurement and vehicle safety.

Academic partners at university-based transportation centers and schools of engineering and public health also support the analysis of the ergonomic, health, and safety attributes of the bus

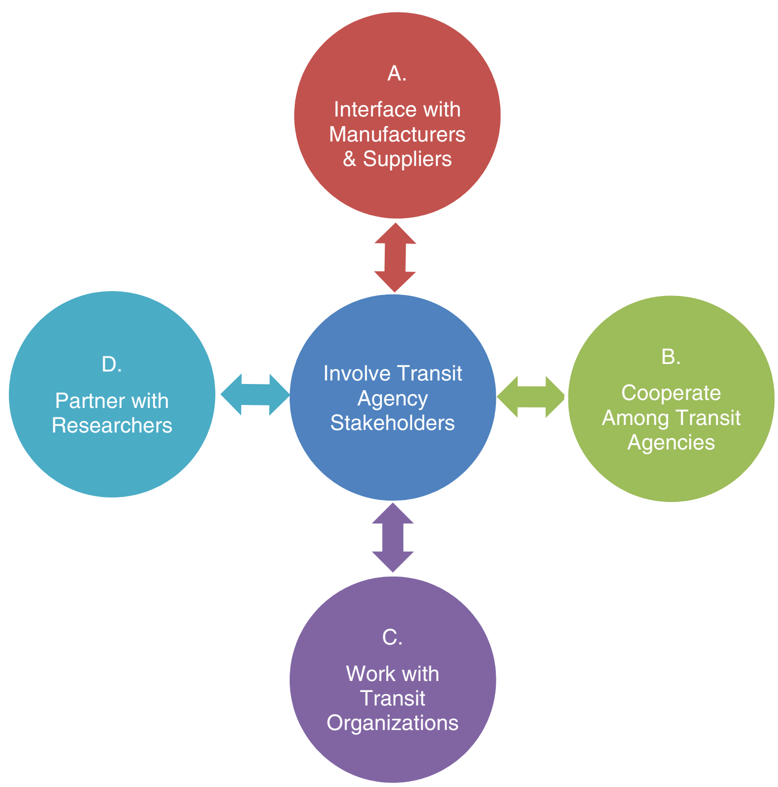

Figure 2. Coordinating industry-wide action to improve bus operator workstation design.

operator workstation. Several of the transit agencies interviewed described working with academic partners to select, test, or develop improved bus designs. Government research groups such as the National Institute for Occupational Safety and Health (NIOSH) have made contributions, and bus operators and their unions have relationships with researchers and vendors that can be a significant source of input to the entire process.

Suggested practices in the four action areas that support coordinated industry-wide action to improve bus operator workstation design are described below, along with considerations and suggestions for achieving each target.

Action Area A: Interface with Manufacturers and Suppliers

Suggested Practice: Health and safety experience and concerns with equipment design, configuration, and installation are communicated to manufacturers of buses and other equipment, during and outside of the award process.

Because manufacturer quotes may be higher for unusual or last-minute requests, early stakeholder involvement and communication with equipment suppliers are important. Bus operators contribute to the exchange by suggesting or designing solutions, both via their employers and at times directly to vendors. Bus operators often are the best people to canvas other bus operators, summarize results, and provide feedback to vendors at union and industry events.

Action Area B: Cooperate Among Transit Agencies

Suggested Practice: The transit agency cooperates with other agencies in procurement planning, specifications, and testing activities that enhance operator health and safety.

Purchasing power can be leveraged through collaboration among transit agencies with similar concerns. Procurement teams already make use of existing channels of communication such as listservs, regional meetings, and informal contacts. Joint efforts by transit agencies could include developing a database of information on available and new technologies or updating the digital CAD model with lessons learned and with specific technology and bus operator workstation advancements. Cost savings could result from jointly engaging an engineering consulting firm to work on equipment design. The collective data could be used to produce shareable output, for example in the 3-D PDF model.

To support communication among transit agencies, it is important for transit agencies to provide procurement team members with time and opportunity to share findings and problems at meetings and through electronic contacts. Bus operators can use union and individual channels to share their concerns and findings, provide input on design steps, and—with employer support—attend APTA and other industry meetings.

Action Area C: Work with Transit Organizations

Suggested Practice: The transit agency shares findings and concerns from current and past procurement with trade organizations, with groups such as APTA's Bus Safety Committee, with labor unions, and with FTA.

National groups currently encourage transit agencies to participate in design steps and data sharing activities. Transit agencies may send representatives to participate in national meetings. Bus operators can help their transit agencies and their unions comment on relevant initiatives, and can participate in appropriate planning meetings addressing bus operator workstation design and bus operator health and safety.

Action Area D: Partner with Researchers

Suggested Practice: Transit agencies collaborate with appropriate research partners to identify and resolve concerns.

Academic institutions and transportation centers are sometimes recruited by transit agencies to develop and assess solutions for transit vehicle and service delivery concerns. These activities can be expanded to address bus operator workstation health and safety. For example, transit agencies can consult with NIOSH transportation research experts. Bus operators, as users, can participate in research projects, and can work with their international unions to initiate or participate in research and develop innovations.

Developing a communication and resource network supports improvement of the available technologies and can make procuring buses that enhance operator health and safety more economical. Such a network can both depend on and support the comprehensive bus procurement process described in the next section.

Suggested Bus Procurement Team Process

This section organizes the research team's recommendations for a bus procurement process that will improve bus operator workstation specifications for health and safety into four phases:

- **Phase I: Build and Support the Procurement Team;**
- **Phase II: Prepare for Procurement;**
- **Phase III: Specification, Request for Proposals (RFP), and Award;** and
- **Phase IV: Complete the Build and Roll-out.**

Each phase is described in a section listing the suggested practices, discussing related issues, and detailing steps and considerations. As displayed in Figure 3, data collection and analysis, design and process tools, and training and communications channels are engaged in varying degrees in each phase. Figure 3 also includes suggested roles for manufacturers.

The active procurement process takes place in sequential steps that involve a broad range of contributions from throughout the transit agency. These contributions are solicited and managed by the procurement team, whether it consists of one or two people or an extended committee.

Phase I: Build and Support the Procurement Team

Suggested Practices Overview

- The transit agency procurement process engages stakeholders to address bus operator workstation health and safety.
- The procurement team members are provided with training to understand and support bus operator health and safety.
- Effective communication about bus operator workstation design and health and safety is maintained.

The procurement process begins with identifying everyone who will be involved and defining what their roles will be. The resulting procurement team can include representatives of any group that contributes to bus procurement. Among the transit agencies interviewed, procurement teams ranged from (a) a single maintenance manager and his technical staff, who called on others only as needed throughout the process, through (b) a few partners from procurement and technical departments, to (c) large, formally structured teams with subcommittees that targeted specified issues such as safety. Stakeholders that should either be on the procurement team or

Bus Procurement Phase	Organizational Steps	Data Collection and Analysis	Tools	Manufacturer Role	Communication	Training
Phase I: Build and Support the Team	1. Recruit stakeholders 2. Train team 3. Maintain communic.	--	Procurement Team Training	--	Maintain among team and stakeholders	Procurement process for BOHS
Phase II: Prepare for Procurement	4. Review past procurement	Past procurement	Ergonomics Training, Feature Guide	--	Between team and operations and maintenance	Layout of bus workstation, other BOHS
	5. Identify BOHS concerns and impacts	Logs, surveys	3-D PDF Model	--	Outreach to bus operators, others	Design concepts
	6. Acquire critical information	Identify available technology	Feature Guide	Provides information	Request input from other transit agencies, vendors, other transportation modes, unions	Blueprint reading
	7. Test bus mock-ups	Systematic data on changes and impacts	3-D PDF Model, CAD Model	Loan equipment	Involve bus operators and maintainers	Testing concepts
Phase III: Specifications, RFP, Award	8. Engage manufacturers	Identify all potential vendors and bus manufacturers	Feature Guide, CAD Model	Factory visits Demonstrations	Share concerns and findings with all potential bidders	--
	9. Draft specifications and RFP that address BOHS concerns	Use analyses to inform specifications	Feature Guide, CAD Model	Understand BOHS	Among team and with other stakeholders	--
	10. Evaluate final RFP changes for BOHS impact	Collect change recommendations in timely way	Feature Guide, CAD Model	Respond to questions about variances	Timely discussions about proposed changes	--
Phase IV: Build and Roll-Out	11. Monitor build process and test pilot vehicles	Develop and use checklists	Feature Guide, CAD Model	Factory visits On site consults Pilot buses	Get input from stakeholders	--
	12. Evaluation and retrofit (ongoing)	Use checklists, mine existing data	Ergonomics training	May assist in retrofits	Discuss with vendors, others	Training for bus operators

BOHS = bus operator health and safety.

Figure 3. Suggested procurement process for bus operator health and safety.

be actively consulted by the team include the maintenance department, operations, purchasing and procurement, upper management, and transit agency boards.

Transit agencies with larger committees may establish systems to make sure that the right stakeholder addresses each question. This interview excerpt from an agency that had a fairly large procurement team shows one way safety concerns can be addressed:

> The bus engineering group starts to design. [A]t each iteration, the engineering group sends it out to the stakeholders to review: the safety department, operations, training, maybe even infrastructure, all at the management level. The safety department makes sure that it's compliant with all the pertinent safety and health regulations, and . . . the engineers have incorporated anything that we have seen in past designs that needs to be improved upon. Engineering decides whether or not it is possible or feasible to do those changes. . . . They bring [the prototype] on to the property and everybody gets the chance to touch it and feel it and sit in it. That is where the bus operators themselves come in, and their union representation would start to get involved. If the prototype is drivable, the instructor staff, the supervisors, put it through its paces, and discuss safety concerns (transit agency interview April 2015).

Although, in this example, bus operators are not represented in the earlier stages, the industry experts and most transit agency respondents agreed that these end-users are underused as a resource. Bus operators can play three distinct roles that enhance health and safety in bus operator workstation design and in bus procurement. They can

- Serve as active members of the procurement team,
- Participate in a targeted evaluation and problem-solving groups, and
- Serve as employee-users in tests and trials, actively engaged in planning the evaluation and serving as test subjects.

Training is essential for orienting the team to the details of the procurement process and providing technical or operations knowledge they may not all share. Persons with specialized technical knowledge or skills are often brought in to assist the procurement team as needed, either through others in the transit agency or via consultants, but problem assessment and decision-making are also enhanced if the team understands procurement fundamentals that affect bus operator health and safety. In particular, ergonomics, design concepts, blueprint reading, and product testing knowledge can be helpful. Detailed training modules that will support the transit agency procurement team are described in Chapter 3 and laid out in Organization Tool 2: Bus Operator Workstation Procurement Team Training (available online).

The recruitment, training, and communication steps that build and support the procurement team are defined in detail in steps 1–3, along with considerations and suggestions for ensuring that bus operator health and safety are established as priorities in procurement.

Step 1: Define Procurement Process and Recruit Stakeholders

Suggested Practice: The transit agency procurement process engages stakeholders to address bus operator workstation health and safety.

The ideal procurement team recruits representatives from bus operations, engineering, maintenance, and safety departments. If they are not formal members of the team, these representatives are called on to participate at relevant stages in the procurement process. The team is organized to raise and address questions of bus operator workstation design, ergonomics, and safety in a systematic way. Bus operators and the safety department are involved early in the procurement process to allow time for design and specification changes to be made without increasing costs. Not all stakeholders are needed at every meeting; however, the bus procurement process provides for sharing information and opinions between stakeholder groups, across departments, and between hourly and management-level participants. Schedules are adapted as needed to allow participation by stakeholders who are involved in service delivery. In particular, bus operators—who can provide insight from their unique knowledge bases—are released from scheduled runs as needed to allow these stakeholders to contribute fully.

Step 2: Prepare and Train Procurement Team and Stakeholders

Suggested Practice: Stakeholders contributing to the procurement process (i.e., procurement team members) are provided with training to understand, analyze, and support bus operator health and safety.

Presenting a core training module that explains the procurement process can help orient the procurement team members, especially new ones. Potential training topic areas include bus operator workstation ergonomics and biomechanics, relevant design and engineering concepts, and health and safety regulations and guidelines. Effective training calls on internal skills and knowledge, with team members helping to develop or deliver training content. Informal learning from experienced team members and others strengthens the procurement process.

Not every participant needs training in all skills, as long as resources are identified and made available for consultation, input, or presentations as needed. The procurement team can also learn from past experience, if institutional history is recorded and shared before experienced individuals leave the organization. Bus operators can serve as trainers, and can provide guidance to others about their job skills and demands.

Step 3: Maintain Internal Communications

Suggested Practice: Throughout the procurement process, effective communication about bus operator workstation and operator health and safety is maintained between the procurement team and executive, management, and line-level employees and their representatives.

It is important for stakeholders to understand why their input is needed and what impact it has. Effective communication means that the results of assessments are shared and decisions are transparent to those who contribute information or opinions. Using multiple communication channels—print, email, meetings, and informal discussions—will facilitate information flow in all directions. Bus operators on the procurement team can assist with communications by reporting on the procurement process via union meetings or newsletters. They can bring information to the team and evaluate how well the results are communicated to others.

Phase II: Prepare for Procurement

Suggested Practices Overview

- The procurement team systematically reviews past procurements for all items affecting workstation design and operator health and safety, engaging the safety team and operators.
- The procurement team collects relevant information about bus operator workstation design and its impact on bus operators.
- The transit agency maintains and refers to an information base of existing and developing technology and its impact on operator health and safety.
- Potential changes are assessed for their impact on operator health, safety, and comfort through mock-ups and loaner equipment.

The selected and trained procurement team starts by establishing a process and setting a schedule for dealing with bus operator workstation health and safety concerns. Many transit agencies use the previous procurement document as a template for the next procurement, highlighting problems or values. The engineers may complete an initial review, or the entire procurement team may evaluate it as a group or in breakout sections. The procurement team then incorporates data collected from stakeholders and manufacturers about desired changes and available equipment.

Assessing the health and safety impact of the existing fleet is usually coordinated by maintenance or technical services, often with input from the safety department. Line-level maintenance workers may be given an opportunity to mark up the procurement document during this phase or during specifications. Some safety issues are identified after review of maintenance and safety records. Although bus operators can recommend changes to new procurement and to existing buses, they often have a more prominent role in retrofit because of their practical experience with the current fleet. One small transit agency that was interviewed described engaging bus operators throughout the procurement process:

> There is a procurement panel, including three drivers who poll the other drivers. The panel reviews the options and results. At employee meetings, they go over the outcomes of the tests and surveys to ensure that everybody is aware of what choices were made and why (transit agency interview March 2015).

Collecting qualitative data is as important as analyzing numbers. Surveys with room for open-ended responses may be harder to code, but they are better at eliciting new information than "Yes" or "No" or multiple-choice formats. Photos or drawings of the bus operator workstation can document where changes have occurred or if they may be needed. An outline of a human body (a body map) marked up by bus operators to show where they experience discomfort, fatigue, or pain can help target configuration and equipment problems. Such surveys and tools may elicit feedback on bus operators' concerns that go beyond the immediate workstation area, such as steps, wheelchair securement, and room for lunch or personal objects.

Surveys and other data collection methods are more likely to be treated seriously if bus operators are involved in their design, review, and distribution. Bus operators can participate by marking up bus operator workstation images with concerns or suggestions, and can co-chair needs assessment meetings as procurement team members or union representatives. The union may want to independently collect body map and survey results and other information about bus operator workstation concerns from coworkers and present the results to management.

It is important to stay up to date about the availability of equipment, academic or industry equipment studies, or trials of new configurations. Doing so takes continuous research. Designated procurement team members can establish and maintain ongoing outreach to designers, manufacturers, research groups, and other transit agencies.

In steps 4–7 of the suggested procurement process, transit agencies review existing data and collect new information from internal stakeholders, from industry colleagues, and from manufacturers. Data collection and decision-making will depend on the type and timing of the procurement cycle (e.g., whether the transit agency purchases through a consortium or individually, in 5-year contract periods or on a rolling basis). Transit agencies will need to adapt the practices to their size, resources, and procurement team structure.

Step 4: Review Past Procurements

Suggested Practice: Stakeholders (i.e., the procurement team) systematically review past procurements for all items affecting workstation design and operator health and safety, engaging the safety team and bus operators.

The procurement team looks at existing information about the health and safety impact of prior bus procurement, including workers' compensation and injury data, incident reports, and repair and replacement logs. Interim changes to the bus operator workstation configuration should be documented and evaluated, as should the original specifications. Informal and ad hoc adaptations made by bus operators commonly signal a problem with the design, and their model preferences can provide insight about workstation flaws and benefits. Bus operators generate useful information over the lifetime of the vehicles, as they report health or safety events they experience, share information and anecdotes about informal adaptations, report concerns with the existing fleet, and participate in reviews of procurement documents and safety reports.

Step 5: Request Information—Internally and Externally

Suggested Practice: The procurement team collects relevant internal and external information about bus operator workstation design and its impact on bus operators. The focus is on identifying bus operator health and safety (BOHS) concerns and impacts.

Data should be collected, recorded, and analyzed in a timely and ongoing way to reflect current conditions and support procurement. Input channels include:

- Email surveys and requests for information,
- Paper surveys distributed to employees,
- Shop-floor meetings to discuss the current fleet or propose changes,
- Procurement team requests for information in safety committee meetings or other meetings,
- Bus photographs or drawings annotated with interim or desired changes,
- Body symptoms maps marked up by bus operators, and
- Contacts with other transit agencies about their experience and suggestions.

A matrix that documents problems, defines the item importance, lists solutions, and records the final decisions will help keep the process systematic and aid in reporting and follow-up. Effective data collection is designed to access the skills and experience of staff at all levels, based on the kind of information they have, time, literacy, and other considerations. Explaining decisions that are made based on the information encourages respondents to participate in generating the information.

Step 6: Investigate New Technology

Suggested Practice: The transit agency maintains and refers to an information base of existing and developing technology and its impact on operator health and safety.

All stakeholders can contribute to the information critical to procurement, and the procurement team can call on different sources. Important sources include internal data, opinions, contacts with other transit agencies, professional literature, and discussions with vendors. Transit agency employees develop and maintain important knowledge and contacts when they participate in industry events, listservs, and other discussions across the industry. Innovative suggestions and new technologies need to be investigated, and vetted for possible problems and vehicle compatibility issues. Bus operators are crucial partners for potential improvements. They can reach out through unions and other external contacts and evaluate the potential impact from the user's perspective.

Step 7: Test or Mock Up Changes

Suggested Practice: Potential changes are assessed for their impacts on operator health, safety, and comfort through mock-ups and loaner equipment.

Information provided should be tested and confirmed within the transit agency. Testing of suggested configurations needs to start early, before the RFP phase. The procurement team can request loans of equipment for installation, or visit neighboring transit agencies for demonstrations. Test periods need to be long enough and demanding enough to push the equipment to relevant limits. This phase can make use of design tools such as the Bus Operator Workstation Engineering CAD Model and the Bus Operator Workstation 3-D PDF Model. Indoor testing does not replace on-the-road experience, especially for issues such as glare or vibration that depends on the environment.

This process can be time consuming. It is facilitated by bus operators who understand design and mechanical concepts and mechanics who understand driving. The transit agency employees, especially bus operators and maintenance staff, should participate in designing of mock-ups that can be built and tested in-house, and actively assist in testing. They should be consulted about planned changes and the validity of the test configuration and conditions, and can serve as live test subjects for changes (large and small, senior and new, male and female, etc.)

Phase III: Specification, Request for Proposals (RFP), and Award

Suggested Practices Overview

- The procurement team engages manufacturers in active exchanges that help identify and resolve concerns related to health and safety before final specifications.
- The RFP reflects stakeholder input to meaningfully address the areas affecting bus operator health and safety.
- Changes proposed at any upper level, later changes, and manufacturer requests for deviations are assessed on the same terms as the procurement draft specifications and RFP.

In this phase, the procurement team integrates findings from the data collection, review, and testing steps of phases I and II into a new or revised set of specifications. Design Tool 1: Bus Operator Workstation Feature Guideline (available online) will provide technical support for assessing and refining recommendations. The procurement team should discuss the potential health and safety impact of available options with manufacturers and get demonstrations. Review teams should be aware that industry promotional demonstrations are typically positive, and procurement team members may tend to rate the proposed changes positively. It is best if the procurement team talks with a range of vendors and other sources, as a lack of information about alternatives can interfere with a balanced assessment of options.

In completing the RFP, safety and health considerations will need to be matched with other technical requirements and assessed in the context of budget, board instructions, time constraints, and cooperation across the organization. Conflict areas may occur in other areas of procurement, not just in the health and safety aspects.

The review process will be iterative, as competing concerns push changes that do not take all issues into account. During the TCRP Project C-22 research, interview respondents voiced concerns about changes being made after the safety considerations had been addressed, when the proposal was assessed in the engineering or especially the budget arena. To avoid bidding and contractual violations, it is essential to clarify and agree on these issues before completing the RFP. In steps 8–10 of the procurement process, the procurement team engages manufacturers, upper management, and other stakeholders to make sure the final award best supports bus operator health and safety.

Step 8: Define Options with All Manufacturers

Suggested Practice: The procurement team engages manufacturers in active exchanges that help identify and resolve concerns related to health and safety before creating final specifications.

Effective procurement teams both bring information to the manufacturers and receive information from them. The procurement team members working on bus operator health and safety interact with manufacturers whenever practical. Systematic lists of questions, checklists, and data summaries ensure that they provide all potential bidders with their concerns and obtain the information they need for decision-making.

During demonstrations, the transit agency team holds on-site discussions about ergonomics concerns. Deviations from the RFP and the Bus Operator Workstation Feature Guideline are recorded with explanations as to why the requirement could not be met or how the requirement was met with a different solution. Bus operators and maintenance workers can participate in factory visits. They also can help prepare checklists or questions to be addressed and assess the responses.

Step 9: Draft Specifications and RFP (That Address BOHS Concerns)

Suggested Practice: The procurement draft and RFP reflect stakeholder input to explicitly address the areas affecting bus operator health and safety.

Comprehensive new bus procurement considers seating, steering, pedals, other controls, ingress and egress, passenger interaction (communication, assault, wheelchairs), roadway visibility (mirrors, glare, blind spots), farebox, personal storage space, and environmental controls. The proposed bus is be designed to fit bus operators ranging from the 5th percentile female to the 95th percentile male working population in relevant dimensions, and also designed to be operated reliably and safely with minimized physical demands. Core stakeholders, including safety department and bus operators and their representatives, participate in defining the terms of the RFP. The RFP references design tools such as the Bus Operator Workstation Feature Guideline and the Engineering CAD Model that accompany these recommendations.

The procurement team may elect to consult people with ergonomics training or expertise, transit agency staff if possible, or consultants from academia or business. The Engineering CAD Model or 3-D PDF Model can be used to test and demonstrate the fit of the proposed equipment to anthropometric variations in the agency's bus operator population and potential future variations.

Step 10: Review Changes Proposed Internally or by Manufacturers (for BOHS Impact)

Suggested Practice: Changes proposed at any upper level, later changes, and manufacturers' requests for deviations are assessed on the same terms as the procurement draft and RFP.

Deviations may be proposed for economic or feasibility reasons. It is important that the reasons for the deviations be made clear and that the potential impacts on operators be assessed. Stakeholders with greater—or later—influence need to be held to the same standards as stakeholders who participated earlier in the procurement process. Changes requested later in the process may be harder to review properly in a timely way. Despite potential scheduling difficulties, it is important that core stakeholders, including bus operators, continue to participate in document reviews and alert the procurement team to any concerns they identify.

Phase IV: Complete the Build and Roll-out

Suggested Practices Overview:

- The team continues to oversee the build process, test pilot buses, and systematically address changes to the bus operator workstation demands to improve the impact on the health and safety of operators and others.
- Safety department staff and bus operators contribute to the evaluation of the fleet for issues that affect health and safety through the bus life cycle. Solutions are identified, implemented on existing buses, and recorded for future procurements.

Health and safety concerns may become apparent as the bus is built or piloted. Having carried out careful testing and specification steps in the earlier phases, the procurement team needs to continue to pay the same attention to what happens in the factory, including how components are combined and how they wear. Bus operators commonly play a more active and skilled role during this phase than in earlier phases; but for many ergonomics concerns, this phase may be too late. To comply with procurement regulations and contractual obligations, substantive changes cannot easily be made after an award is granted.

If needed changes are extensive or require input from the manufacturers, they may be referred to the procurement team. As discussed earlier, recording and analyzing any interim adaptations or repairs helps inform the next procurement cycle. Transit agencies can develop checklists similar to those used for preventive maintenance inspections (Schiavone 2005) or workplace safety inspections. The pattern of problems observed and corrected by transit agencies can also contribute to the industry discussions, as was illustrated in Figure 2. Steps 11 and 12 of the procurement process summarize how this work continues through the testing phase and the bus life cycle.

Step 11: Monitor Bus Build Process and Test Pilot Buses

Suggested Practice: The procurement team continues to oversee the build process, test the pilot buses, and systematically address changes needed to meet the ergonomic demands of the bus operator workstation to improve any impact on the health and safety of operators and others.

Representative and extreme conditions are tested by bus operators, in time frames that reflect actual use. Improvements to the bus operator workstation design are made in response to findings. Some changes that arise during this step may affect other stakeholders, such as maintenance workers or bus passengers. Representatives of these stakeholder groups should continue to be involved to ensure that all perspectives are reflected in the procurement team's decisions. Checklists for assessing the workstation demands and equipment, along with systematic reporting formats, can increase the reliability and validity of the assessments. Both naïve and experienced bus operators will provide useful perspectives. As in earlier phases, bus operators can develop and use checklists, help define test routes and conditions, test drive prototype and pilot buses, and recommend improvements.

Step 12: Evaluate and Correct Problems (Ongoing)

Suggested Practice: Throughout the bus life cycle, the safety department and bus operators contribute to the evaluation of the fleet for issues that affect health and safety. In-warranty and fleet defects and refit and retrofit solutions are identified and implemented on existing buses and documented for future procurements.

APTA's Standard Bus Procurement Guidelines (2013) recommend that procurement documents include language stating: "The Agency may immediately declare a defect in design resulting in a safety hazard to be a Fleet Defect." To keep the cost of making changes down, bus operators and maintenance workers should be encouraged to report safety and health concerns about the workstation in a timely way, either directly to management or via joint labor-management or union safety committees.

Retrofits and other changes should be documented throughout the bus life cycle and reviewed during the next procurement, using checklist or complaint systems. Bus body and workstation maps provide an additional analytic mode for reporting concerns and summarizing data, and may be more practical for some stakeholders. These data are more easily accessed if entered into databases on a rolling basis.

Design and Procurement Summary

The recommendations presented in this chapter reflect the input of transit agency staff, of labor union leaders who are themselves bus operators, and of industry experts. In contributing to the research, these interview and survey respondents shared diverse experience and perspectives on transit agency procurement practices, on vehicle design, and on workplace ergonomics and health and safety. They agreed that effective procurement and an improved bus operator workstation require cooperation among stakeholders, careful data collection and analysis, and a timely focus on the demands of the bus operator's work. Technical recommendations to support this process are defined in Design Tool 1: Bus Operator Workstation Feature Guideline, applied in the CAD tools, and explained in Chapters 4 and 5 of this report. Further transit agency insight and experience are detailed in Appendix D and Appendix E, which are available from the TCRP Project C-22 webpage.

In addition to an improved procurement process, training is needed to make procurement teams and bus operators more knowledgeable about the vehicles they purchase and drive. The training recommendations laid out in Chapter 3 should contribute to a more effective procurement process that safeguards bus operator health and vehicle safety.

CHAPTER 3

Training to Support the Procurement Team and Bus Operator Ergonomics

Introduction

The overarching goal of the bus operator workstation procurement process—and of the design recommendations to protect operator health and safety presented in the balance of this report—is to engage all relevant stakeholders in procuring buses that fit the bus operators, reduce biomechanical demands, and can be operated and maintained safely.

Training was defined as an essential early step in preparing and supporting the procurement team. The research team for TCRP Project C-22 was also charged with developing an ergonomics training plan for bus operators to improve their health, safety, and job performance. These training areas overlap: Both the procurement team and bus operators need to understand the limitations and proper use of the bus operator workstation, and how the work demands faced by bus operators affect their health and safety. The procurement team requires additional administrative and technical knowledge, and the bus operators need to know how to protect themselves and what to do if they identify a workstation problem or experience work-related discomfort, strain, or injury.

This chapter details the content of these two important training targets:

- **Procurement team training** to enhance bus operator ergonomics, health, and safety in three areas:
  - Procurement practices and policies;
  - Core technical skills and knowledge needed by all team members; and
  - Engineering and design skills and knowledge represented on or accessible to the team.
- **Ergonomics training for bus operators**, covering the following:
  - The ergonomics demands of bus operator work and workstations;
  - Areas of concern, along with possible solutions (e.g., seating, mirrors, steering wheels, etc.);
  - Transit agency programs, policies, and forms related to bus operator workstation design and operator health and safety.

Organization Tool 2: Bus Operator Workstation Procurement Team Training (available from the "Procurement Team Training" link on the *TCRP Report 185* webpage) outlines content areas for the transit agency to consider to support its procurement team. Organization Tool 3: Ergonomics Training for Bus Operators (also available online) is a comprehensive presentation designed for adaptation by transit agencies to include their own information and images. Organization Tool 3 also can be used to provide training to members of the procurement team on ergonomics and the demands of bus operators' work.

Procurement Team Training

As described in Chapter 2, the suggested practice for Step 2 of the procurement process is to provide stakeholders with training to understand, analyze, and support bus operator health and safety. In other words, the entire procurement team needs information, not only about the procurement process as carried out at the transit agency, but also about how workstation design can affect bus operator health, safety, and performance. An understanding of the demands of bus operators' work and of basic ergonomics, design, and engineering concepts is important for all team members involved in procurement related to the bus operator workstation, with some team members or resources providing advanced technical competence and knowledge.

Suggested training content in these areas is defined in this section, and arranged for presentation in the Procurement Team Training tool. The training template is designed to help transit agencies prepare and support their procurement teams in ensuring that the buses they purchase promote best practices for ergonomics, health, and safety. The tool is organized as a series of module outlines covering the areas of knowledge and skills suggested by transit agencies, unions, and industry experts. Each module lists the objectives (purpose) for the training. The specific content required should be developed by the transit agency. Reference materials and existing training materials are suggested. The presentation template can be filled in with information, images, and content specific to the transit agency and the group being trained.

Training Area 1: Procurement

Modules 1 and 2: Content Overview

- **Module 1: Procurement Process** covers an orientation to stakeholder and team roles, including a review of the administrative steps of bus procurement acquisition planning and of targeted design areas related to bus operator health and safety.
- **Module 2: Procurement Update** covers changes or updates to the agency's procurement process and includes a review of the previous procurement document, establishment of the calendar, and targeted assignment of team responsibilities (e.g., regarding data collection, analysis, and development of specifications).

Covering the procurement process, Module 1 and Module 2 review the steps of real-life bus procurement acquisition planning, define the roles of procurement team members and other stakeholders, and illustrate practical examples of targeted design areas for bus operator health and safety. The modules also cover establishing the calendar for important deadlines including training, information collection, analysis and planning, specifications, RFP, review, award, factory visit, pilot, roll-out, warranty period, evaluation, and ongoing activities. These modules may be presented by members of the procurement department staff or by the procurement team facilitator. It is suggested that materials provided during the presentation include the Standard Bus Procurement Guidelines (APTA 2013), the bus procurement team process guidance tool (Suggested Procurement Practices for Bus Operator Health and Safety, available on the *TCRP Report 185* webpage), and the transit agency's most recent bus procurement documentation.

Training Area 2: Technical Skills and Knowledge

Modules 3–7: Content Overview

- **Module 3: How the Workstation Affects Health and Safety** covers the demands of the operator workstation (e.g., seating, controls, visibility, signage, fare box, wheelchair).
- **Module 4: Ergonomics** covers ergonomics and biomechanics concepts (e.g., reach, joint posture, force demands, vibration, anthropometrics).

- **Module 5: Occupational Health and Safety** covers related content (e.g., vehicle safety, slips and falls, health).
- **Module 6: Demands of Driving** covers bus operation including a ride-along.
- **Module 7: Demands of Maintenance Work** covers demands related to bus operator workstation design.

All procurement team participants need to understand the basics of the bus operator workstation design related to ergonomics, health, and safety. An active role in identifying problems, suggesting and assessing changes, and testing delivered buses calls for more detailed knowledge, as defined in these modules. A briefer review may be adequate for team members not making material decisions.

Module 3 sets the stage for the procurement process by defining the demands of driving that can affect bus operator health and safety. Module 4 focuses on the ergonomics principles that will inform equipment selection. Note: Organization Tool 3: Ergonomics Training for Bus Operators, described later in this chapter, can be adapted for use in this module.

Module 5 establishes an understanding of other demands of the work environment. Modules 6 and 7, covering operations and maintenance, ensure that the team understands the implications of the decisions they make about the bus operator workstation. Modules 6 and 7 may not require a highly detailed presentation if all the participants have experience in these departments; however, reviewing these modules in the context of the current procurement will still be helpful.

These practical modules can be customized for presentation by procurement team members or others who have experience in the area, such as safety, operations, and maintenance staff. In particular, bus operators can help design or deliver the workstation and bus operations modules, and maintainers can assist with the last module. The transit agency may prefer to contract some content, such as ergonomics, through certified Occupational Safety and Health Administration (OSHA) training centers or the National Transit Institute (NTI).

Suggested materials that can inform training development or be provided to procurement team members are listed with each module in the training template. For example, Module 3 refers to the Bus Operator Workstation Feature Guideline (Design Tool 1). Some sources, like Design Tool 3: Bus Operator Workstation 3-D PDF Model, are referenced later in the advanced technical information modules. Other useful materials include health resources, such as Part 1 of *TCRP Report 169: Developing Best-Practice Guidelines for Improving Bus Operator Health and Retention*, and the transit agency's own maintenance and bus inspection checklists.

Training Area 3: Advanced Technical Skills and Knowledge

Modules 8–10: Content Overview

- **Module 8: Product and Vehicle Design** covers background knowledge about bus design, selection, and manufacture that the procurement team needs to make practical and effective proposals for improvements, and tools for developing effective RFPs.
- **Module 9: CAD and Specifications** covers blueprints and specifications models, and can be presented using Design Tool 2: Bus Operator Workstation Engineering CAD Model and Design Tool 3: Bus Operator Workstation 3-D PDF Model.
- **Module 10: Product Testing** covers the phases of equipment and vehicle testing for occupational health and safety, including planning an effective testing protocol, use of prototypes and mock-ups, and testing to failure.

Many transit agencies arrange technical training that covers bus engineering and maintenance for select employees. For help in the procurement process, the transit agencies may rely on department-specific training and knowledge or familiarity with practical skills (e.g., ergonomics knowledge among safety department staff or blueprint reading in engineering). The procurement team can call on knowledgeable people in those departments to provide explanations or formal training.

A safety manager interviewed for this project recognized the need for safety staff to be able to read blueprints and specification documents in order to contribute to discussions of bus safety, and developed a course with the transit agency training department. Modules 8, 9, and 10 will help transit agencies follow this example. When the procurement team, and sometimes bus operators or maintainers, are involved in bus evaluation at the manufacturer level or in the pilot phase, this kind of advanced training in areas such as bus design and testing is especially important.

The suggested training modules are designed to establish a shared understanding of technical areas in a procurement team whose members typically bring with them a range of knowledge, experience, and responsibilities. Training can enhance procurement even in a large transit agency that includes many experts. It encourages a smaller procurement team to be alert to and knowledgeable about technical areas they may not deal with on a regular basis. It is especially helpful for defining and bringing into focus operations and maintenance information that administrative team members may not address in their typical work.

Module 8 establishes the background for bus design, selection, and build, and provides tools for developing effective RFPs, allowing the procurement team to make practical and effective suggestions for improvements. Module 9 should communicate basic skills for interpreting and commenting on images and descriptions of equipment, provide experience with tools used in design and procurement, and let participants practice reading blueprints and design specifications. Module 10 is designed to support the organization in evaluating new equipment and workstation configuration changes, establish a common language for discussing product and vehicle testing, and lay out a testing protocol format to adapt as needed during procurement.

Procurement Team Training Summary

Time for training is always at a premium. In recognition of this constraint, the proposed modules can all be scaled to suit the transit agency size, resources, and needs, and they can be provided more or less formally. At a minimum the issues should be summarized at the beginning of each procurement cycle so they can be raised and clarified during the specifications and procurement process.

As discussed, these modules can be developed by the appropriate departments in each transit agency, adapted from outside materials, or provided by vendors such as NTI or other safety training groups. Properly designed in-house training presentations are often the most effective approach, making use of participants' skills and knowledge and framing the training within the transit agency culture and practice. Some transit agencies have train-the-trainer or training skills courses that procurement team members and peer trainers can attend that will help them design and deliver modules. Training skills courses are also provided by transit training institutes, unions, and other organizations. International unions and some local unions have extensive experience and resources in occupational health and safety training and train-the-trainer programs that may be helpful.

Bus Operator Training

Along with improved design, bus operator health and safety depends on bus operators' skills, knowledge, and attitudes, which are supported by training. A review of correct body mechanics and instructions on seat settings may be part of new hire safety training for bus operators. But this minimal instruction does not prepare a new worker to be an active partner in keeping the workplace safe and healthy, nor does it make use of the skills and insight of more experienced bus operators.

Comprehensive ergonomics training teaches workers to understand and to ameliorate their work demands. In the transit industry, ergonomics training should cover how to use the provided equipment, how to work as comfortably and safely as possible, and how to contribute to the selection of improved workstation elements. Training that accomplishes these objectives has been produced for other industries by occupational health groups, labor unions, and ergonomics professionals. Examples of comprehensive ergonomics training can be found on the OSHA website (OSHA n.d.).

During this phase of the TCRP Project C-22 research, the research team collected information from transit agency staff, unions, and industry experts about training they had provided or observed, and reviewed training examples produced by transit organizations, including transit agencies, NTI, and unions. The findings were used to produce Organization Tool 3: Ergonomics Training for Bus Operators, a presentation template that transit agencies can adapt for use with their own information and images. Organization Tool 3 also can serve as the basis of Module 4 training for the procurement team.

Status of Bus Operator Ergonomics Training

The importance of safety and ergonomics training for bus operators is widely recognized, but there is general agreement that not enough training of this type takes place. Related practical training is provided for seat adjustment, driving skills, and other tasks; sometimes this is done on test equipment, freestanding seats, or mock-ups for equipment such as wheelchair ramps. One local union president described an in-depth orientation process:

> When they get the new buses in pretty much everybody goes through a 2-day course, mostly in the classroom, and everybody gets a chance to go out and drive at least for a couple of hours to make sure that [they're] ready to handle the bus. They tell you about the difference between turns between the older bus and what this bus would do (union official interview May 2015).

The industry experts emphasized that this kind of training is essential to protect bus operators and improve the bus operator workstation. The training they suggested would help bus operators:

- Understand the physical, cognitive, and other demands of the workstation;
- Set and use workstation elements for safety and comfort;
- Practice good body mechanics;
- Provide input to the employer on workstation safety, health, and comfort;
- Use health and safety checklists and forms to record and report concerns; and
- Participate in analyzing and improving ergonomics risks.

Examples of Ergonomics Training for Bus Operators

Transit agencies often include ergonomics as part of their new hire safety training. The training focuses on posture choices, steering techniques, body mechanics, and stretches, but it does not explain how the working conditions contribute to potential problems or explain the biomechanics involved. The training tends to consist of behavioral instructions rather than the comprehensive ergonomics understanding and skills that will allow bus operators to participate fully in health and safety improvements, including as participants on a procurement team.

NTI developed a musculoskeletal disorders prevention training program for transit workers about 10 years ago (NTI 2008). This comprehensive course provides detailed and extensive content. It contains examples and information about many transit job responsibilities. Bus operators and transit agencies report that it has been a valuable resource and helpful on the job. It includes workplace assessment forms and activities that could contribute to the improvement of the bus operator workstation if the procurement team takes advantage of the data the bus operators generate. The NTI training provides a useful model for a training plan that can be adapted and carried out by each transit agency, as described below.

Ergonomics Training for Bus Operators: A Template for Transit Agencies

Bus operators and other transit employees need to—and want to—work safely. To do this, they need to understand the suggested work practices and the reasons behind them. Bus operators are likely to take training more seriously when it reflects their experience. They can best contribute to improved rules, policies, and work environments when they are aware of risks they may face and have tools for assessing, analyzing, and making recommendations about them.

Effective ergonomics training explains the science of workplace demands, defines the potential health impact of those demands, illustrates effective solutions to ergonomics problems, incorporates worker suggestions, and supports practice of skills and behaviors that will be transferred to the workplace. A comprehensive employer workplace ergonomics program depends on worker involvement in the ongoing process of hazard assessment and corrections, and a well-trained workforce that is prepared to participate in that process.

Organization Tool 3: Ergonomics Training for Bus Operators is a presentation template for ergonomics training that is designed to be adapted and tailored by transit agencies to suit their needs. It can be used on its own or in conjunction with existing packages such as the NTI course. This tool will help transit agencies provide location-specific training for bus operators to promote improved ergonomics practice, health, and safety. It can provide the foundation for the ergonomics module for procurement team training, and is also suitable for use by transit unions and other groups.

The tool consists of more than 40 presentation slides. Transit agencies can call on their in-house safety or ergonomics expertise or call on outside consultants to adapt the template to their needs. Some transit agencies may want to work with the training team to develop a complete trainer's script. The template contents could also be used to complete the more generic content of the NTI training. Selected slides or sections also can be inserted into other transit agency training presentations.

Slides with detailed content are presented in sections to facilitate presentation and printing (see Figure 4). These slides outline the content to be covered. Many define a single concept with images. Trainers can use the slide images to discuss the issue in the header, asking group participants to comment. The images are copyright-free and the source link for each image is provided in the notes section for presenters who wish to access the sources.

As part of preparation for the training module, the presenter adapts the template, filling in information, images, and content specific to the transit agency and the group being trained. Most of the slides can be easily modified.

Training Summary

The Ergonomics Training for Bus Operators presentation tool outlines an inclusive model of training that helps the bus operator contribute fully to health and safety in the workplace. This inclusiveness is illustrated especially in the suggested hands-on and out-of-class work and learning

Section 1. The ergonomics demands of work

- Physical
- Physiological
- Visual
- Cognitive
- Health impact

Section 2. Bus operator workstation target areas

- Seating
- Mirrors
- Pedals
- Wheelchair and other passenger assistance
- Signage and other overhead tasks
- Visual demands
- Controls
- Assault barriers

Section 3. Transit agency programs, policies, and forms

- Ergonomics program outline
- Identifying and reporting problems
- Checklists

Section 4. Training notes

- Hands-on work
- Learning activities
- Out-of-class work

Figure 4. Ergonomics Training for Bus Operators: an adaptable template.

activities. The template's flexibility is intended to encourage transit agencies to incorporate the content and activities into their complete training plans.

The exercises, hands-on practice, out-of-class work, and discussions described in Section 4 of Organization Tool 3: Ergonomics Training for Bus Operators should be inserted throughout the training. The complete workshop requires 2 to 3 hours but could be extended if more discussion and review are desired. Training can be scheduled in 30-minute or 60-minute sessions with the flexibility to be delivered either within a shorter period or over an extended period that allows more opportunity for out-of-class activities and discussion of findings.

The ergonomics training and the procurement team training are suitable for both experienced and novice employees. It should be emphasized that training is as important for people who know what they are doing as it is for people who do not. If training is limited to new employees, the information may be harder to absorb, remaining abstract until the employees know what the work is really like. Moreover, if training groups are limited to new employees, they cannot make use of important transit agency experience. Experienced procurement team members and bus operators can profit from new perspectives on what may seem like familiar problems, and both new and experienced employees benefit from repeated opportunities to contribute to each other's learning. Modules in both presentation templates can be used for refresher sessions or delivered as an entire package. When training is repeated, it is important to update the content with new examples and, if possible, new materials.

CHAPTER 4

Development of Bus Operator Workstation Design Guidelines

Introduction

The research team completed several activities to develop the updated bus operator workstation design guidelines. First, the team reviewed current transit bus industry guidelines related to bus operator workstation design from both the United States and international organizations. Second, the research team gathered input from the transit bus industry on the structure of effective guidelines. Third, the team applied current transit bus vehicle architecture, along with updated design guidance, to develop an updated workstation design feature guideline document, a CAD model for engineering requirement communication, and a 3-D PDF model with a user guide for procurement team communication.

The SAE practices, CAD tools, and modern human modeling simulation tools used to develop Design Tool 2: Bus Operator Workstation Engineering CAD Model are intended to improve awareness of the operator's needs by both purchasing agencies and bus manufacturers throughout procurement. The research team's intent was to stretch the expectations of transit agencies and manufacturers regarding the common features that should be provided in any standard transit bus operator workstation.

Each activity and tool described in this chapter provides a detailed explanation of the investigation into other bus operator workstation guidelines and specification of the tools developed for this guideline. This detail may be of most interest to individuals with experience in ergonomics and vehicle packaging among procurement teams, vehicle manufacturers, and component suppliers.

Review of Current Bus Operator Workstation Guidelines

As part of the literature synthesis, the research team gathered transit industry bus operator workstation guidelines from the United States and Europe.

- **U.S. Sources:** In the United States, there are two primary sources: *TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines* and the Standard Bus Procurement Guidelines (APTA 2013), the latter developed by APTA as a tool to assist with the RFP process.
- **International Sources:** Internationally, the first source is a European Commission initiative called the European Bus System of the Future (EBSF), which provides guidelines for a "next generation" of buses. As part of developing a new generation urban bus system, EBSF has developed specifications for the bus operator workplace. These specifications are contained in a document titled Recommendation for a Code of Practice of Driver's Cabin in Line-Service Buses (European Commission 2011). The second source is ISO 16121-1:2012(en) Road Vehicles—Ergonomic Requirements for the Driver's Workplace in Line-Service Buses, Part 1: General Description, Basic Requirements (ISO 2012).

The research team compiled comparative specifications from these publicly available sources to illustrate similarities and differences in a single International Bus Operator Workstation Design Matrix, which has been appended to Design Tool 1: Bus Operator Workstation Feature Guideline (available online). Because TCRP Project C-22 focused on updating *TCRP Report 25*, the research team also indicated in the matrix whether the specification was updated, added to the *TCRP Report 25* guidelines, or omitted from the guidelines due to obsolescence. The background and purpose of each of these guidelines is described in detail in the next section.

TCRP Report 25 Guidelines

TCRP Report 25: Bus Operator Workstation Evaluation and Design Guidelines was developed through TCRP Project F-4 by the Pennsylvania Transit Institute of Pennsylvania State University during the late 1990s. The guidelines accommodate bus operators from the 5th percentile female to the 95th percentile male U.S. adult population.

The key operator workstation areas addressed by the guidelines include design and location of the operator seat, steering wheel, foot controls, radio, transfer tray, public address system, sun visor, modesty panel, stanchions, controls, gauges, and other displays. To develop the guidelines, the TCRP Project F-4 research team reviewed previous bus operator workstation design research, conducted a task analysis of the transit bus driving task, completed a survey of transit bus operators, and evaluated an operator workstation mock-up for visibility, reach, and comfort (You et al. 1997).

In reviewing the final deliverables from TCRP Project F-4, the TCRP Project C-22 research team found two important areas that became the basis for the updated guidelines in *TCRP Report 185:*

1. The workstation design approach was based on the neutral seat reference point (NSRP), and
2. The anthropometric data set was based on univariate linear body lengths and posture angles or range of motion.

Each of these areas is briefly discussed in the remaining sections of this chapter.

Examining the NSRP Approach Used in TCRP Report 25

The NSRP systematic design structure for developing the bus operator workstation guideline in *TCRP Report 25* was based on a reference and methodology that focuses on a fixed seating reference point rather than using the cab floor and pedals as the basis for arranging all other workstation components.

The authors of *TCRP Report 25* made the assumption that the bus operators would adjust the seat and steering wheel to meet their needs for visibility, arm reach, and seating comfort. However, the NSRP approach could generate guidelines that recommend component positions and adjustment ranges that require some operators' legs and feet (i.e., those of operators who are shorter in stature) to be suspended above the workstation floor (see Figure 5).

For comparison, the TCRP Project F-4 research team examined an alternative design approach called the heel reference point (HRP). HRP uses the accelerator pedal/floor (i.e., accelerator heel point) as the fiducial point (see Figure 6). Using the HRP approach, both the 95th percentile male and 5th percentile female can place their feet on the bus floor.

The authors of *TCRP Report 25* concluded that, to accommodate bus operators of varying heights, guidelines based on the NSRP approach would require adjustable floors and pedals. However, the adjustable floor was not attempted in dynamic or static evaluations of the workstation because of its potential impact on safe ingress/egress from the workstation. The authors

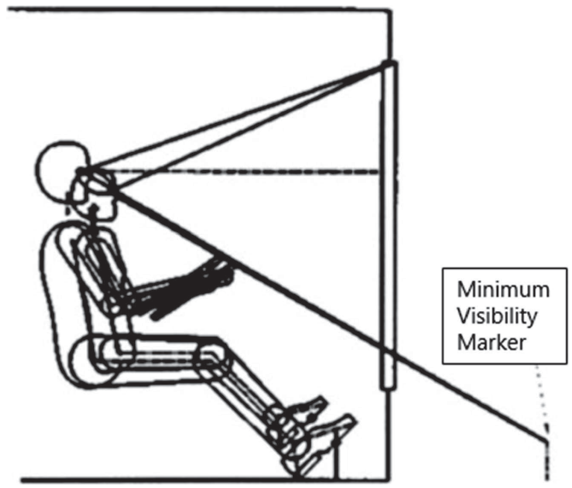

Figure 5. NSRP workstation design approach (Pennsylvania Transportation Institute 1997).

of *TCRP Report 25* also decided not to pursue adjustable pedals because of concerns about safety and reliability. Without adjustable floors or adjustable pedals, assumptions based on a fixed NSRP and optimized visibility might not be valid for operators of various sizes.

The effects of the NSRP approach used in *TCRP Report 25* were evident in the findings of the workstation mock-up evaluation. In the mock-up, the bus operators chose to position their seats below, and their steering wheels and instrument panels forward and above, the anticipated 5th, 50th, and 95th percentile positions (see Figure 7). Although data were not captured on the position of the bus operators' feet, specifically the right foot and heel, the bus operators' choices can be explained as a result of bus operators first positioning the seat so that they could comfortably reach the pedals from the floor and then proceeding to match their arm reach with a comfortable steering wheel position. This explanation contrasts with the assumption that bus operators simply adjust the bus controls to match a small range of comfortable seating positions.

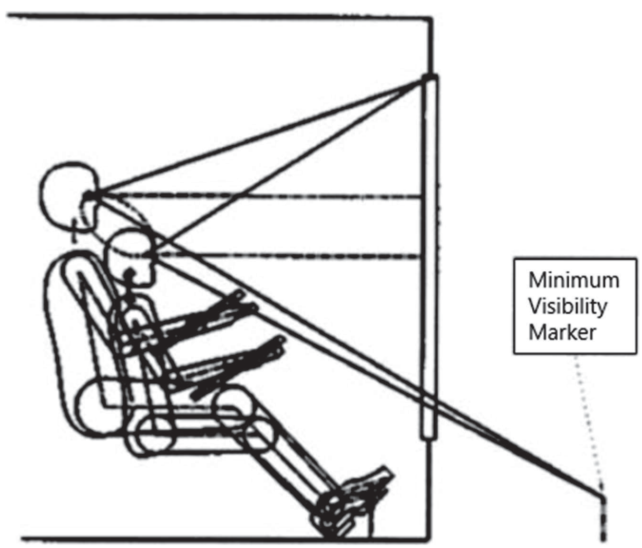

Figure 6. HRP workstation design approach (Pennsylvania Transportation Institute 1997).

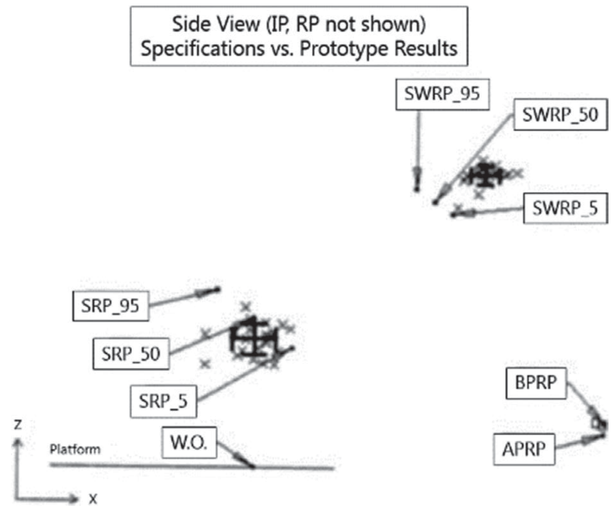

Figure 7. Comparison of design values and prototype evaluation results, side view (Pennsylvania Transportation Institute 1997, Fig. 3.7).

Update to the HRP Approach

To incorporate information and suggestions based on bus operators' foot and heel position, the TCRP Project C-22 research team elected to update the bus operator workstation guidelines using the HRP approach. This approach provides the best strategy for designing a transit bus operator workstation that meets the needs of operators while minimizing deviation from transit bus models available on the road today. For example, core requirements for any vehicle workstation could be that the operator's feet can rest comfortably on the floor while not using the pedals and that the operator can maintain a stable pedal position on the accelerator pedal while resting that foot on the floor. When combined with knowledge of the current user population and simulation tools, the HRP approach will provide reliable and valid guidance for the design of transit bus operator workstations.

The HRP approach has been and continues to be widely applied throughout the transportation industry across light and commercial vehicles through the application of SAE RPs. The HRP approach starts with the assumption that there is a fixed point on the floor behind the accelerator pedal that is common across all operators and independent of the size of the operator. The HRP approach is applied to packaging the controls and clearances around operators and passengers in vehicles. These RPs were referenced in *TCRP Web-Only Document 1*, the TCRP Project F-4 contractor's final report. The SAE RPs address the following vehicle workstation packaging guidelines:

- Fiducial point on or near the accelerator pedal (SAE J1516);
- Seating reference points and positions relative to that accelerator reference (RP J1517, J826);
- Operator leg positions (RP J1521);
- Operator stomach profile (RP 1522);
- Operator eye locations (RP J941);
- Operator headroom space (RP J1052); and
- Operator viewpoints and view planes (RP J1050).

These workstation packaging guidelines were developed based on the collection and validation of many operators' component positions and body positions. These data were then regressed to determine boundary and position guidance equations that could predict how large numbers of drivers prefer vehicle workstations to be arranged.

Ongoing progress is being made among commercial vehicle manufacturers and SAE committees to update the RPs that form the paradigm upon which many, if not most, light and commercial vehicles have been developed for decades. Modern simulation tools utilizing multivariate manikins have been applied in this update to the bus operator workstation guidelines. This approach may serve to fill some of the gaps that are being refined in the SAE RPs.

Examining the Anthropometric Data Set

The anthropometric data that were collected for *TCRP Report 25* and applied to the 46 anthropometric design functions were univariate dimensions based on a single physical dimension (i.e., stature) and a now-dated general civilian population. As applied, the data set assumed that an individual has the same percentile dimensions for all body segments.

Using this univariate approach, a 95th percentile male would be considered to have 95th percentile leg lengths, arm lengths, stomach depths, and so forth. However, given that no individual uniformly fits a given percentile across all body segments, this univariate approach (i.e., accounting for one physical dimension such as stature) creates unrealistic representations of the user population.

Operator packaging analyses must account for the natural anthropometric variability found in the user population (Guan et al. 2012). Only an anthropometric data set built on multivariate dimensions (i.e., accounting for several physical dimensions such as leg length and sitting eye height) can deliver such guidance for humans whose body segment lengths are not all consistent.

The application of univariate body dimensions can result in erroneous workstation operator component arrangements. For example, a male in the 95th percentile (based on stature) would be assumed to also have a 95th percentile femoral (upper leg length) and a 95th percentile shank (lower leg length). Inserting the corresponding lengths into the geometric relationships and design function equations used in bus driver workstation guidelines would yield suggested seat and steering wheel adjustment positions that fit a small number of operators—those whose upper and lower leg lengths match the model—but would be unlikely to fit the true range of bus operators.

A person with a 97th percentile lower leg length may have an 80th percentile upper leg length. Of greater concern, an operator may have a 1st percentile overall stature and a 26th percentile overall stomach depth. Such an operator may have to move the seat close to the pedals in order to reach them; however, the operator will also need to move the steering wheel forward, away from the stomach. Application of a multivariate approach better captures the true dimensions of the operator population.

For TCRP Project C-22, the development of a data set using multivariate dimensions was completed using manikins in CAD human modeling software. This work is described in Chapter 5, with additional details provided in Appendix C. To facilitate comparison between the univariate and multivariate approaches, the original anthropometry table used in TCRP Project F-4 is reproduced in Appendix C as Table C-2.

APTA Guidelines

APTA is an international organization that represents the interests of its membership through advocacy, innovation, and information sharing. Most APTA members are public organizations that are involved in the areas of public bus, paratransit, light rail, commuter rail, subways, waterborne passenger services, and high-speed rail. The membership includes large and small companies who plan, design, construct, finance, supply, and operate bus and rail services worldwide. APTA members also include government agencies, metropolitan planning organizations, state departments of transportation (DOTs), academic institutions, and trade publications (APTA 2014). As part of its committee work, in 2013 APTA published the Standard Bus Procurement Guidelines as a tool to assist with the RFP process (APTA 2013).

The Standard Bus Procurement Guidelines were developed as a joint effort between APTA and other organizations including FTA. With assistance from many other state and city transportation authorities from across the nation, these groups developed these recommendations and guidelines to promote safety in transportation (APTA 2014).

Specifically, these guidelines provide minimums that must be met when passenger buses are being produced or purchased. They cover many high-level details, such as service life, overall weight and capacity, maintenance and inspection protocols, and overall dimension limits. Also included are very specific details such as engine requirements, noise limits, fare box placement, glare considerations, and seat/pedal/control ratios (APTA 2013).

EBSF Guidelines

The EBSF project engaged members from the five leading European bus manufacturers and 42 other partners, including transport operators and national transport associations, public transport authorities, the supply industry, research centers and universities, and consultancy firms. The group was overseen by the International Association of Public Transport (UITP).

EBSF's goal was to develop a "new generation of urban bus system" for the drivers and users of the system. This goal was met by developing and validating a new bus system in seven European cities, based upon feedback from users, operators, and authorities. An end report was produced for general use (EBSF 2014).

The EBSF report included guidelines and recommendations on overall bus design, as well as specific details and requirements for safety and comfort for the operator and passengers. These include, but are not limited to, size and position of steering wheel and clutch, bus operator view specifications for visibility, accelerator and brake positioning, bus operator seat minimums, and requirements for environmental factors such as noise and air quality (EBSF 2014).

ISO Guidelines

The ISO 16121 guideline, Road Vehicles—Ergonomic Requirements for the Driver's Workplace in Line-Service Buses, was developed through a technical committee, as is typical for ISO standards. The ISO 16121 guideline was prepared by the Technical Committee ISO/TC 22, Road Vehicles, Subcommittee SC 13, Ergonomics Applicable to Road Vehicles.

The purpose of ISO 16121 is to provide designers of line-service buses (i.e., transit buses) with guidance on how to develop the bus operator workstation—which serves as the bus operator's workplace, as described by the standard—to provide ergonomic accommodation. The guideline was based on a study completed in Germany (VDV 234) and also considered the recommendations of related international guidelines such as those in *TCRP Report 25*.

ISO 16121 includes four parts as follows:

- **Part 1: General Description, Basic Requirements.** Part 1 provides basic requirements for an ergonomic and comfortable seating position. These include size and location dimensional requirements that affect the bus operator seat, pedals, and steering wheel.
- **Part 2: Visibility.** Part 2 provides requirements for the bus operator's field of view forward of the vehicle, around the passenger entrance area, and within the workstation compartment.

- **Part 3: Information Devices and Controls.** Part 3 provides requirements for the location of information devices and controls.
- **Part 4: Cabin Environment.** Part 4 provides requirements for the bus operator workstation environment (e.g., temperature, noise, and ventilation).

A review and comparison of the ISO 16121 guideline to the EBSF guideline revealed many similarities. A few elements that were not provided by other guidelines were new to the ISO guideline, including the following: minimum elbow room, foot well pedal clearance, and access to the bus operator workstation. These elements have been included in the updated bus operator workstation guideline.

Capturing Industry Input to Procurement Guideline Development

To gain insight on how best to construct the guidelines for industry adaptation, the research team conducted interviews with members of appropriate APTA committees, gathering feedback about members' impressions of the current ergonomic guidelines for transit operator workstations and what elements are needed for effective guidelines.

Participants

The research team used professional contacts to help identify members from APTA's Procurement and Materials Management Committee, Bus Technical Maintenance Committee, and Bus Safety Committee. These committees were targeted for recruitment due to their involvement in the procurement standards used by the transit industry. Once a participant was contacted, a phone script was followed to introduce the study and screen for eligibility. Each person eligible and interested in participating was scheduled for an interview and a confirmation note was emailed along with a copy of an Informed Consent Form. A member from each committee was recruited and participated in a telephone interview. A total of three telephone interviews were conducted.

Key Findings

To develop this list of key findings, a member of the TCRP Project C-22 research team reviewed the three interview transcripts. In particular, the researcher looked for comments related to how best to present the research results to facilitate improvements in bus procurement practices. Interview participants had suggested attributes for the research report and also commented on ways the research might fit in with APTA's procurement guidelines.

Report Attributes

Some attributes mentioned by interview participants included the following:

- Taking a holistic approach to the whole operator compartment;
- Looking at more than just ergonomics (e.g., proper heating, air ventilation, security, and types of lighting);
- Considering issues for drivers that are not in the 95th percentile (e.g., proper mirror adjustment);
- Addressing issues of potential distress to drivers, such as whole-body vibration and glare; and
- Making operator safety elements a standard part of bus design and construction.

Relationship to APTA Guidelines

- Interview participants' suggestions varied regarding how the research results of TCRP Project C-22 could fit in with the APTA Standard Bus Procurement Guidelines. Comments ranged

from potentially incorporating suggestions for relevant design changes into the next update of the APTA document to creating an appendix to the APTA guidelines or simply referencing the TCRP research, as appropriate.
- One participant also mentioned that the research results could provide a useful resource for transit agencies that are putting together an RFP (transit organization interview August 2014).

Production Transit Bus Architecture

The approach selected by the research team was to provide guidance for bus operator workstation design based upon the existing vehicle architecture of transit buses that are on the road today. The scope of this work focused on the workstation environment immediately surrounding the bus operator. In other words, the guidelines support components and features that the bus operators pass or can reach when accessing the seated workstation or using the seated workstation.

The guidelines do not suggest deviations in the structure or glass or exterior mountings in the operator compartment section of the bus, nor do the guidelines suggest changes to the passenger compartment to the rear of the bus operator. In order to apply realistic boundaries to the workstation guidelines, information from transit bus manufacturers and transit bus agencies was requested. Vehicle-level information was provided by one manufacturer in the form of 2-D drawings and 3-D solid-body data. Component and feature-level information was obtained through physical benchmarking of transit buses.

Bus Manufacturer Non-Disclosure Agreement and CAD Data

The research team established a Non-Disclosure Agreement (NDA) between VTTI and a prominent transit bus manufacturer to allow for exchange of transit bus data for modeling. These data provided a reliable example of a transit bus upon which the research team applied the HRP approach in developing the Bus Operator Workstation Engineering CAD Model. The research team worked with transit bus manufacturers to obtain generic transit bus CAD components (e.g., floor heights above ground, mirror locations, relationships among the steering wheel, seat and pedal, and daylight openings) upon which the ergonomic templates for operator accommodation, reach, visibility, and ingress/egress were built. These data should increase the utility of the update to the guidelines, allowing future procurers to more closely align expectations and requested operator workstation improvements with manufacturers' capabilities.

Because of the NDA, the research team has included limited views of the vehicle CAD model in this report. These views include vehicle components such as the following:

- Daylight opening glass,
- Dash panel,
- Operator workstation floors,
- Column mounting,
- Grab handles,
- Ground plane, and
- Generic pedal and seat supplier data.

Furthermore, the research team referenced only basic packaging reference points, spheres, envelopes, and sheet bodies.

Some components in the CAD model were reverse engineered from physical measures taken on site visits or found using other methods (see Figure 8). These data are considered public and

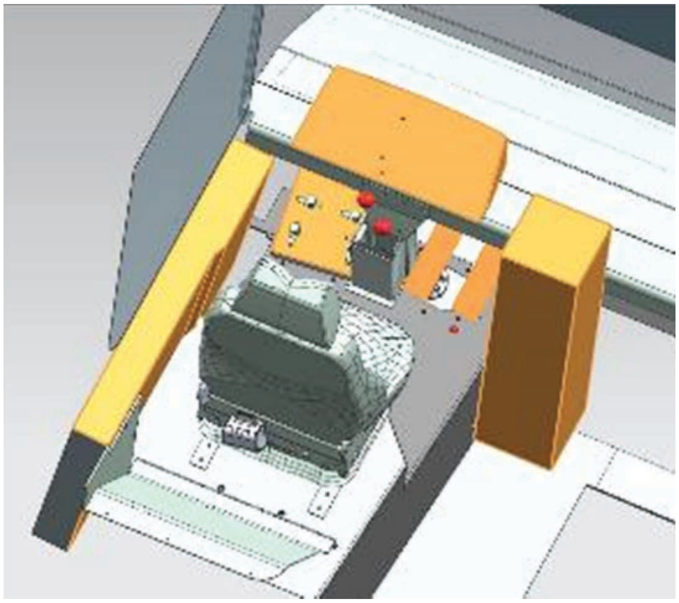

Figure 8. Some bus operator workstation components (highlighted in orange) were reverse engineered from physical measures on site visits.

are included with the Engineering CAD Model to provide application context for the related packaging recommendations.

Transit Agency Site Visits

The research team worked with two regional transit agencies to conduct site visits. During the two site visits, the research team collected physical measurements and photographed operator workstations in two different current production low-floor transit buses (see Figure 9 and Figure 10). Data from these visits were used to validate the CAD models and to provide additional information for the design and analyses of the operator workstation.

Figure 9. Low-floor transit bus operator workstation, Example 1.

Figure 10. Low-floor transit bus operator workstation, Example 2.

Updated Bus Operator Workstation Design Guideline Tools

Operating a transit bus requires moderate levels of muscle activity, as well as alertness to maintain awareness of common objects in the surrounding transit bus environment, such as pedestrians, vehicles, and static obstructions. Effective posture for control and direct visibility are two key assumptions that must be upheld in any transit bus operator workstation guideline in order to deliver safe, efficient, and comfortable operation of the vehicle. This point reinforces the need for a more upright posture.

It is likely that if a more relaxed and reclined workstation component arrangement were provided, the operators may be challenged to complete their necessary duties. Therefore, the SAE Class B occupant packaging paradigm was applied to the workstation seat, steering wheel, pedals, and hand controls arrangement.

Common SAE Class B Operator Packaging Parameters

Class B vehicles as defined by SAE include heavy trucks, medium-duty trucks, and some types of buses, including transit buses. Common Class B operator packaging parameters are listed in SAE J1516. These include the following seat and steering wheel attributes:

- Torso Angle (A40): 8°–18°;
- Wheel Diameter (W9): 440–560 mm;
- Track Travel (TL23): ≥ 100 mm;
- Track Rise (A19): 0°; and
- Seat Height (H30): 405–530 mm.

Using the SAE Class B operator package, defined by these dimensions, the research team sought to develop the updated bus operator workstation guideline tools—including the Bus Operator Workstation Feature Guideline and the 3-D Bus Operator Workstation Engineering CAD Model—as products that align with the rest of the commercial bus and truck industry that apply the same operator packaging paradigm.

Bus Operator Workstation Design Tools

The following bus operator workstation design tools provide component-, feature-, and vehicle-level guidance for the development or procurement of bus operator workstations within transit buses. These tools can be accessed online from the *TCRP Report 185* webpage.

- Design Tool 1: Bus Operator Workstation Feature Guideline (listed online as “Bus Operator Workstation Feature Guideline”);
- Design Tool 2: Bus Operator Workstation Engineering CAD Model (listed online as “Bus Operator Workstation Engineering CAD Model” and available as an IGS file or a STEP file); and
- Design Tool 3: Bus Operator Workstation 3-D PDF Model (listed online as “Bus Operator Workstation 3-D PDF Model” and provided with an accompanying user guide).

It is important to understand the assumptions and construction applied in the development of these design tools.

Creating a Bus Operator Workstation Feature Guideline

The research team used the information gained from the research to construct a stand-alone, updated feature guideline document. The document is intended to provide design guidance for transit bus manufacturers and transit bus agencies procuring buses. The primary scope of this document is limited to the key elements of operator workstation design that impact the health and well-being of the bus operator.

Based on industry feedback, the research team devised a standardized format for the updated guidelines to improve users’ comprehension of the key design criteria and their supporting rationales. Pertinent design guidelines are summarized in a table provided at the beginning of each section. The table allows readers to quickly find guideline criteria for key aspects of the operator workstation. If more information is needed to support the use of the criteria in design, additional details are provided about each guideline in sections labeled as follows:

- **Definition:** Provides a description of each individual operator workstation feature;
- **Figure:** Where possible, provides an illustration of each specific feature;
- **Design Guideline:** Provides suggested design objectives based on ergonomic principles and vehicle design literature; and
- **Need for Design Guideline:** Provides the reasoning for the design criteria as well as the factors that need to be considered when designing the operator workstation feature.

Taking a holistic perspective for the operator workstation, the research team added guidelines to address issues such as whole-body vibration transmitted through the seat and steering wheel, operator workstation task lighting, glare, and control forces. Those guidelines that became obsolete due to changes in contemporary ergonomics were removed from the set of *TCRP Report 25* guidelines. Finally, those *TCRP Report 25* guidelines that required updating to reflect current literature findings were modified in the new guideline set.

Creating a Bus Operator Workstation Engineering CAD Model

The research team applied 2-D and 3-D data from a current production transit bus to establish the basic architecture of a transit bus operator workstation. The modeling of components was accomplished by using two different solid-modeling CAD software applications (NX and Solidworks). The CAD images demonstrated in this report, with the exception of those images that include manikins, were created using both CAD software systems. Gaps in the CAD data were filled by reverse engineering components from physical measurements of transit buses.

The research team visited two transit bus operation centers in southwest Virginia to photograph various model types and years and to capture localized component measures (e.g., pedals, steering wheels, and fare boxes). When the vehicle CAD model was completed, the research team had a detailed benchmark upon which to build the suggested Engineering CAD Model. SAE RPs were applied as tools to develop the operating packaging references and envelopes. Additional guidelines were applied that might enhance the Engineering CAD Model in meeting the needs of today's procurement practices and ultimately meeting the needs of the transit bus operators.

Ergonomics Design Considerations

An appropriate operator package will allow short-legged operators to comfortably rest their feet on the floor. This can be presumed to be possible with operators using an approximate 120° knee flexion angle. A second and related assumption is that the operator is seated such that the upper leg is approximately parallel with the workstation pedal floor. A slight incline is actually preferred, but for the sake of this general calculation, a flat (0°) seat pan angle is assumed. These assumptions can aid the users of the Engineering CAD Model in determining what minimum seat height should be targeted above the pedal floor. The designer should be aware that this will affect the decisions for the pedal-floor-to-seat-floor height, as well as the choice of seat lower/suspension and seat upper/cushions construction.

- **H-Point Height:** Recent anthropometric measures of 5th percentile female dimensions such as popliteal height (under-knee height to floor) and thigh clearance combined with typical minimum shoe heights can be applied to this question (Guan et al. 2012). By combining these dimensions, a minimum seat h-point height can be derived that approximates the hip heights of short-legged operators. Basing the design on this minimum seat h-point height, the needs of the remainder of operators can be accommodated using ranges of adjustment in the seat and steering wheel. These ranges of adjustment are discussed in the following sections of this chapter.
- **Determining the Minimum Seat H-Point Height:** To determine the minimum seat h-point height, consider these dimensions:
  - 5th percentile female popliteal height to floor: 360 mm;
  - 5th percentile female thigh thickness: 143 mm;
  - Approximate h-point height above popliteal body reference: 71 mm;
  - Shoe height estimate: 25 mm; and
  - Estimated knee flexion angle: 120°.

  Combining these variables into the following equation yields the 5th percentile female h-point height:

  $$\text{Cosine}\left(\text{knee flexion minus } 90^{\circ}\right) = \text{seat h-point height/lower leg length.}$$

  Considered another way,

  $$\text{Cosine}\left(\text{knee flexion minus } 90^{\circ}\right) * \text{lower leg length} = \text{seat h-point height.}$$

  Using the dimensions listed, lower leg length will equal 360 mm plus 71 mm plus 25 mm, and the minimum seat h-point height is calculated as:

  $$\left[\cos\left(120^{\circ} - 90^{\circ}\right)\right] * \left[360 \text{ mm} + 71 \text{ mm} + 25 \text{ mm}\right] = 395 \text{ mm.}$$

- **Minimum Seat H-Point Height Considerations:**
  - H-point accuracy range: ± 25 mm;
  - Accounts for anthropometry measurement standard deviations, shoe height variability, knee flexion angle preference, and h-point estimate; and
  - 5th percentile female h-point range: 370 to 420 mm.

  The selected seat h-point height played a significant role in defining the rest of the operator workstation in the Engineering CAD Model. This height is referred to as H30 in the RPs in SAE J1100: Motor Vehicle Dimensions. However, rather than arbitrarily selecting the number from within the range of vertical seat travel, the research team applied 2-D drawing and 3-D CAD data of a common transit bus seat. The lowest seat h-point height was determined to be 412 mm. The range of vertical seat adjustment above that lowest position was determined to be approximately 166 mm. These seat heights, combined with SAE RPs J1516 and J1517, were used to determine the range of seat adjustments needed in the Engineering CAD Model to fit operators of a Class B vehicle.
- **Visibility for Transit Bus Operators:** Visibility is another very important consideration. It is the highest priority for each operator to monitor the surrounding environment and make informed decisions on what actions to take in controlling the vehicle and protecting their passengers. To that end, a robust operator workstation seat and control arrangement will maximize each operator's capacity to maintain a direct view of the surrounding environment across the range of individual sizes that make up this vital workforce. Thus direct visibility will play a significant role in the Engineering CAD Model.

Bus Operator Workstation Reference System and Fiducial Vehicle Points

The SAE 3-D reference system is established in the RPs of SAE J1100: Motor Vehicle Dimensions. The location and orientation in position and angle of the workstation, components, and human models referred to in this document are all relative to this workstation reference system (WRS). Vehicle manufacturers often choose to affix the vehicle model to easily recognizable positions and orientations, but they also commonly choose to position their engine models, interior/exterior cabin body models, and chassis models at different locations. At later stages of the vehicle design, integration exercises are performed to check the fit of the assemblies.

With that predictable challenge in mind, the research team chose to select a reference system that would be both recognizable to transit bus manufacturers who must commonly deliver vehicle dimensions for procurement activities while still placing the focus of the model on the workstation design. Therefore, the WRS illustrated in Figure 11 was set such that the axes align with the SAE references:

- X-axis is fore-aft,
- Y-axis is cross-bus, and
- Z-axis is vertical.

The origin (point 0, 0, 0) of the WRS was set such that the X-axis zero was located at the front axle center, the Y-axis zero was located at the mid-point of the bus width, and the Z-axis zero was located at the operator workstation pedal floor. The choice of the Z-axis zero was specifically made to highlight the fiducial reference of the accelerator heel point (AHP), which is the point from which the Engineering CAD Model has been built.

It is important to specify the origin point as a *fiducial reference point.* However, to ensure that the Engineering CAD Model can be properly applied across various transit agencies' and manufacturers' CAD systems, other fiducial points (sometimes called *packaging references* in

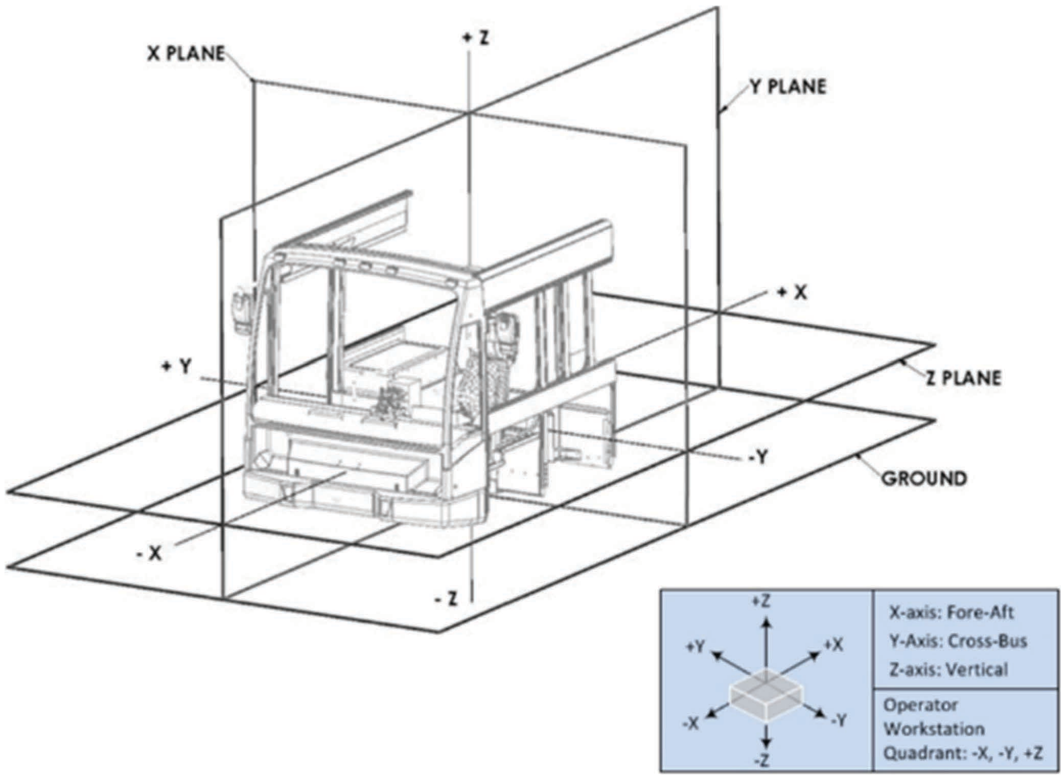

Figure 11. The transit bus operator WRS imitates the SAE reference system (SAE J1100). [Note: Bus model data illustrated here for demonstration of vehicle orientation relative to axes only. Bus model data is not available with any format of the guideline CAD data.]

the model) also were developed. These additional fiducial reference points allow users of the Engineering CAD Model to consider those operator workstation references without being tied down to one specific vehicle architecture and origin point. To help users identify both the origin point and other fiducial reference points, all fiducial references are represented in the model using solid-body spheres (see Figure 12).

One of the packaging references was located at the forward-most point on the bumper and at the center of the vehicle, along the Y-plane. Another fiducial point was operator-centric and located under the operator's seat at the seat-mounting hole. This seat-mounting reference should be useful for highlighting differences between the CAD guidance model and a specific vehicle's seat-mounting height, which could have significant effects on the assumption of the seat H30 dimension above the AHP and the level of operator accommodation. Lastly, the APTA (2013) visibility target, which stands 2 feet (609 mm) in front of the bus bumper and 3.5 feet (1,066 mm) above the ground, has been included as one of the fiducial points. It was located along the operator centerline. Although the visibility target would not be used to position the Engineering CAD Model, it is a significant fiducial element that ties together the bus architecture between the operator workstation and the outside world, between the operator workstation and the vehicle (bumper), and between the vehicle (bumper) and the outside world.

Bus Operator Workstation Engineering CAD Model

Design Tool 2: Bus Operator Workstation Engineering CAD Model was the result of combining information from an existing transit bus operator workstation compartment, the bus

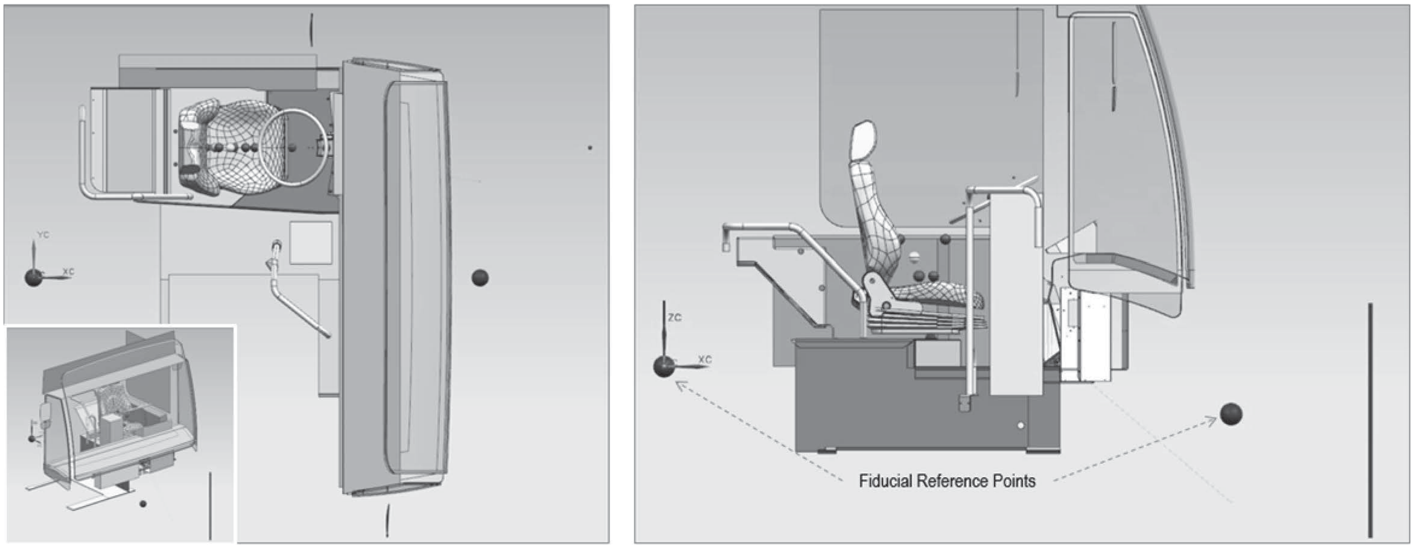

Figure 12. The bus operator workstation fiducial reference points in top view (isometric inset) and side view.

operator packaging results from the application of the SAE Class B packaging, the International Bus Operator Workstation Design Matrix, and simulated human modeling validation. A number of features were combined for components in direct contact with the bus operators. These features, shown in Figure 13, are outlined in the balance of this section.

- Existing transit bus architecture (manufacturer dependent)
  - Ground plane
  - Pedestrian floor

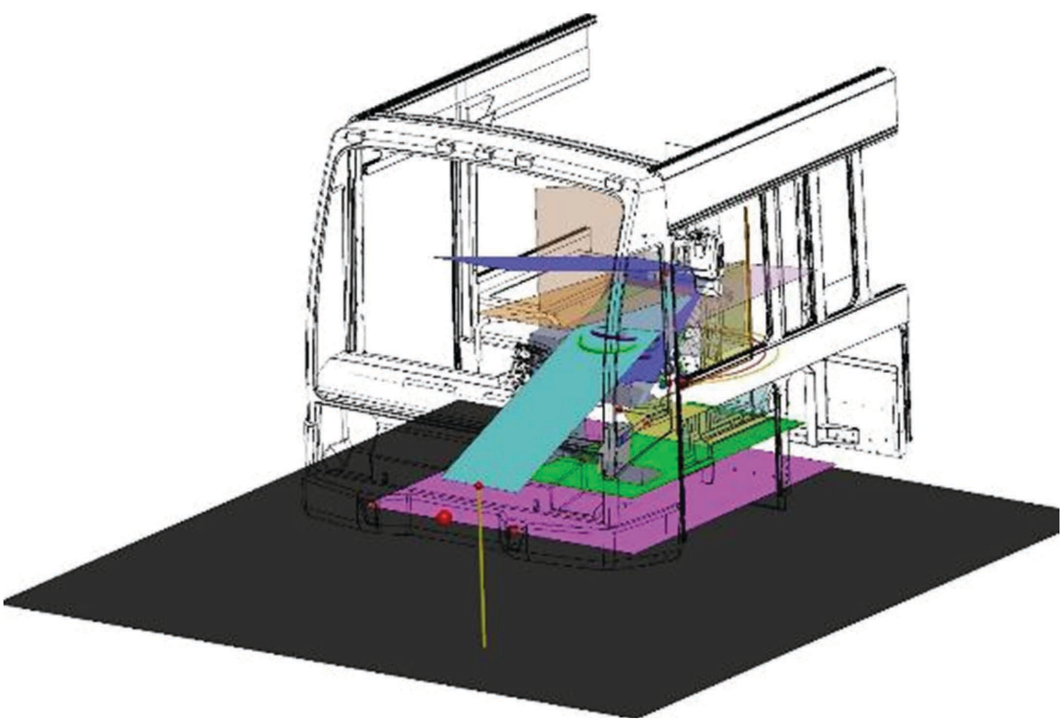

Figure 13. Bus Operator Workstation Engineering CAD Model guideline data (solid-body colored envelopes only) superimposed over the transit bus operator WRS with wireframe bus—contextual demonstration only.

  - Operator platform
  - Seat floor
  - Accelerator pedal position\type
  - Steering wheel column pivot point
  - Center instrument gauge panel
  - Seat manufacturer's h-point (fixed relative to seat cushions)
    - Seat selected by manufacturer and contract agency
  - Vehicle fiducial points:
    - Workstation reference system (WRS) X, Y, Z
    - Bumper point
  - APTA visibility target
- Guidance
  - Operator accommodation
    - Operator fiducial points
      - Accelerator heel point (AHP)
        - Platform floor to seat mid-vertical height
        - Manufacturer selected accelerator pedal
      - Accommodation tool reference point (ATRP)
        - Platform floor to seat mid-vertical height
      - Steering wheel point (SWP)
  - Seat h-point range
    - ATRP height above operator platform
    - Vertical seat adjustment range
    - 2.5th percentile accommodation tool reference line (ATRL) to 97.5th percentile ATRL
  - Steering wheel tilt/telescope range
    - SWP position
  - Steering wheel rim size
  - Steering wheel clearance
  - Stomach and shin/knee clearance contours
    - ATRP height above operator platform
  - Shoulder clearance envelope
  - Foot well clearance envelope
- Exterior visibility
  - Eyellipses
    - Seat horizontal fore-aft travel
    - Seat torso prescribed angle
    - ATRP height above operator platform height (AHP)
    - ATRP distance rearward of AHP
  - Vertical visibility
    - Upward: ATRP 15° from eyellipse
    - Downward: ATRP visibility target from ground and bumper
  - Operator-side glass visibility
    - APTA maximum lower height above platform floor, AHP
    - APTA minimum rearward position from AHP
  - Sun-visor shading (does not apply to rolling sunscreens)
    - Windshield: Eyellipse lower with 5° maximum upward
    - Operator-side glass: Eyellipse lower with 5° maximum upward
- Controls
  - Reach curve
    - Reach curves 600 mm above AHP: Fingertip and grasp
  - Left instrument panel

- Japan Automobile Manufacturers Association (JAMA), Japanese Industrial Standard (JIS) downward display view limit
  - Operator eye height above ground
  - Eyellipse mid-eye centroid
- Foot-switch plate
- Operator platform access
  - Even-split step height
    - Manufacturer dependent operator platform height
  - Shoe clearance discs on steps
    - Minimum of one disc on step
    - Minimum of two discs on operator platform
  - Steering wheel position for access
    - Steering wheel position 5° forward of vertical column tilt

- Proposed guidance
  - Emergency access: APTA operator-side glass lower and rearward limit
  - Thermal/security barrier door
  - Fare box maximum size and position

Creating a Bus Operator Workstation 3-D PDF Model and User Guide

In keeping with the theme of the project—to increase awareness of the bus operator's needs and the process by which those needs can be met through appropriate communication among the stakeholders in the procurement process—it was deemed appropriate to make a 3-D tool accessible to a wider audience than just engineers with CAD experience. To accomplish this purpose, the Bus Operator Workstation Engineering CAD Model was exported into a universal format that is available to anyone, creating Design Tool 3: Bus Operator Workstation 3-D PDF Model. An image from this model is shown in Figure 14. For readers who are unfamiliar with 3-D PDFs, a user guide also was developed. Both the user guide and the tool can

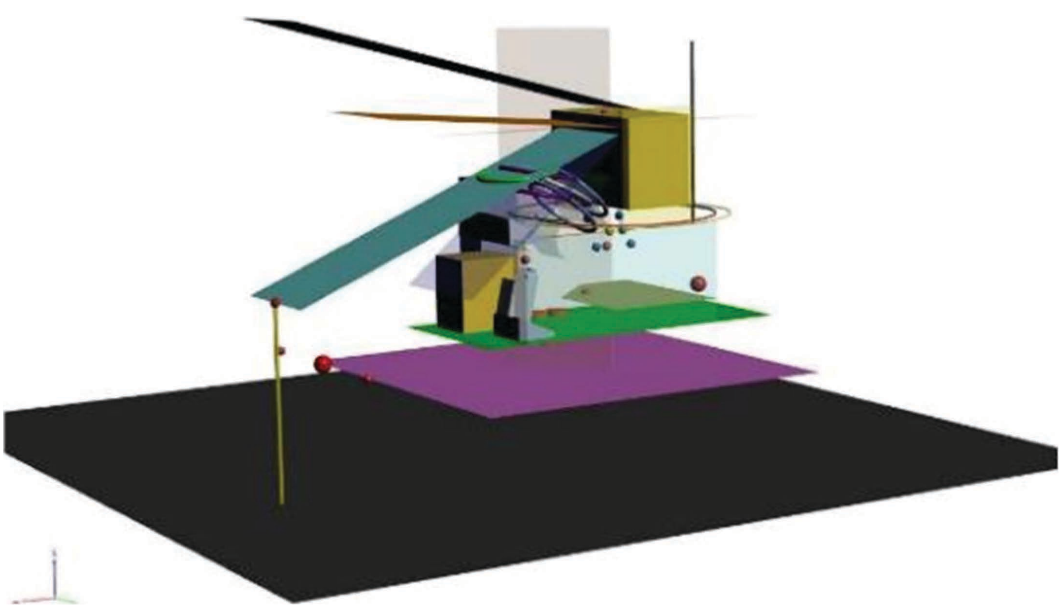

Figure 14. A front isometric view of the Bus Operator Workstation 3-D PDF Model. Ground and bus platform, vehicle references, clearance envelopes, reach envelopes, visibility planes, seat access, and seat/steering wheel/pedal packaging references are demonstrated.

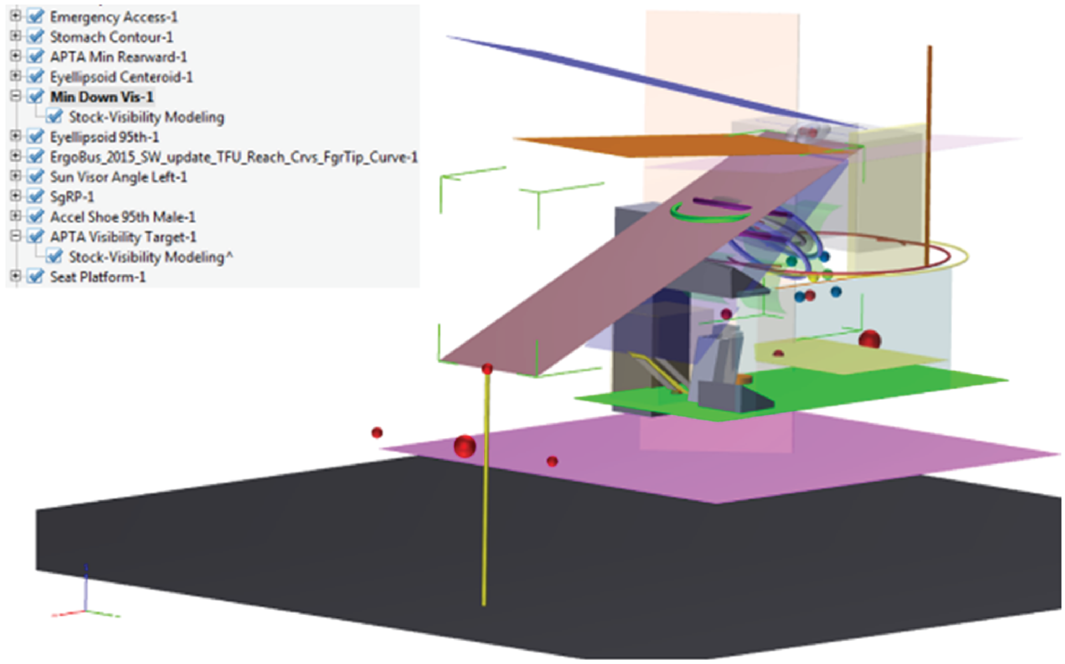

Figure 15. The Bus Operator Workstation 3-D PDF Model and tree structure. The minimum downward visibility plane to the APTA minimum visibility target is selected. A green box surrounds the part in the model, and light gray highlights the related part, which is also bolded, in the tree structure.

be accessed from the *TCRP Report 185* webpage by going to www.trb.org and searching for "TCRP Report 185".

Multiple features of the 3-D PDF model make it accessible to non-traditional CAD users or users who are not familiar with vehicle packaging models. The model includes a tree structure that includes parent assemblies and child parts. The assemblies and parts include names that demonstrate the function of the guideline features. When parts in the model are selected using a computer mouse, the part name will appear in the tree structure (see Figure 15). Some tools, such as sectioning and dimensioning tools, are available to users with an interest in investigating the universal model in more detail. The 3-D PDF user guide walks the user through the basic steps required to open and navigate the model, in addition to selecting, sectioning, and measuring parts.

Guideline Development Summary

The methodology chosen to develop the updated bus operator workstation guideline deviated from the *TCRP Report 25* anthropometric data and vehicle design functions. This path allowed the research team the freedom to include design requirements from multiple international guidelines. Industry feedback was collected from transit agencies that could be future users of the guidelines. The SAE Class B operator packaging RPs were applied to the location and positioning of the bus operator workstation seat, controls, and components. In order to bound the arrangement of the workstation elements, the research team obtained current production vehicle data.

Vehicle-level CAD data of a traditional low-floor transit bus were provided by a manufacturer. The seat supplier supplied seat drawings. Dimensions on two different transit bus manufacturers' workstations were captured to fill in component and part data that were not provided with the manufacturer-supplied data. The exercise of combining vehicle data, supplier drawing data, and physical benchmarking data demonstrated a need for greater integration of supplier and manufacturing data.

In order to specify the appropriate position and range of positions for bus operators, the research team suggests that SAE packaging dimensions (SAE J1100) be made available on supplier drawings. This is a fundamental example of one way it can be helpful to involve Tier 1 part suppliers in the procurement process along with the agency and bus manufacturers. This inclusiveness can help to ensure that communication and specification of bus operators' needs do not stop at the vehicle level, but rather migrate to the assembly and component level. If components such as seats, for example, carry specification detail in 2-D and 3-D CAD, this level of detail can support the next generation of transit bus engineering development and transit agency procurement.

The physical benchmarking exercise also made obvious the point that flat treadle accelerator and brake pedals are common with two different major bus manufacturers. This is not necessarily a negative, considering that Class B operator postures allow for a significant range in the degrees of freedom for the operator's legs to move up and down. The research team has not made a case against the application of flat pedals in this update to the guidelines. It is the opinion of the researchers that low-force (15–40 N) treadle pedals can be applied as stable and efficient means of throttle control for transit bus operators.

CHAPTER 5

Human Modeling Validation of Bus Operator Workstation Design Guidelines

Human modeling software (RAMSIS) was applied for the demonstration of operator anthropometry, workstation fit, and workstation component accessibility. A cadre of manikins was developed to serve as sample models of transit bus operators. The sample provided insight into how bus operators of various minimum and maximum body-size variables (e.g., stature, sitting height, abdomen depth, arm reach, leg reach/clearance) would be accommodated inside a workstation design and adjustment range (e.g., seat, steering wheel, pedals).

Like Chapter 4, this chapter supplies information that includes a detailed explanation of the validation of the bus operator workstation dimensions developed for the updated guidelines and supporting tools created in TCRP Project C-22. This detail may be of most interest to individuals with experience in ergonomics and vehicle packaging among procurement teams, vehicle manufacturers, and component suppliers.

Development of Multivariate Manikin Cadre from NIOSH Survey Models

During the research phase of TCRP Project C-22, recent anthropometric measurements specific to the transit bus operator population were not publicly available. Therefore, a recent measurement database—the 2010 NIOSH U.S. Long-Haul Truck Driver Survey, which could provide a human dimensional sample model (Guan et al. 2012) of similar transportation operators—was applied as the basis for the manikin development.

The application of long-haul truck driver anthropometry may raise some concerns about how closely the measurements of long-haul truck drivers match those of transit bus operators. It should be noted that Guan et al. (2012) found that the NIOSH sample of commercial truck drivers could be categorized as heavier than the general population. The male truck drivers were found to be, on average, 13.5 kg (29.8 lb.) heavier than males in the general U.S. population, and the female truck drivers were found to be, on average, 15.4 kg (34.0 lb.) heavier than females in the general U.S. population. However, this population estimate can be compared to other recent measures of bus operators in the transit industry. French et al. (2007) found that the prevalence of obesity, defined in terms of body mass index (BMI) as BMI ≥ 30 kg/m2, was 56% among transit workers, while another study, by Escoto et al. (2010) found that transit workers had an average BMI of 32.3 kg/m2. Given this information, the research team concluded that use of the NIOSH data would be reasonable in relation to providing sufficient accommodation for bus operators.

Appendix C of this report details the numerous body dimensions that were developed for this TCRP research using information from the NIOSH survey. Those dimensions were replicated to compose a range of multivariate model operators representing a range of transit bus operators. These multivariate anthropometric dimensions are compared to the univariate dimensions applied in TCRP Project F-4 in Appendix C, Table C-2.

The NIOSH survey provides dimensions for 30 models. To simplify the development process for TCRP Project C-22, however, a primary collection of six models was used for packaging and the development of reach and clearance envelopes. Images of the cadre of manikin operators are given in Figure 16 (female) and Figure 17 (male). These manikins are centered in 3-D space at their lower torso, which highlights the difference between their sitting heights, leg lengths, and corpulence (abdominal depth).

In addition to the NIOSH survey-based manikins, a generic small female manikin was added to the human modeling validation (see Figure 18). This manikin was based upon the modeling parameters provided by the human modeling software body builder NHANES III anthropometric survey toolkit (see Figure C-1 in Appendix C). This manikin was applied throughout the modeling validations to confirm that the suggested seat/steering-wheel/pedal configuration was suitable for someone with a small stature and low BMI. This manikin was also applied to all visibility, reach, and clearance envelope checks.

Lastly Appendix C, Table C-1, provides qualitative descriptions in the column titles of the sizes of the models that were chosen to be part of the primary cadre representing the range of sizes in the operator population. These percentiles demonstrate the general category that the manikin represents. For example, "Female O," may be generically referred to as an

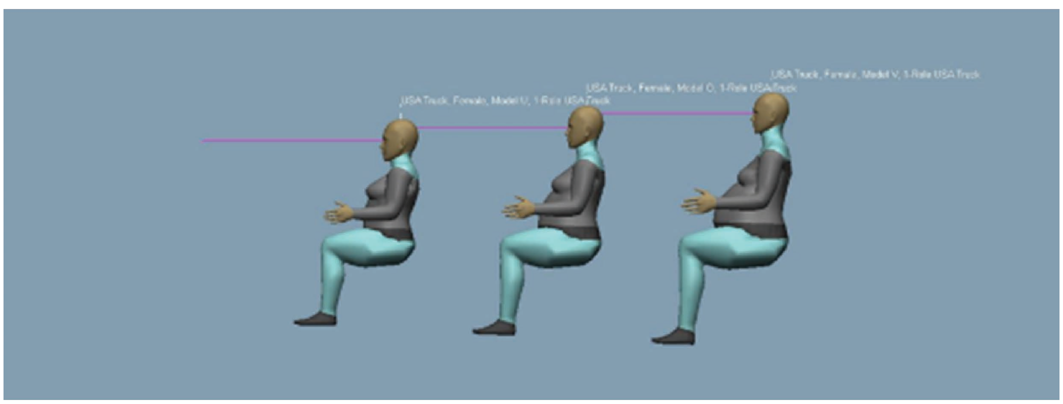

Figure 16. Primary operator cadre, female manikins, left-side view.

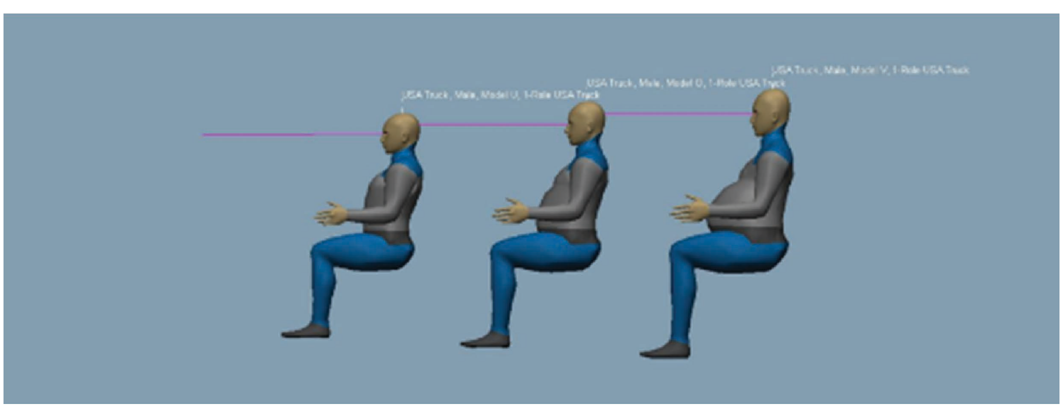

Figure 17. Primary operator cadre, male manikins, left-side view.

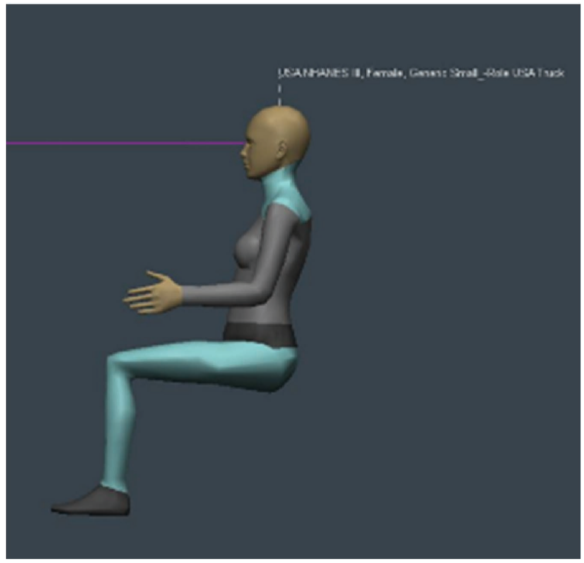

Figure 18. NHANES III Small Female applied to human modeling validation.

average female with a 47th percentile stature and 69th percentile waist circumference. It may seem inaccurate to represent an "average female" with a waist percentile that is above average, but that is the nature of true size variance in any human population. The strength of these representative manikin models, as built through a process called principal components analysis (PCA), is that real operators in the world (whose body components rarely match 50th percentile stature, weight, and arm length) can be evaluated through simulation analysis (Guan et al. 2012).

Manikin Deviations from Models and Modifications

Almost all the operator manikin dimensions used in TCRP Project C-22 meet the same criteria for allowable error used in the NIOSH survey. The allowable error in the NIOSH survey was reported in the survey's Appendix B, Mean Absolute Differences of Inter-Observer Errors in Team Training. The TCRP Project C-22 research team used these values of anthropometric measurement precision to define the tolerance within which each manikin's construction dimension was allowed to vary from the NIOSH model.

Exact model values were attempted across all manikin dimensions. Deviations occurred with instances of some dimensions that were dependent. "Acromial Height, Sitting" (the shoulder height of a seated individual above a flat surface) was one dimension in which some manikins' dimension could not be forced to meet the model allowable error tolerance without causing multiple higher-level dimensions to exceed their tolerances. This occurred for one of the female manikins (Female U) and two of the male manikins (Male U and Male V) despite repeated efforts to flex other primary and secondary dimensions.

It is worth noting that the dimension designed in the human modeling software to account for upper-arm length differs from the body landmarks on participating drivers of the NIOSH survey. Guidance was provided by the software anthropometric staff, who suggested that a correction factor of 90% should be applied to the NIOSH "Shoulder-Elbow Length" model measurements. Detailed specifications and steps applied to the construction of the manikin cadre are provided in Appendix C.

Verification of SAE Packaging RPs

The bus operator packaging model that resulted from the application of the current production vehicle data combined with the SAE Class B operator workstation RPs was verified by posture calculation with the male and female operator cadre. The initial posture calculation for each manikin was run with the steering wheel set at the middle of the recommended range (i.e., the SWP position), along with other constraints common to transit bus operator workstation components.

The posture for each manikin was rerun at least once while the steering wheel was adjusted to minimize arm reach and maximize hand clearance to each manikin's stomach and thighs. Ultimately, these packaging simulations were the test of the location and adjustment range of the seat and steering wheel to evaluate whether 95% of the operator population could be expected to keep their feet on the floor or pedals while meeting the APTA visibility line-of-sight target and maintaining a comfortable position in the seat (APTA 2013).

The "Shin/Knee and Stomach Contours" were also imported from the Engineering CAD Model to compare the contour locations and sizes against the manikin packaging. Reach curves were also developed for each manikin at its final posture location. The reach curve representing the minimum bus operator distance was selected from among the cadre to provide position guidance in the CAD model for primary controls used while driving.

Initial Posture Calculation and Constraints

The initial posture calculation involved four external constraints and two internal constraints on each manikin. The external constraints included the following manikin-to-component restrictions:

- Right shoe to the accelerator pedal plane and left shoe to the foot-switch block,
- Manikin h-point to the recommended seat h-point range parallelogram,
- Left and right hands to the steering wheel outer rim at 9 o'clock and 3 o'clock positions, and
- Eyes fixated on the APTA visibility target.

The constraints internal to each manikin included a soft hand grasp for left and right hands and pelvis rotation locked at 0°. Figure 19 illustrates the manikin and vehicle constraint components.

Steering Wheel Position Optimization and Posture Recalculation

After each manikin was constrained at the middle of the tilt/telescope range of the steering wheel adjustments, the steering wheel was repositioned to consider other postures and clearances for each manikin (see Figure 20). Each recalculation for each manikin followed this sequence:

1. Calculate posture with manikin according to original constraints.
2. Adjust steering wheel tilt and telescope within range to minimize reach for manikin.
3. Check stomach and thigh clearances for minimum hand clearance: 50 mm.
4. Repeat posture calculation.
5. Check the manikin h-point against the recommended seat travel constraint.
6. Check stomach and thigh clearance.
7. If clearance is below limit, adjust steering wheel and repeat sequence from Step 2.

Evaluation of Packaging for Bus Operator Cadre

Once the manikin packaging was completed, a qualitative visual verification was run with each manikin. The research team checked that (1) the manikin's feet had maintained contact with

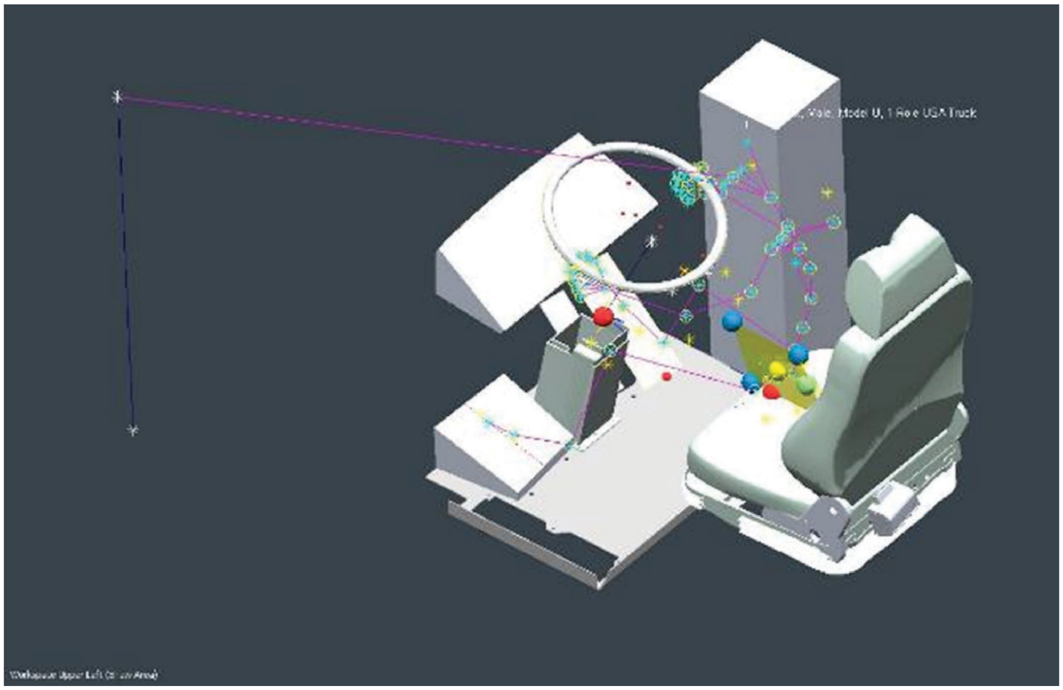

Figure 19. Posture calculation and constraints of manikin Male U to the bus operator workstation components.

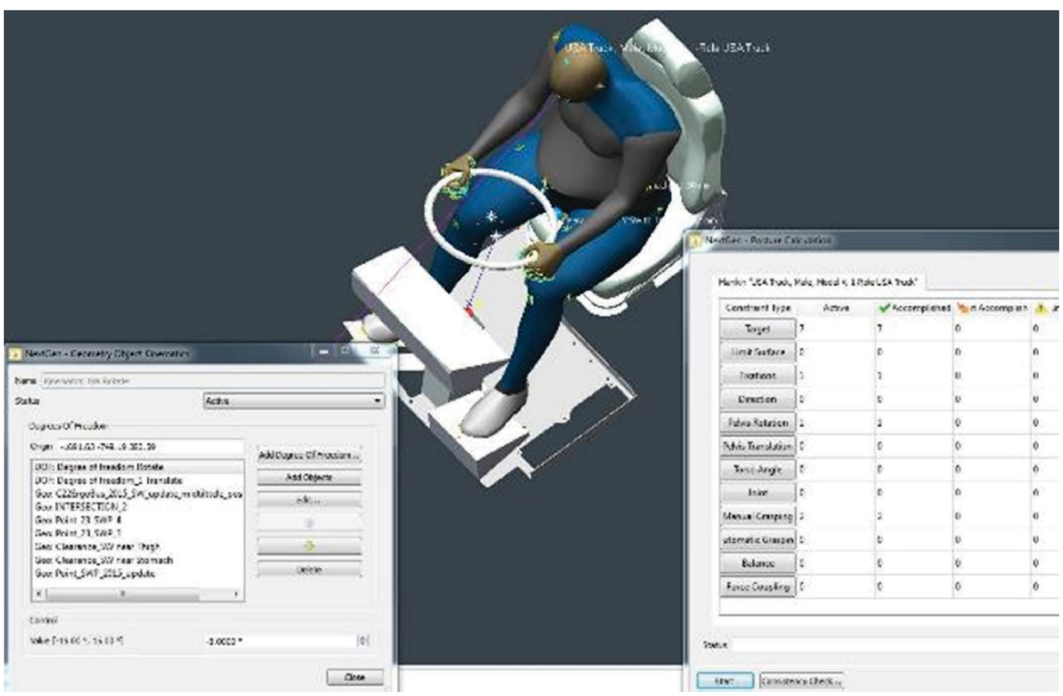

Figure 20. Optimizing steering wheel position for reach and stomach/thigh clearance on manikin Male V.

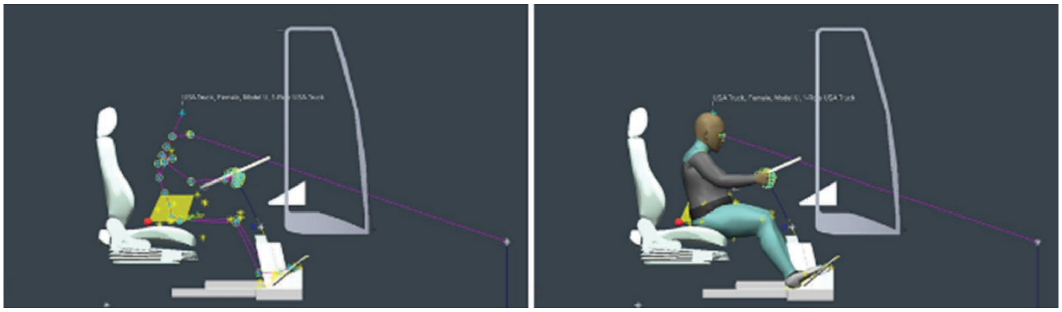

Figure 21. Posture calculation result for manikin Female U.

the pedals and floor, (2) the h-point was kept within the recommended seat fore-aft and vertical travel, and (3) no component obstructions existed between the visual gaze of the manikin and the APTA visibility target in front of the bus.

The results for each manikin are available in the right-side views as listed from Figure 21 to Figure 26). Note that the seat is located at the rear extent of the recommended horizontal range in these images to make the manikin positions easier to view and compare. These results are significant, suggesting that a large range of transportation operators can comfortably find a posture in the suggested Bus Operator Workstation Engineering CAD Model. Furthermore, the resultant posture did not create an unfavorable result for operators' forward visibility as defined by the APTA visibility requirement.

Demonstration of SAE Clearance Contours

The stomach and shin/knee contours that were constructed in separate CAD software according to SAE J1521 and SAE J1522 were imported into the human modeling software with the

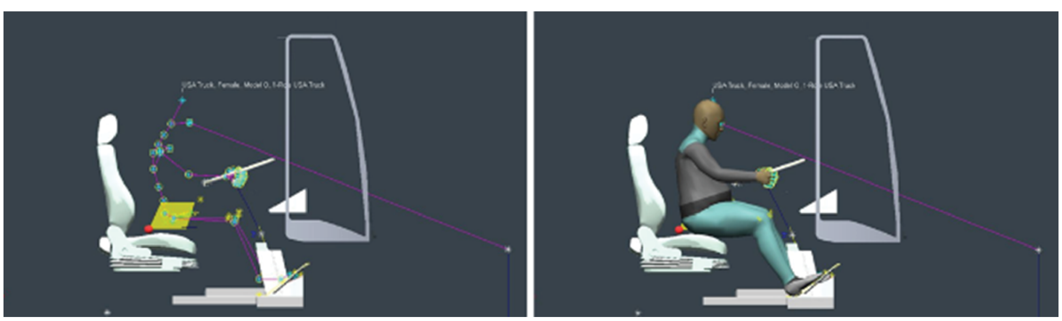

Figure 22. Posture calculation result for manikin Female O.

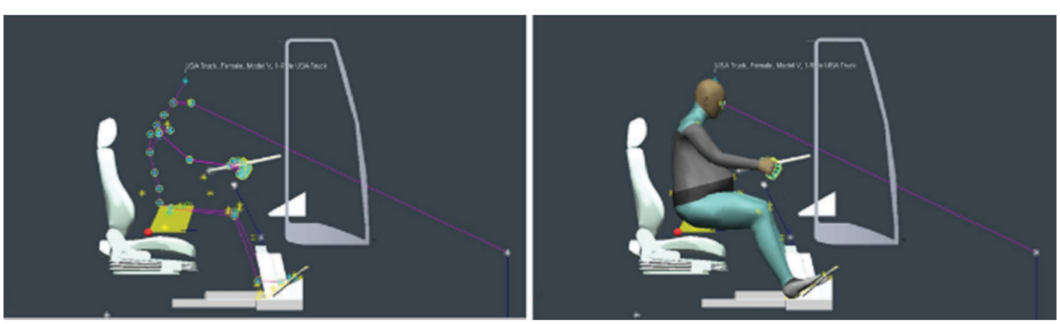

Figure 23. Posture calculation result for manikin Female V.

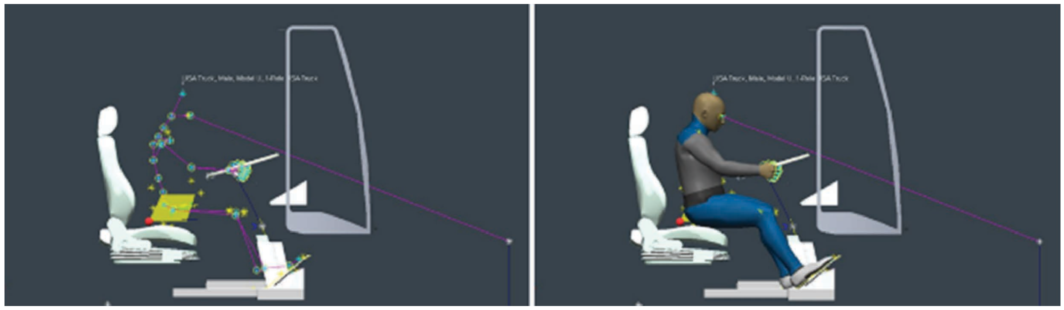

Figure 24. ***Posture calculation result for manikin Male U.***

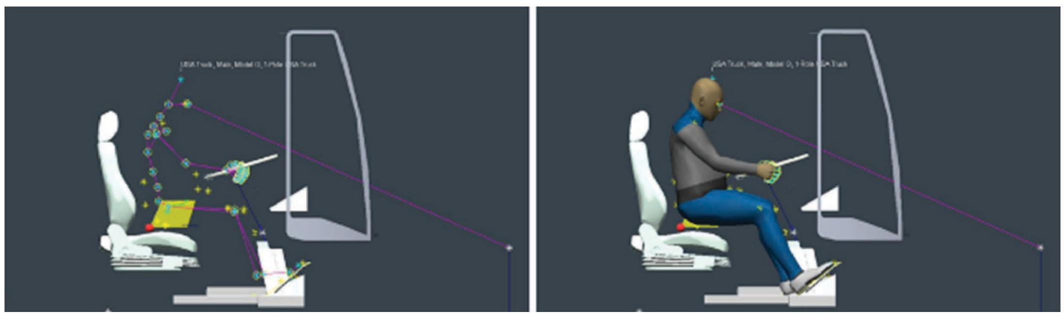

Figure 25. ***Posture calculation result for manikin Male O.***

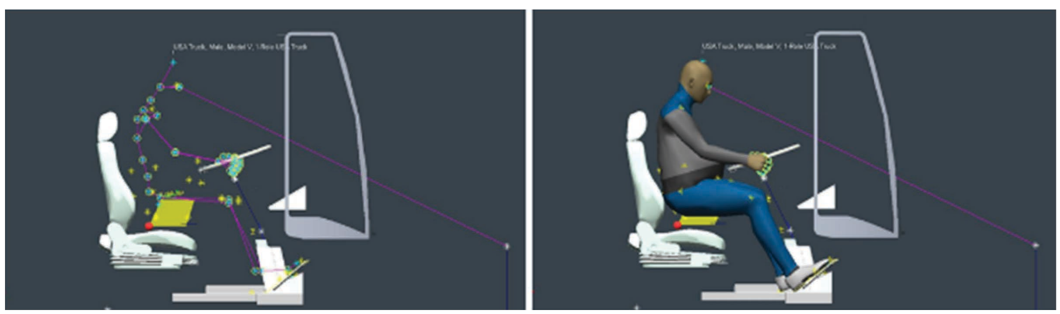

Figure 26. ***Posture calculation result for manikin Male V.***

intention of verifying that the contours predict clearances required by the manikin cadre. The contours were checked against the stomach and shin/knee positions of all manikins. However, manikin Male V was observed carefully because of his extreme height, buttock-to-knee length, and abdominal depth (see Figure 27). The red-dotted curves from the contours can be seen near his stomach and in front of his knees. This result suggests that the contours protect for the clearances that operators need around the steering wheel, steering column, and instrument panel components.

Construction of Manikin Reach Curves

Once the posture was verified for each manikin, reach surfaces were constructed for both arms of each manikin, originating at each clavicle and extending out to their index finger tip using the human modeling software. Each manikin's reach surface was exported to CAD software and sectioned at a typical height for instrument panels in order to create reach curves.

The reach curves were compared, and manikin Female U was found to have the minimum forward and side reach. An additional reach curve was developed from clavicle to hand grasp

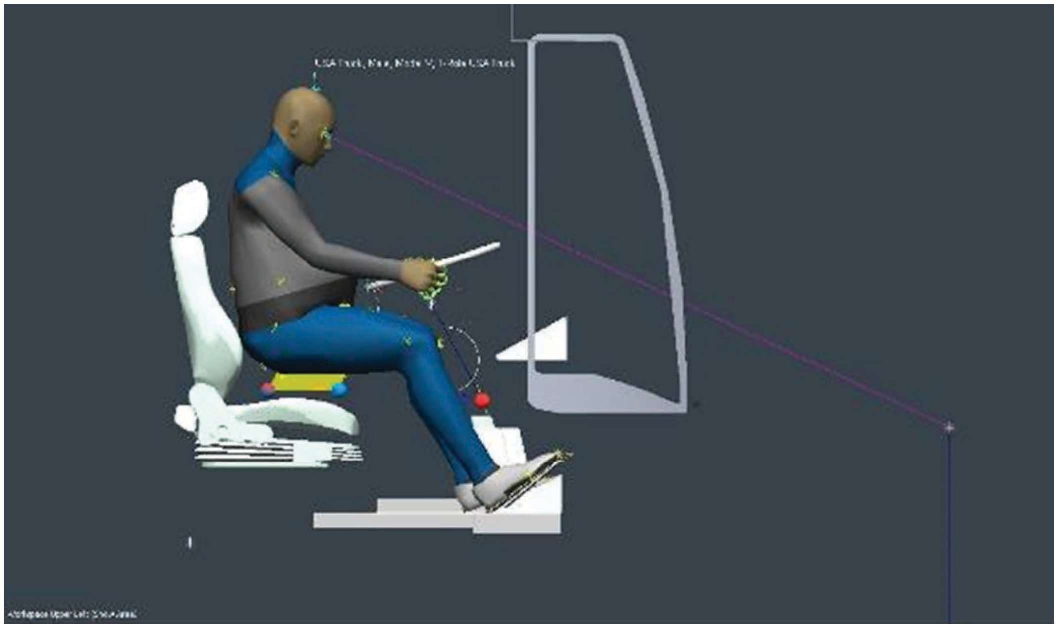

Figure 27. SAE shin/knee contours and stomach contour near manikin Male V (red-dotted curves).

for manikin Female U to be applied for controls requiring hand grasp. The index-fingertip and grasp reach surfaces for Female U are provided in Figures 28 and 29.

The resulting reach curves for finger and grasp reach that were constructed from the reach surfaces have been provided in Design Tool 2: Bus Operator Workstation Engineering CAD Model. Further specification and construction details are provided in Appendix B: Bus Operator Workstation Engineering CAD Model Specifications, particularly in Figure B-17).

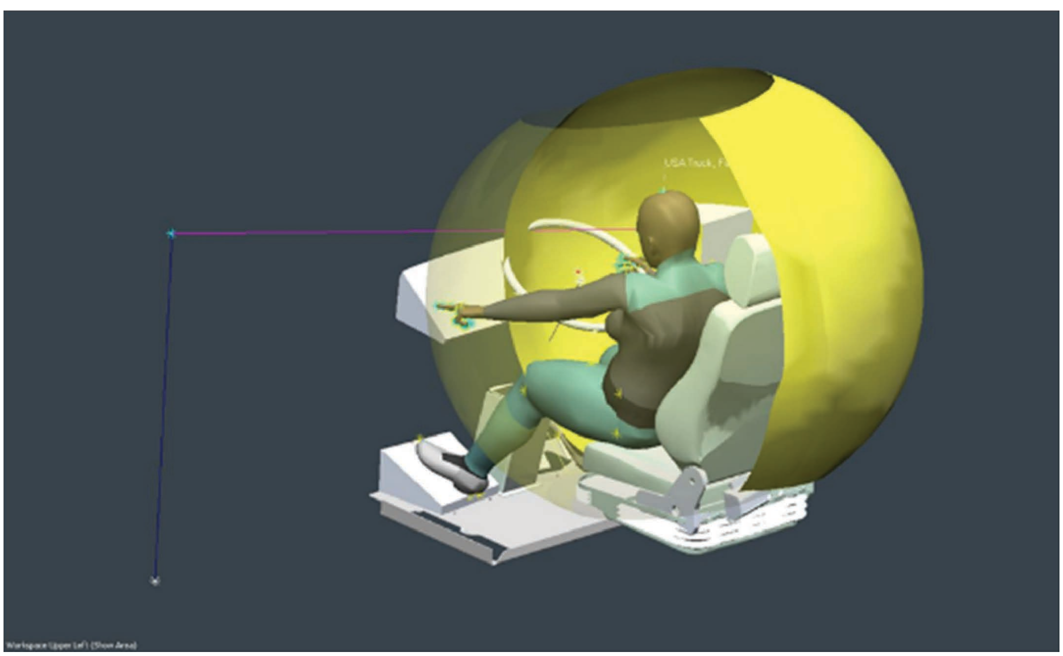

Figure 28. Reach curve construction for manikin Female U—left and right arms from clavicle to index finger.

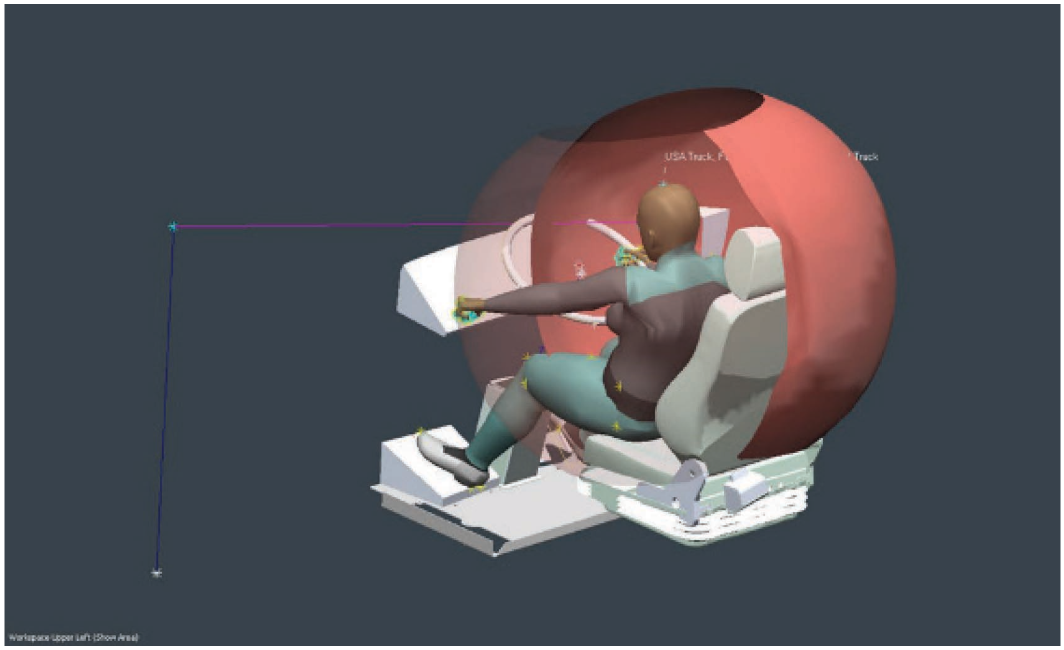

Figure 29. Reach curve construction for manikin Female U—left and right arms from clavicle to hand grasp.

Human Modeling Validation Summary

The Bus Operator Workstation Engineering CAD Model was developed as a combination of international transit bus design guidelines and SAE packaging RPs bounded by current production North American transit bus vehicle architecture. The model was intended to provide suggested seat, steering wheel, and pedal positions and adjustment ranges to accommodate the range of bus operators within the workstation design. Visibility planes, clearances for seated bus operators, and clearances for seat access were built upon the seat/steering-wheel/pedal arrangement. In order to test how this workstation design would accommodate the population of bus operators, the model was validated by the human modeling simulation.

The human modeling validation required the creation of a sample of manikins representing the range of bus operators. The 2010 NIOSH Truck Driver Anthropometric Survey was applied because the survey was recent, was collected from the United States, and was collected from a similar vocational population. The manikins were arranged into the workstation model using typical bus operator packaging constraints such as recommended seat range, recommended steering wheel range, production pedals and foot-switch plate, and the APTA visibility target.

One critical assumption that had to be tested was whether the range of bus operators could keep their feet on the pedal floor while seated in a comfortable posture and still meet the visibility requirement established in the APTA guideline. This assumption was confirmed based on the human modeling simulation presented. Additional packaging clearance envelopes for legs and stomach were also compared to the result of the manikin positions. Finally, the human modeling simulation provided maximum reach curves to be applied back into the Engineering CAD Model.

CHAPTER 6

Conclusions

Bus Procurement Process, Industry Outreach

To define the elements of a bus procurement process that effectively addresses bus operator health and safety, the researchers investigated current transit agency practice, industry expert insight, and the relevant research and practice literature. Management and union representatives from 10 transit agencies around the country were interviewed about the structure, team make-up, associated training, and steps of their bus procurement activities as they related to bus operator health and safety. A survey about bus operators' role in procurement was returned by 26 transit unions, representing 36 workplaces in the United States and Canada.

Transit industry experts were interviewed about their observations of and recommendations for practices supporting effective collaborative bus procurement. Experts included a government researcher involved in participatory ergonomics, a former bus operator with extensive experience in bus operator health and safety, a participatory design specialist, and an experienced transit agency manager who is involved in procurement training development. Despite initial interest, the manufacturing contacts declined to be interviewed.

Integrating Bus Operators into the Procurement Process

The make-up of procurement teams varied significantly across the agencies interviewed, ranging from one or two technical or procurement experts to an extensive stakeholder committee with subcommittees and working groups. Safety departments, maintenance workers, and bus operators were typically consulted at some point. The procurement method also varied: buses might be purchased through regional contracts or independently, in defined procurement periods, or using a process of rolling acquisition. Wide stakeholder involvement was reported as being most important to a successful procurement process, followed by the details of the process that were honed through experience, and how well the team worked together. Most respondents commented on the value of procurement team participants' long experience in the transit field, and expressed concern about the loss of that experience as people retired. The primary barriers to procuring vehicles that optimize bus operator health and safety were time constraints on getting and sharing information, and lack of adequate solutions and technology.

The suggested steps for a bus operator workstation design and procurement team process that protects operator health and safety cover these areas:

- Coordinating industry-wide action to improve bus operator workstation design. Transit agencies can communicate among themselves, with manufacturers, and with trade, academic, and government groups to encourage the development and dissemination of improved bus operator workstation design.

- Enhancing the procurement process in four phases, as follows:
  - **Phase I: Build and Support the Procurement Team:** An effective team of stakeholders is recruited and trained;
  - **Phase II: Prepare for Procurement:** The team acquires information about health and safety concerns, vehicle issues, and available technologies and solutions;
  - **Phase III: Specification, Request for Proposals (RFP), and Award:** The specifications and final award address bus operator health and safety; and
  - **Phase IV: Complete the Build and Roll-out:** The buses are monitored as they are built, piloted, and used to ensure bus operator health and safety.

The process described also illustrates the roles bus operators can play in each phase of assessment, design or selection, and evaluation. Bus operators can contribute by serving on the procurement team throughout, by participating in practical evaluation and problem-solving, and by acting as employee-users in tests and trials (i.e., either actively engaged in planning the evaluation, or as test subjects).

It is important to recognize that in many transit agencies bus operators are not actively integrated into the procurement process. They may be surveyed about their overall opinions or about specific changes, but this often happens late in the procurement process when change is expensive or unfeasible. The nature of the transit bus operator's work may make it harder for them to attend meetings or be available on demand. Bus operators are aware of bus design issues that affect their health and safety, however, and in the interviews conducted for this research, transit agencies and unions acknowledge that increasing their role could benefit the procurement process and improve operator health and safety. The challenge to transit agency procurement is to integrate the voice of their users—bus operators—in an effective and efficient manner. A process to improve consideration and inclusion of bus operators is provided in Organization Tool 1: Bus Operator Workstation Procurement Process (available from the *TCRP Report 185* webpage as "Suggested Procurement Practice for Bus Operator Health and Safety").

Bus Procurement Team Training for Procurement Teams and for Bus Operators

Many of the skills needed for successful procurement are developed by transit agency employees over years of experience. Effective procurement teams can either recruit members with these skills or call on them as needed. Team members can teach others by sharing their experiences and issues with various technologies of which they are aware.

Each set of stakeholders can contribute to the training and preparation of the procurement team, either in group presentations or in less formal settings. Safety department staff can explain ergonomics and injuries, maintenance workers and engineers can assist in reading specifications and generating feasible changes, and bus operators can demonstrate how they work and how they adapt the workstation. The backgrounds of individual members of the procurement team can be leveraged on procurement teams before and during the procurement activity, as can data collected in the course of service delivery (e.g., injury and illness logs or maintenance records), contributing to an effective understanding of the bus operator workstation.

More formal training to support procurement is most critical when new bus acquisition is on the horizon. Organization Tool 2: Bus Operator Workstation Procurement Team Training (listed online as "Procurement Team Training") can be used to prepare participants to understand the procurement process, the demands of the bus operator workstation and work tasks, methods for assessing and even redesigning bus equipment, and how to collect and analyze needed information. The CAD models and design specifications will increase the procurement team's grasp of the interaction of numerous bus operator workstation requirements. These tools should be used throughout transit agency training and procurement to merge the real-world operating environment and the design and procurement process.

Ergonomics training can benefit all bus operators, both to reduce their risk of injury and to improve their ability to contribute to bus specifications and improvements. Organization Tool 3: Ergonomics Training for Bus Operators (listed online as "Ergonomics for Bus Operators Training Template") is available to serve as a training template. This tool lays out the needed content and suggests activities to increase bus operator understanding and involvement. It is designed to be adapted and filled in with examples from the transit agency and other sources that will be meaningful to the bus operators.

Bus Operator Workstation Costs

A discussion of the application of benefit/cost analysis (BCA) and a return on investment (ROI) calculation to bus operator workstation design is provided in Appendix A: Bus Operator Considerations for Purchase Price. This information is intended to provide guidance for future research projects or industry endeavors that seek to determine what opportunities exist to improve the bus operator workstations based on a payback to individual agencies versus society as a whole. These analyses require a detailed accounting of the research costs, product costs, and health and injury records, in accordance with models that can demonstrate how a reduction to injury and accident frequency and loss of productivity are a result of changes to bus operator workstations.

Bus Operator Workstation Design Guidelines

Robust bus procurement specifications will provide durable, comfortable, and safe workstations in which bus operators can excel at their role of transporting passengers safely to their jobs and homes. Proper specification of the bus operator workstation accommodates the needs of the range of users. The ability for specifications to be successful depends on the processes and tools available. For TCRP Project C-22, information was collected and tools were built based on the framework of driver packaging processes that is common in light vehicle and commercial vehicle applications across North America and internationally. The tools and research report developed as a result of this research are organized to support continuing improvement that is in step with the larger domain of ground transportation driver packaging processes and models. Existing key procurement bus design elements are maintained in the guideline and in the models to support current procurement activities, while stretching existing bus operator workstation accommodation paradigms to support optimal bus operator health and safety.

Design Tool 1: Bus Operator Workstation Feature Guideline (listed online as "Bus Operator Workstation Feature Guideline") is structured to be simple for the procurement team to apply on a component-by-component basis. Feature images were included as possible to provide context. Appended to this guideline is a list of frequently used and critical controls in the bus operator workstation as referenced in the 2013 APTA procurement manual. Also appended to this guideline is a comparative matrix of the international bus operator workstation guidelines.

The integration of components and features into the whole bus operator workstation is an equally necessary task. For example, the accommodation of the bus operator workstation cannot be sacrificed to the passenger compartment walkway or seating; the bus operator's seating accommodation cannot be minimized to meet visibility requirements; and the steering wheel adjustment range should not be reduced to provide for bus operator seat access. The locations and adjustment positions of related components must be balanced to meet a hierarchy of requirements.

With regard to integrated guidance, a CAD model was developed for use by agency and manufacturing participants in the procurement process. Design Tool 2: Bus Operator Workstation Engineering CAD Model (listed online as "Bus Operator Workstation Engineering CAD Model") has been provided in two universal CAD files formats, STEP and IGES files. The purpose of the Engineering CAD Model is to bring the guidelines into a fully executable and moldable format on which individuals trained in CAD tools can (1) see how the workstation component and feature guideline pieces form the bus operator workstation guideline as a whole, and (2) compare this to existing transit bus architecture. Industry and research groups may download, apply, and update the model throughout business and research endeavors. It is the hope of the research team that this guideline format will be used as a building block for future improvements to transit bus operator workstations and their guidelines.

To support communication of these integrated workstation features, components, and guidance to individuals on procurement teams who do not have training on or access to CAD modeling, a universal model also was developed and is provided online as "Bus Operator Workstation 3-D PDF Model" (available with a user guide, from the *TCRP Report 185* webpage). Although the application of this model is very straightforward, the user guide has been made available to help first-time users of 3-D PDF files to open, navigate, and perform basic dimensioning of the guidance features and components.

Next Steps

The primary source of integration of feature and component guidance provided in this effort has been SAE Class B packaging processes. The original driver anthropometric and seating studies used to develop the SAE Class B vehicle packaging practices and tools occurred in the 1980s (Philippart et al. 1984; Shaw and Sanders 1984; Shaw and Sanders 1985). Efforts have been under way in years past and continue into the present to update the processes used to develop Class B vehicle seat, steering wheel, eyellipse, and clearance contours, as evidenced by a study completed at the University of Michigan Transportation Research Institute (Reed 2005). The study by Reed on Class B processes for commercial vehicle trucks intended to follow a similar vein of research to one that was previously accomplished in Class A processes for automotive (Manary et al. 1998). The Class B studies have not yet been validated for transit or other buses, however; nor have they been developed into SAE RPs for other commercial vehicles. Furthermore, the application of tools connected to that study also requires anthropometric raw data statistics that are not publicly available. The research team suggests that further studies are needed for validation across all commercial vehicle vocations (truck, transit bus, and other bus), along with the pursuit of cross-germination of efforts into updating SAE processes for Class B vehicles. Studies such as (Reed 2005) highlight weaknesses in the current SAE processes, most specifically the lack of vertical seat travel inside of the foundational studies that provided the basis for the SAE Class B processes. This makes human simulation modeling tools not only helpful, but also critically necessary when updating the vehicle architecture and operator workstations in Class B vehicles, such as transit buses.

The validation of the bus operator workstation was built upon data from a fairly recent survey of commercial vehicle drivers of heavy trucks. These data were selected due to the strength of information documenting the increasing size of North Americans over the last three decades. It is reasonable to assume that the population of heavy commercial vehicle drivers may have a higher body mass index (BMI) than that of transit bus operators. Therefore, the application of data from the heavy vehicle commercial vehicle driver survey may be considered somewhat extreme. The research team was provided with wise counsel regarding the changing shape and size of the workforce within the transit bus group and across the United States as a whole. This is a reasonable consideration, and the research team sought to reinforce the cadre of bus operator human modeling subjects with an NHANES III sample of a small female. However, it is strongly suggested by this research team that the transit bus industry and trade organizations seek to capture a nation-wide anthropometric sample that might be applied to best predict the needs of this changing workforce.

Lastly, this research team has sought to provide guidance that can positively impact the health and safety of bus operators and the public they serve by surveying known design and technology solutions. Some physical and software solutions exist which are not discussed in this report (e.g., hydraulic over electric steering columns, which can reduce bus operator arm and back strain; bus body roof column designs that reduce the forward-visibility obstruction for bus operators and technologies to reduce pedal forces and increase awareness of pedestrians in the transport environment). Evaluation of these opportunities will require trained teams, a common process, and a common design foundation with other ground vehicles. This research team strongly encourages that additional research be undertaken to continue building upon this foundation of people, processes, and technology.

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APPENDIX A

Bus Operator Considerations for Purchase Price

A Proposal for Benefit/Cost Analysis versus a Return on Investment Analysis

By: Sound Science, Inc.

What is Benefit/Cost Analysis?

Benefit/cost analysis (BCA) is used by public policy makers to determine whether the benefits of public policy exceed the costs. The ratio implied by this term, as written, suggests beneficial public policies must have benefits that sum up to more than the costs, so that the ratio of benefits to costs exceeds one. For example, when the Department of Transportation mandates a policy or regulation, a BCA may be required to demonstrate that the policy achieves positive economic welfare such that the total social benefits exceed the total social costs. This is not a private-sector calculation, but rather one that must incorporate at the margin all the benefits (e.g., both health and safety benefits for bus operators) and the costs (e.g., the incremental cost to design and build the new workstation).

This does not mean the same as return on investment (ROI). Investors, whether they are in the private sector or the public sector, are concerned that ROI is positive. That is, they are concerned that the costs will not be so burdensome that they cannot earn a positive return from the investment. These investors or operators rationally may be concerned that the new workstation reduces injuries and their costs sufficiently to justify the incremental cost of adoption. If their workforce is stable and the workers spend much of their careers with the transit agency, they may also be concerned about health benefits as well as safety benefits. This is because they expect that they will pay the costs associated with illnesses and repetitive motion injuries associated with the current workstation. For example, if the pedals associated with the current workstation cause a chronic occupational illness or injury, the transit agency probably will pay the cost of such chronic health problems and thus has an economic interest in this cost and can recover a benefit from a workstation that reduces such chronic health problems (Hannerz and Tüchsen 2001; Tse et al. 2006).

Formal adoption of features of a new workstation by the transit industry will likely require a full BCA. For identification or evaluation of a beneficial design that may provide a positive ROI to the transit agency, a simple ROI analysis may be appropriate.

The webinar “Cost-Benefit Analysis for Ergonomics” (Ergoweb 2013) provides a good example of an ROI analysis designed to improve the firm’s bottom line by improving ergonomic design. It addresses the questions “Are your ergonomics recommendations sometimes met with questions about cost and effectiveness? Do you hesitate to recommend certain solutions because they seem too expensive? Are you looking for tools that will help you promote ergonomics as an investment and not just a cost?" The presenter also provides a good online ROI calculator (Puget Sound Chapter of the Human Factors and Ergonomics Society 2012) The calculator is useful when attempting to do ROI and can contribute to a BCA, but will not completely address the problem of total social costs and benefits, as it is aimed toward the employer's economic interests, not the entire economy.

Theory of Benefit/Cost Analysis

The general principle of BCA rests on the utilitarian notion that the benefits of any public policy should exceed the costs. For public policy purposes, analysis of the total social cost—the economic cost to society—must include all social costs. Utilitarianism requires that policy ethically should seek to achieve the greatest good for the greatest number (Mill 1879; Bentham 1823), where the greatest good for the greatest number means greatest total welfare or welfare per person. Theoretical foundations for this lie in welfare economics: the Hicks-Kaldor model, which provided the modern foundation for BCA, quantifies this determination (Hicks 1939; Kaldor 1939). Social costs include all of the costs, including those with prices that are incorporated within transactions, and those without prices that are costs external to the market transaction. Social welfare and environmental costs are very difficult to price into the cost of service, though not impossible. Economists say that these costs lie external to the market; they are "externalities" (Viscusi, Harrington, and Vernon 2005). For a good online summary, see "Benefit-Cost Analysis" (Portney 2008).

Employee safety and protection from injury, as well as public safety, are easier to include within price, as long as institutions providing for liability are structured appropriately. If liability rules are clear and coverage limits are appropriate, public liability and property damage (PL & PD) insurance ensures that the public is protected and the operator takes this risk into account when hiring, training, and managing the workforce, as well as when pricing the service. When operations are outsourced, such as when an organization puts work out for bid to the external market (e.g., for drivers, mechanics, or equipment), liability can become less clear. Those who outsource to cut cost and do not ensure that outsourced entities are fully responsible for their actions run the risk that costs that had previously been internalized (e.g., health and safety, as well as PL & PD) may become external to the market.

In other words, the subcontracting process may, under ideal circumstances, shift activities to those most competent to perform them. Subcontracting may, however, reduce cost by shifting responsibility for risk to a third party that may not internalize all the costs or the benefits in price. Under those circumstances, the subcontractor may shift safety cost to the public in the form of an "externality" and the transit agency subcontracting the work may find that performance has been degraded by the subcontractor, unbeknownst to the transit agency (Sclar 2000). This is the "principle-agent" problem and it bedevils the subcontracting problem (Holmstrom 1979; Milgrom and Roberts 1992; Stiglitz 1987).

Legacy airlines, for example, are perfectly capable of operating regional airline routes that feed their hub and spoke systems and their trunk lines. However, they may have reduced cost by subcontracting these routes to small regional airlines that "operate" flights on behalf of the legacy airline at lower cost simply because they cut corners to reduce expenses, shielding the legacy carrier from liability in the event of a crash (Young 2010). For the purpose of BCA, however, these institutional arrangements make no difference as long as costs previously internal to the market have not shifted outside the market and, if they have shifted, have not been incorporated into the analysis.

Employee health can be included within price only insofar as employee turnover is low and tenure is long. In occupations and organizations whose employees are very stable, it is possible to at least partially attribute health and chronic physical problems to the job and hence these costs can be monetized within the price. Transit agencies, for example, have a substantial number of long-term employees; it therefore may make sense for them to incorporate health costs into their analysis. Truckload trucking companies, on the other hand, have a relatively small number of long-term employees, as turnover has exceeded 100% annually for decades; they likely shift driver health costs to society in the form of an externality. It is important here to note that it makes no difference for this purpose whether the price is paid by individual customers (fare-paying customers) or by tax subsidies, as long as the price accurately reflects all internalized costs.

ROI or BCA: What to Include?

Businesses and organizations (such as transit agencies) use BCA in a private-cost way by comparing the benefits attributable to any operational element (such as the introduction of a bus or a route) to the costs incurred. That is, does the addition of each unit of capacity deliver sufficient benefits (generally revenue) to justify the added cost? *TCRP Report 25* (You et al. 1997) treated social costs as private costs, which drastically underestimated both social costs and benefits. It essentially performed an internal ROI analysis, not a BCA.

When a service provider assesses cost of service, it will incorporate capital and labor costs as well as R&D (the development cost for the technology used to provide the service; in this case, the transit bus), for example. To the extent that the service provider has responsibility for the cost of employee health and safety, it will incorporate these costs into its model. For employers with substantial turnover, employee health cost (except for sick time and lost work time) may be external to the price. It is important to quantify the extent to which employers actually “own” employee health cost.

Ideally, any attempt to perform a BCA would include a marginal social cost approach. “The marginal social cost of a good or service is defined as the increase in total social costs that results from producing one additional unit of output of the product above the level being produced” (Committee for Study of Public Policy for Surface Freight Transportation 1996, 2). It is not clear that the marginal approach is necessary in the BCA for the introduction of new technology, such as the bus operator workstation design in this project, because it depends on whether the technology is mandated by a government agency or adopted voluntarily by transit agencies interested in the positive ROI. In the event a new workstation is mandated by regulation, a BCA of such a new workstation must include all of the relevant costs associated with developing and implementing such a workstation as well as the social benefits, especially on worker health and safety. The inclusion of these and additional elements will ensure that public policy makers make the most efficient choices in implementing a new bus operator workstation design (Gramlich 1997). In addition, to the extent that ROI analysis is necessary to convince transit agencies that the new workstation is in their best interest, on the assumption that transit agencies must see that the benefits exceed the costs for them, solid background research will provide the foundation.

As referenced above, the last attempt to do this for bus operators was the "Bus Operator Workstation Evaluation and Design Guidelines" project, completed in 1997 and published as *TCRP Report 25*. The approach taken by the authors of *TCRP Report 25* did not distinguish between private and public costs, however, or between private and public benefits; it was a business case costing exercise to determine ROI and did not incorporate any of the principles of welfare economics discussed in this appendix. As a result, the authors constructed a private-cost model that incorporated the component costs associated with the new workstation (not the marginal component cost) and the medical benefits associated with reduced injuries, measured by a before-and-after case comparison within one transit agency that adopted the new workstation. Further, the data included only "direct medical costs" and "workers' compensation costs" and did not attempt to incorporate measures of chronic musculoskeletal and other health effects. With these extremely limited data, they "projected [an] injury reduction rate of 80 percent…." The approach taken did not meet the minimum requirements for BCA in public policy (see Adler and Posner 2001; Committee for Study of Public Policy for Surface Freight Transportation 1996; Gramlich 1997; Karlsson 2005; National Center for Environmental Economics 1983, 2000, 2008a, 2008b; National Research Council (U.S.) 2008; Viscusi, Harrington, and Vernon 2005).

Elements to Include in a BCA and a ROI Analysis

A BCA and ROI analysis should include the following data and information on costs and benefits.

Cost

- Cost of producing the current bus operator workstation. Contact manufacturers—both original equipment manufacturers (OEMs) and suppliers—to determine the marginal cost of production. That is, what is the marginal or incremental cost of the new workstation, separate from the cost of the bus? Manufacturers will be the only reasonable source of information, though presumably someone could reverse-engineer the current workstation and estimate costs. For this, data should be obtained from the suppliers manufacturing the workstation and integrated with data from the OEMs that must integrate the workstation into the overall bus design and final price to customers.
- Cost to develop the new workstation. This includes the private cost for workstation suppliers to design and manufacture it, as well as the cost of installation, once designed. It should include all costs associated with the development.
- Cost of optional elements in the workstation, such as security/thermal barrier.
- Materials cost difference, if any.

Benefits

- To what extent does the new workstation impede or reduce impediments to drivers who need to help passengers? If the new workstation reduces impediments, quantify the benefits in terms of ergonomics as well as productivity. Does new workstation make it easier and quicker to access the passenger cabin of the bus? Document the time saving and possible productivity enhancement.
- To what extent does the new workstation improve efficiency? Is the bus operator better able to do his/her tasks without having to lose productive time? If the bus operator is able to perform tasks more efficiently, bus operator efficiency and productivity will improve, and a BCA (or even ROI analysis) should document the improvements.
- If a more automated fare-collection system were unified into the workstation, it likely would increase productivity. For example, it could reduce productivity loss associated with helping passengers access the fare box. Since workplace violence has become a major issue in transit bus, the automated fare-collection system also may reduce bus operator stress associated with bus operator attempts to collect fares from riders.
- Quantify the likely safety improvements, if any. Will the new workstation reduce the probability and severity of crashes? What is the internal cost of crashes to the transit agency, the cost to the individual bus operator, the cost to passengers, the cost to the public, and the potential environmental cost? The cost savings attributable to features of the new workstation would be the benefits associated with these safety improvements.
- Quantify the reduction in workplace injury associated with the new workstation. Include traumatic injury as well as chronic injuries such as repetitive stress injuries caused by the previous workstation's poor ergonomic design. Quantify the value of the reduction in doctor, physical therapy, and hospital visits, as well as reductions in sick days and workers' compensation costs.
- Predict the extent to which the new design workstation will change transit bus operator health and safety experience.
- Quantify and monetize improvements in health that can be anticipated with the new workstation.

Data Needed

- The contractor should locate appropriate data on transit bus safety, bus operator health, and bus operator injury.
- Research the literature on the cost of health and safety and estimate the cost changes that may occur. A reduction in cost would be attributable to benefits in this analysis; an increase in cost would be negatively attributable to benefits.
- Obtain crash data and crash costs from public data. Note that such data may be hard to obtain on a macro level, so plan to survey APTA members regarding these costs. These costs will become the baseline against which to measure changes anticipated as a result of this workstation revision.

- Obtain occupational illness and injury data from workers' compensation insurance claim data as well as group medical data (Bushnell 2011). Both of these may be obtained with the cooperation between transit agencies and their insurers.
- To the extent that researchers anticipate reduced crash likelihood and severity due to some new technology associated with the workstation (anti-glare glass, for example), account for the changed experience as well as the changed cost in the estimates. (Belzer presented a current initiative, now being sponsored by the U.S.DOT, to develop an anti-glare coating for transit bus windshields at the Bus Safety Subcommittee meeting of the Transportation Research Board (TRB) Truck and Bus Safety Committee in January 2014. This would reduce the likelihood of transit bus collisions with fixed objects, vehicles, bicyclists, and pedestrians, particularly at night with interior lights on. It also would reduce fatigue by reducing eyestrain and driver stress.)
- Collect data from manufacturers to assess the incremental marginal costs associated with the development of the new workstation. Take care to distinguish the anticipated new costs from current costs. This would include tooling, assembly line updates, assembly time, and other costs. When differencing the cost of the new workstation against the old, take care to subtract current costs from the anticipated costs of the new workstation.

APPENDIX B

Bus Operator Workstation Engineering CAD Model Specifications

Introduction

The following information is provided in order to demonstrate the steps and specifications that were applied to the creation of the Engineering CAD Model which was then exported into the 3-D PDF Model.

Bus Operator Workstation, Engineering CAD Model, Packaging Reference Components, and Points

Two operator packaging points were established as the references around which the seat and steering wheel positions are based. The first point is the accelerator heel point (AHP), which is located at the centerline of the heel of the right shoe on the accelerator pedal at rest. The second point is the accommodation tool reference point (ATRP) as defined in SAE J1516. Before being able to develop these points, it was important for the research team to obtain the specification of a seat h-point either through CAD drawings released from the seat manufacturer or through methods of physical measurement.

The research team was able to obtain a specification of the seat h-point from a 2-D CAD drawing that had been developed by the seat supplier. This point was a seat index point (SIP) that is constructed through a common practice (see SAE J1163) that stems from ISO 5353. Other seat h-point procedures are typically developed in other highway vehicles and referred to as the seating reference point (abbreviated SgRP). They can be constructed using the SAE J826 H-Point Machine (HPM) or using SAE J4002 HPM-II. However, the SIP can be suitably applied and provided sufficient detail to generate the necessary packaging reference points. The dimensions for the SIP in the seat drawing reference a seat-belt anchorage point (see Figure B-1).

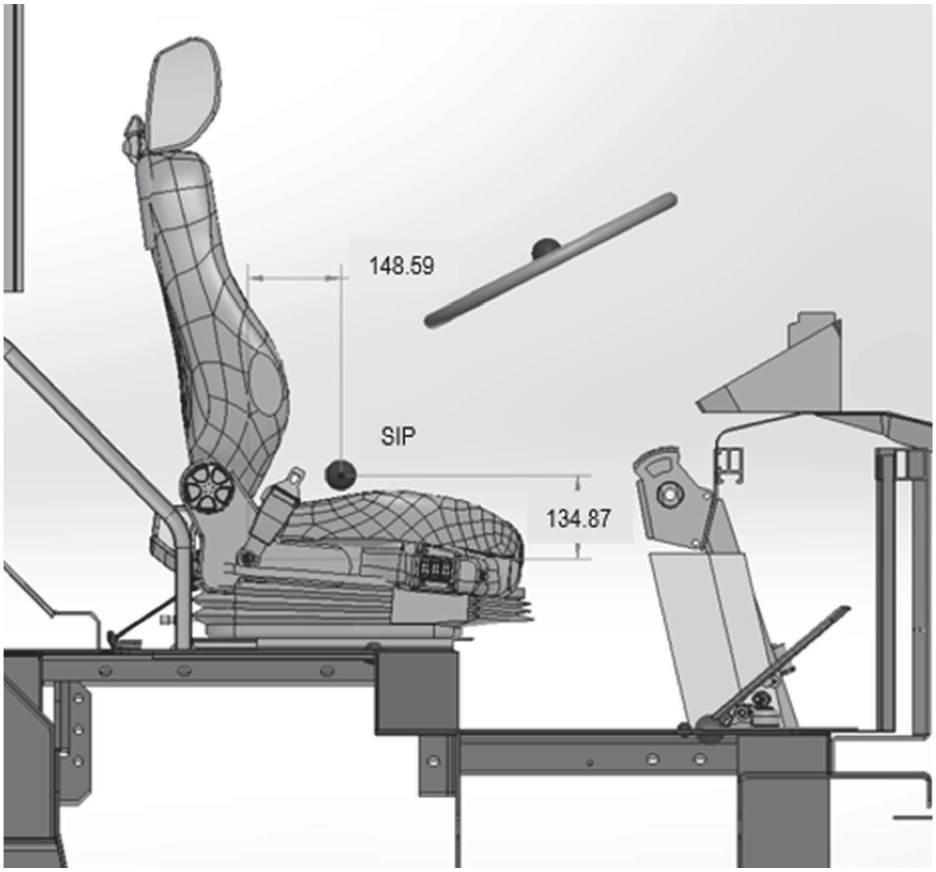

Figure B-1. Seat index point (SIP) position relative to seat-belt anchorage point as defined in a seat supplier drawing. The seat position was assumed to be at the full down position.

The derivation of the accelerator heel point (AHP) per SAE J1516, Equation 4, requires first selecting a seat height. The drawing provided by the seat supplier demonstrated one example of a typical h-point height range, which when measured to the pedal floor (H30) extended from 412 to 578 mm. Rather than relying on a purely theoretical H30 value or range, the research team selected the mid-vertical h-point value of 495 mm and applied it to Equation 4 to obtain the shoe plane angle (SPA) of 37°. A shoe plane was constructed to align with the accelerator pedal.

The shoe plane imitated a 95th percentile male shoe from the National Institute for Occupational Safety and Health (NIOSH) survey (Guan et al. 2012). The shoe plane had a length of 334 mm and a width of 126 mm. This plane was constructed as a 3-D model. One end was aligned with the pedal floor and the plane was inclined 37° above the pedal floor. The shoe plane was brought into contact with the accelerator pedal pad. The centerline of the rear edge of the shoe plane that makes contact with the pedal floor was the AHP. This model is demonstrated in Figure B-2. Figure B-3 demonstrates the position of the AHP relative to the workstation reference system (WRS) absolute zero.

The resulting AHP coordinates in the model were as follows:

- Xc: 1714.9 mm
- Yc: 500.5 mm
- Zc: 0.0 mm

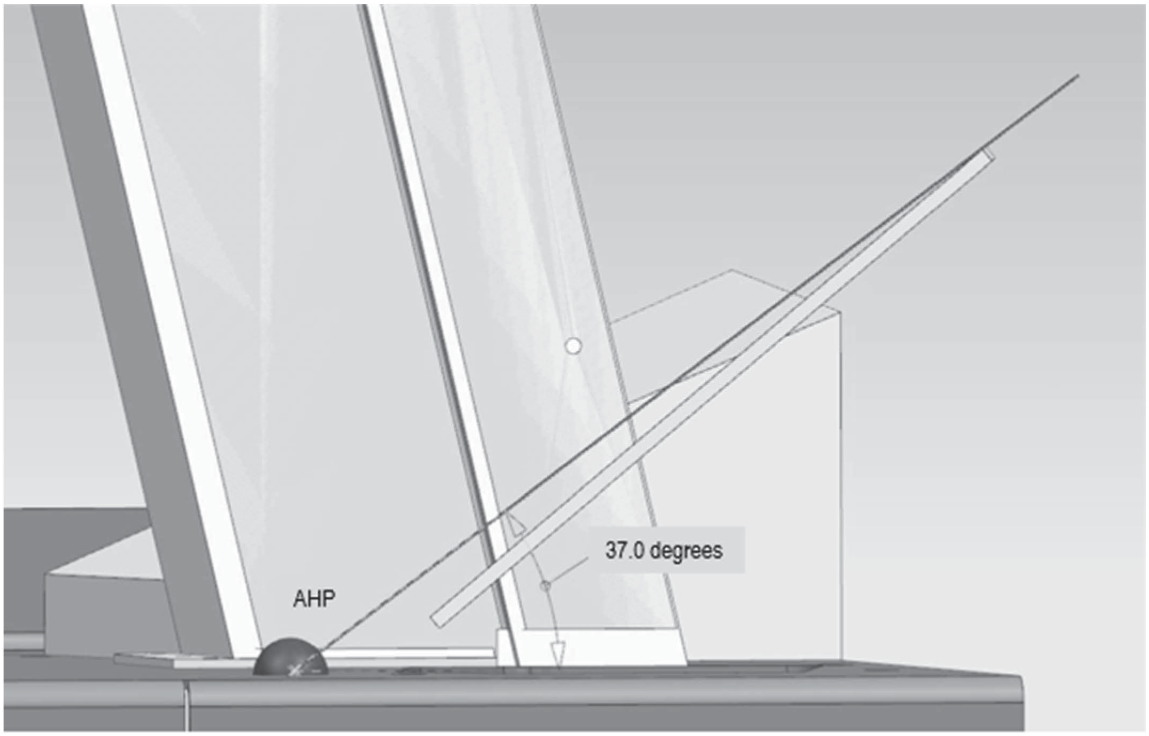

Figure B-2. The determination of the AHP according to SAE J1516.

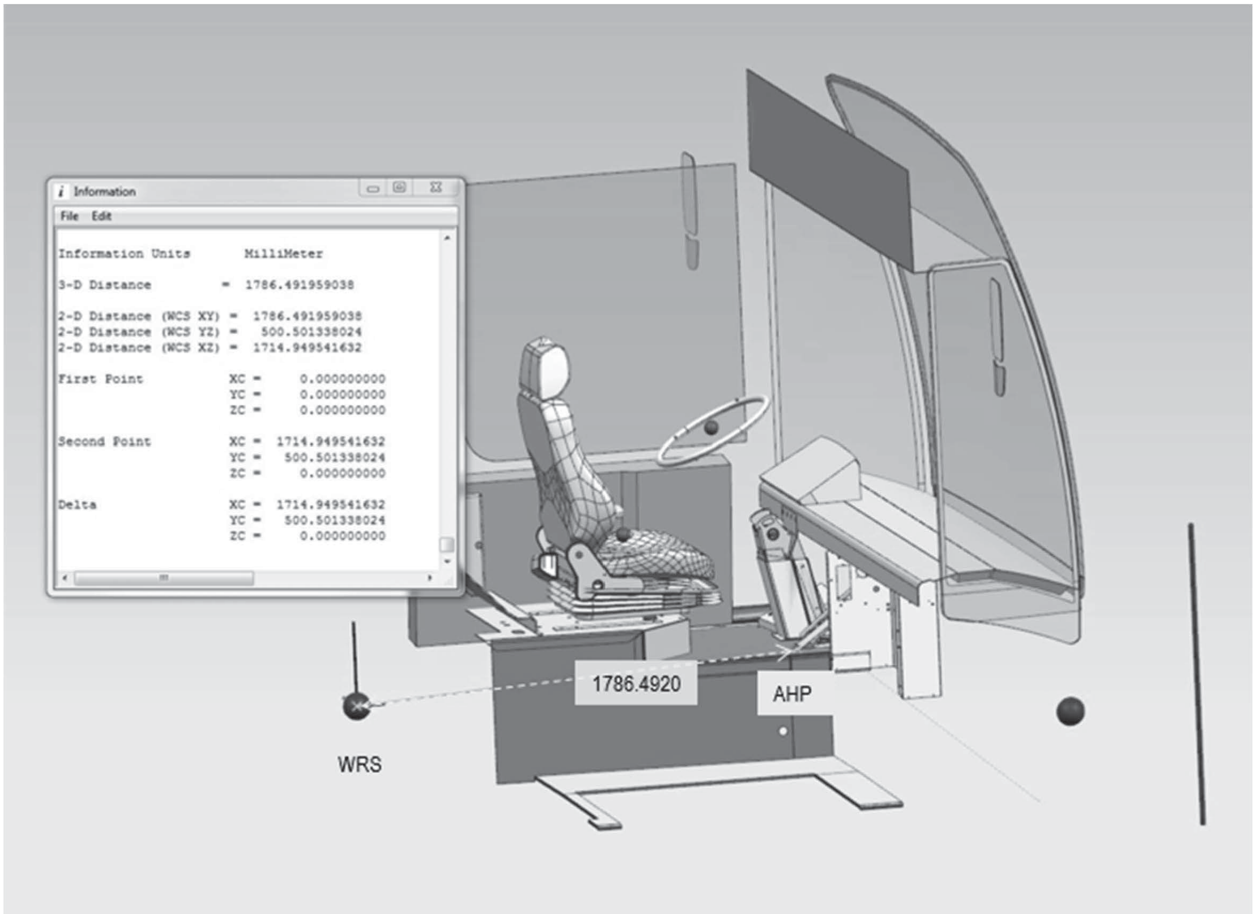

Figure B-3. The AHP reference from WRS absolute zero.

The second point, the accommodation tool reference point (ATRP), is again based on the mid-vertical h-point value of 495 mm. The ATRP was derived from a 50th percentile accommodation tool reference line (ATRL) as defined per SAE J1516. A 50:50 male-to-female gender ratio was selected for the transit bus operator population (SAE J1516, Eq. 1). This decision was based on data from workforce population data on transit and other bus vocation operators per Equal Employment Opportunity (EEO) tabulation from 2006 to 2010 (U.S. Census Bureau). The resulting ATRP was 495 mm above the AHP, 578 mm rearward of the AHP, and along the operator centerline (outboard 249.7 mm) (see Figure B-4).

The resulting deltas from the AHP to the ATRP in the model were as follows:

- $\Delta X = 578.0$ mm
- $\Delta Y = 249.7$ mm
- $\Delta Z = 495.0$ mm

The resulting ATRP coordinates in the model were as follows:

- Xc: 1136.9 mm
- Yc: 750.2 mm
- Zc: 495.0 mm

Figure B-4. Seat calculated ATRP (SAE J1516) from WRS absolute zero.

The suggested steering wheel diameter in the guideline is 457 mm. That same dimension was applied to the size of the steering wheel in the model (see Figure B-5). The point that is on top of the rim face and located in the center of the steering wheel diameter is commonly referred to as the steering wheel point (SWP). This point serves as another workstation packaging reference point and is useful to specify the location and range of adjustment for the steering wheel.

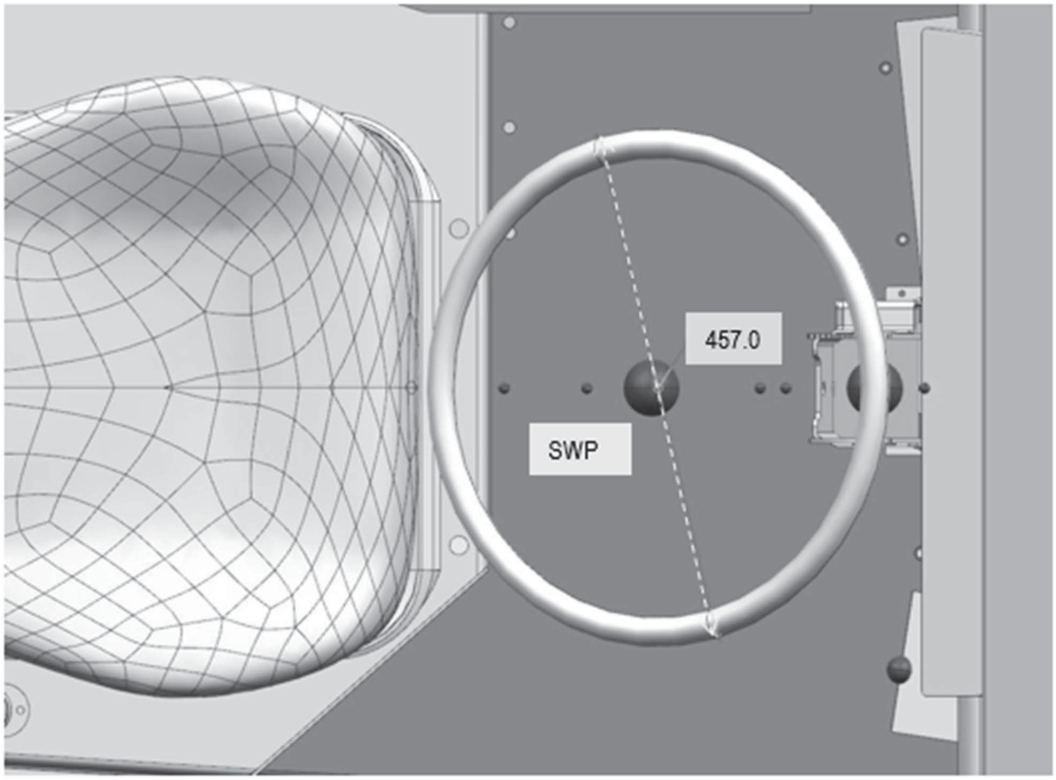

Figure B-5. Suggested steering wheel size (457 mm) with rim top/diameter center steering wheel point (SWP).

Seat and Steering Wheel Adjustment Range

Following the declaration of the two fiducial package points, AHP and ATRP, the seat travel range and steering wheel range were developed. The research team utilized multiple ATRLs to develop boundaries for a range of seat adjustments that accommodates 95 percent of the operator population (see Figure B-6). This was accomplished by applying the ATRL 2.5 percentile equation to define the front limit of the seat travel and the 97.5th percentile equation to define the rear limit of the seat travel. The current production seat height range example of 412 to 578 mm was inserted as the "Z-values" in the 50:50 gender ratio equations (SAE J1517, Eq. 1 "X_97.5" and Eq.1 "X_2.5").

This h-point range closely approximates the shape of a parallelogram with boundary points as specified below and demonstrated by the four outer blue spheres in Figure B-6. The SIP sphere stays fixed relative to the seat cushion as the seat is adjusted vertically and horizontally. The ATRP sphere is provided for comparison. Another sphere, the ATRP 95th sphere, represents a typical reference position for vehicle manufacturers with the seat at mid-vertical along an ATRL that follows a 95th percentile curve. This would fall in front of the rearward-most suggested seat travel line, which was set to follow the 97.5th percentile ATRL curve. The SgRP is also provided at the h-point position when the seat is located at full rearward and full down.

Full Rear, Full Up re. AHP

- ΔX = 644 mm
- ΔZ = 578 mm

Full Rear, Full Down re. AHP (*SgRP*)

- ΔX = 722 mm
- ΔZ = 412 mm

Full Forward, Full Up re. AHP

- ΔX = 436 mm
- ΔZ = 578 mm

Full Forward, Full Down re. AHP

- ΔX = 490 mm
- ΔZ = 412 mm

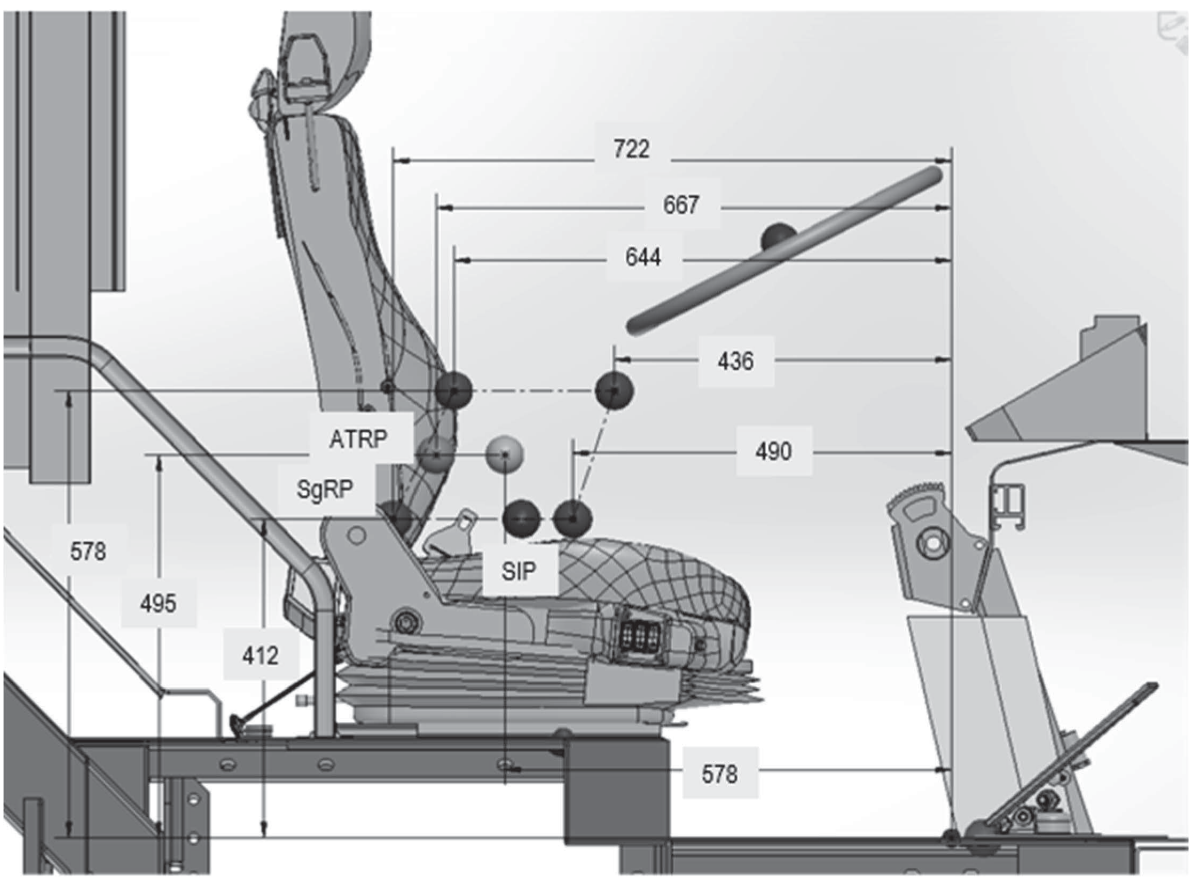

Figure B-6. Seat adjustment range as calculated using 2.5th percentile and 97.5th percentile ATRL (SAE J1517) with SIP, ATRP, and SgRP.

Using the SWP described along the rim top and diameter center, the steering wheel center point was positioned using a combination of vehicle data from the physical measures of a similar column and a result of the guideline development analysis. As evident in Figure B-7, the separation of the SWP from the AHP is 221 mm horizontal (SAE J1100 dimension "L11") and 770 mm vertical (SAE J1100 dimension "H17").

The required minimum steering wheel tilt range is ±15^{o} (suggested was ±20^{o}). The required range was applied for the CAD guideline model along with a steering wheel telescope range of ±55 mm (see Figure B-8). The mid-range SWP position was set at 27^{o} rear of vertical. This telescope range is known to be much larger than some current production transit bus columns provide today, but this feature would allow for a significant increase in accommodation for transit bus operators.

Mid-Tilt, Mid-Telescope re. AHP

- $\Delta X = 221$ mm
- $\Delta Z = 770$ mm
- αY: 27°

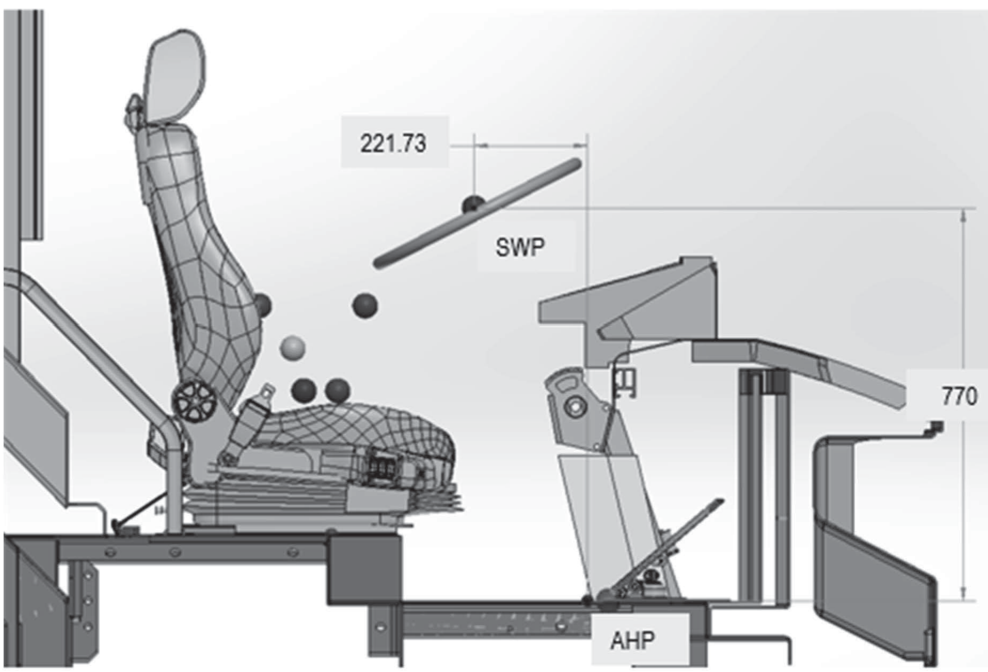

Figure B-7. Steering wheel SWP relative to AHP at the middle of the suggested tilt/telescope adjustment range.

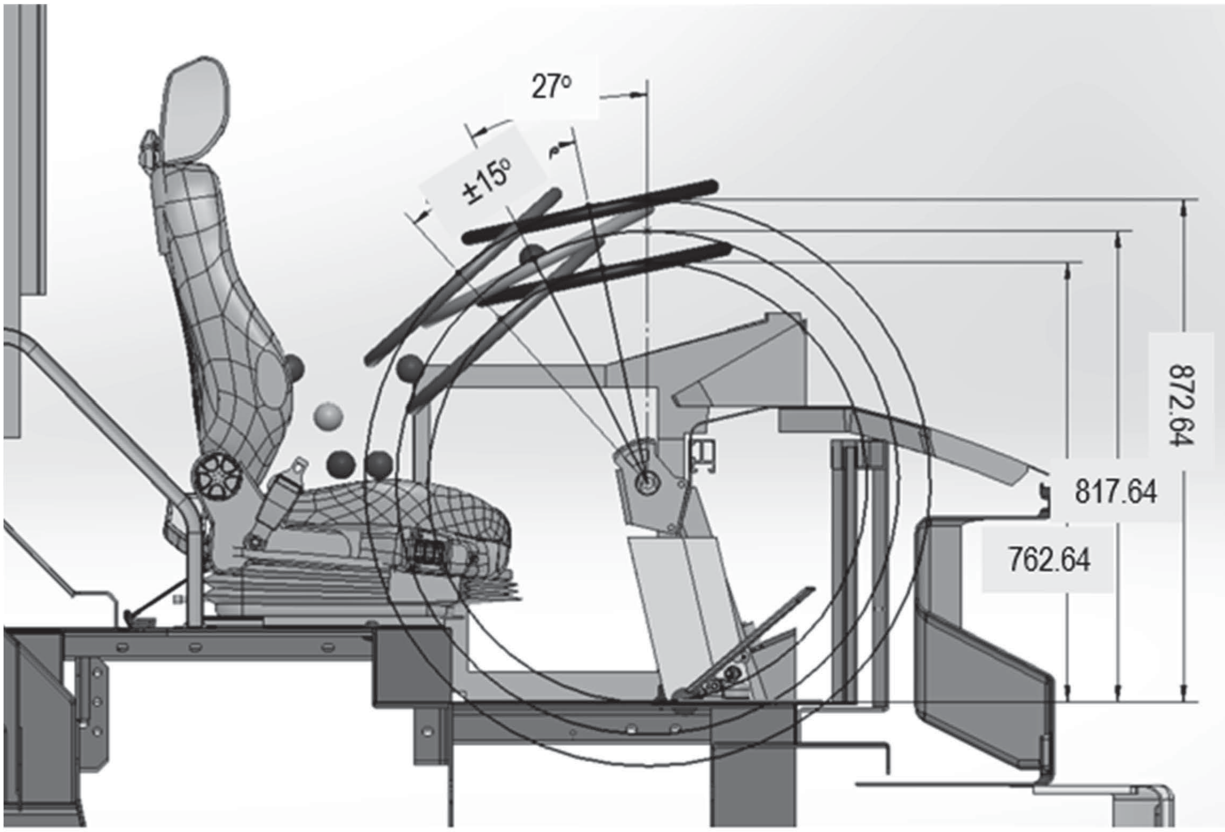

Figure B-8. The suggested steering wheel tilt/telescope adjustment range. The angles are measured relative to vertical or SWP mid-range angle and heights are relative to AHP.

Application of the SAE RPs for Bus Operator Packaging Envelopes

Other packaging envelopes can be derived by applying the ATRP values into the appropriate SAE RPs such as eyellipses (SAE J941, Appendix E), shin/knee clearance contours (SAE J1521), and stomach clearance contour (SAE J1522). The Z-value of the ATRP (H30) was applied in determining the shin and knee contours for establishing clearance zones for the operator's legs when applying the pedals, in accordance with SAE J1521. Since transit bus vehicles are almost universally driven by automatic or automated-manual transmissions, the clutch shin and knee contours were not applied.

The left foot and leg are used by transit bus operators to control the foot-switch turn signals and high beams. Therefore, clearance zones for the accelerator pedal were applied to both the right leg shin and knee contours as well as the left leg shin and knee contours. A 50:50 male-to-female gender ratio was selected and the ATRP Z-value was inserted into equations 7 and 8 to obtain the delta X and Z contour reference values from the ATRP (dX = 431.8 mm forward, dZ = 19.6 mm up). This contour reference was positioned at the operator centerline.

A constant-radius arc of 113.25 mm was drawn at the operator centerline from the contour reference as directed in SAE J1521. The RP does not specify the width of the clearance or the arc-length. The clearance contour was extended on both sides of the column cover to fully cover the areas of shin and knee motion. The arc-length was arbitrarily selected to extend from directly above the contour reference forward and around 160°. See Figure B-9 for top and right-side views of the shin/knee contours.

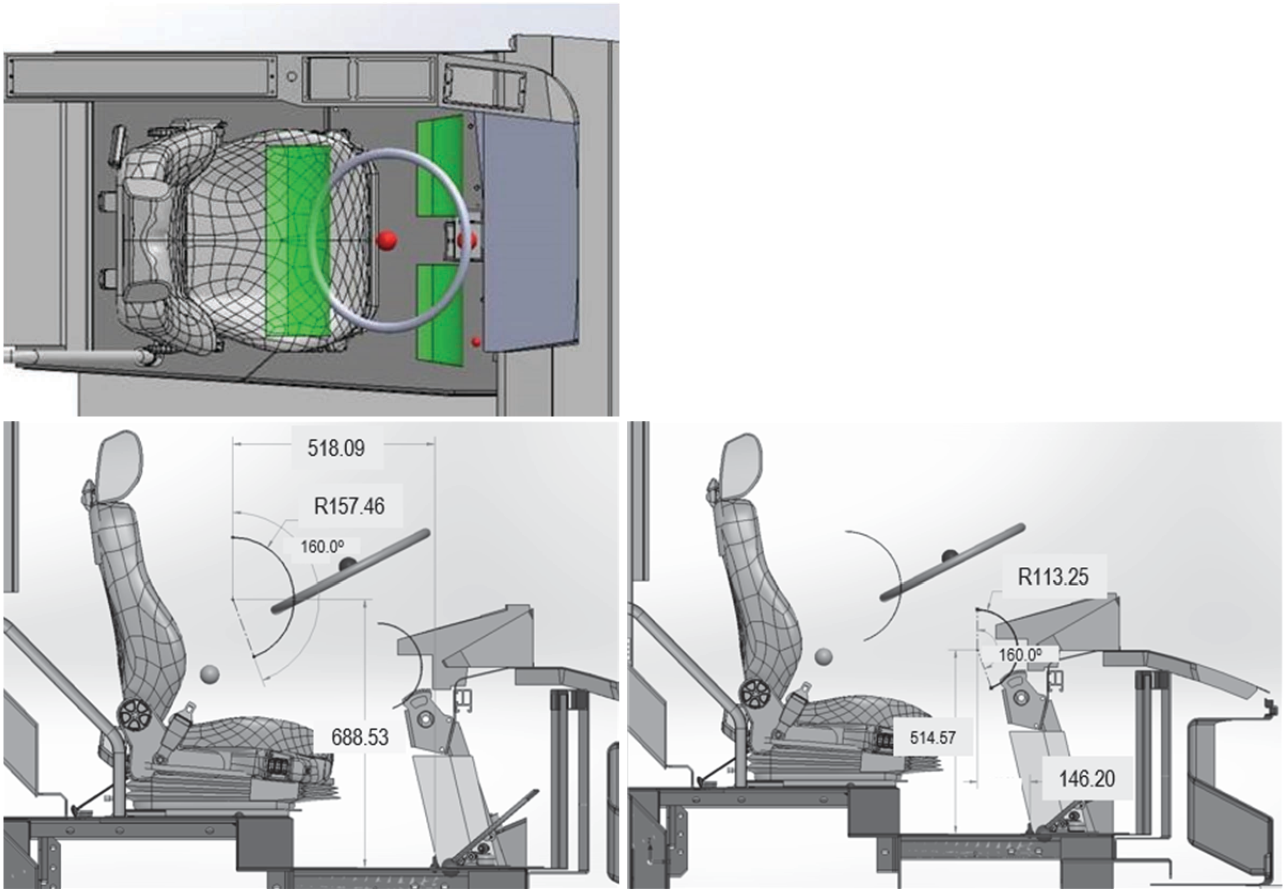

Figure B-9. Shin/knee contours and stomach contours referenced from the AHP. Contours pictured with steering wheel at mid-range adjustment and seat at supplier-provided position. Left-upper image is a top view of all contours. Left-lower image is a right-side view of the construction of the stomach contour. Right-lower image is a right-side view of the construction of the knee/shin contours.

The stomach clearance contour was built according to SAE J1522 in a very similar fashion to the shin and knee contours. A 50:50 male-to-female gender ratio was selected and the ATRP Z-value was inserted into equations 1 and 2 to obtain the delta X and Z contour reference values from the ATRP (dX = 59.9 mm forward, dZ = 193.5 mm up). The contour reference was positioned at the operator centerline. A constant-radius arc of 157.46 mm was drawn at the operator centerline from the contour reference as directed in SAE J1521.

Again, the RP does not specify the width or arc-length. The clearance contour was extended from the operator centerline both left and right to match the width of a 95th percentile Male Abdominal Breadth, Sitting dimension (471 mm) as defined by the NIOSH survey. Again an arbitrary arc-length was selected to extend from directly above the contour reference forward and around 160^{o}. See Figure B-9 for top and right-side views of the stomach contour.

The 3-D eyellipses were constructed according to the process specified for Class B vehicles in SAE J941, Appendix E. The size of the two identical eyellipses was constructed with axes defined by a 95th percentile eyellipse and Seat Track Travel (TL23) greater than 133 mm. Each eyellipse had a centroid represented by a sphere at its axes' centers. The two eyellipse centroids were separated by ±32.5 mm around the operator centerline such that the centroids were separated by 65 mm. The mid-point of the two eyellipse centroids is referred to as the mid-eye centroid, which simply represents a geometric reference between a user's eyes—literally on the user's bridge of the nose.

The position of the mid-eye centroid was determined by applying the 50:50 gender ratio equations E1 (ATRP X-value rearward of AHP) and E2 (ATRP Z-value above AHP) in SAE J941, Appendix E. Additionally the process requires selection of a seat or manikin torso angle rearward of vertical (A40). The research team selected 10^{o} for this value. This design value was obtained from the same example of a current production seat and transit bus described for determining the operator package references of the ATRP and AHP. The mid-eye centroid was aligned with the operator centerline. The eyellipses were also rotated 11.6° below horizontal and around the cross-bus axis (Y-axis). The resulting eyellipses are available to review in Figure B-10.

Eyellipse Construction Specifications

Axis Lengths:

- ΔX = 198.9 mm
- ΔY = 105.0 mm
- ΔZ = 86.0 mm

Mid-Eye Centroid w.r.t. AHP

- ΔX = 529.5 mm
- ΔY = 249.7 mm
- ΔZ = 1150.4 mm
- Side-View Tilt around Y-axis: 11.6° below horizontal

It is worth noting that the process for Class B vehicles in SAE J941, Appendix E, calls for a second rotation of 5.4^{o} to the right of operator centerline in top view or toward the passenger-entry area of the bus. However, the researchers chose not to apply this rotation. This rotation has been removed from the current SAE Class A (auto) eyellipse development processes as they have been demonstrated to provide little utility in visibility analyses (SAE J941 2010; Manary et al. 1998). The same conclusion has been supported in similar exercises that are in progress to update the SAE Class B eyellipses (Reed 2005). However, it has not been removed from the current version of the Class B eyellipse process (SAE J941, Appendix E, 2010).

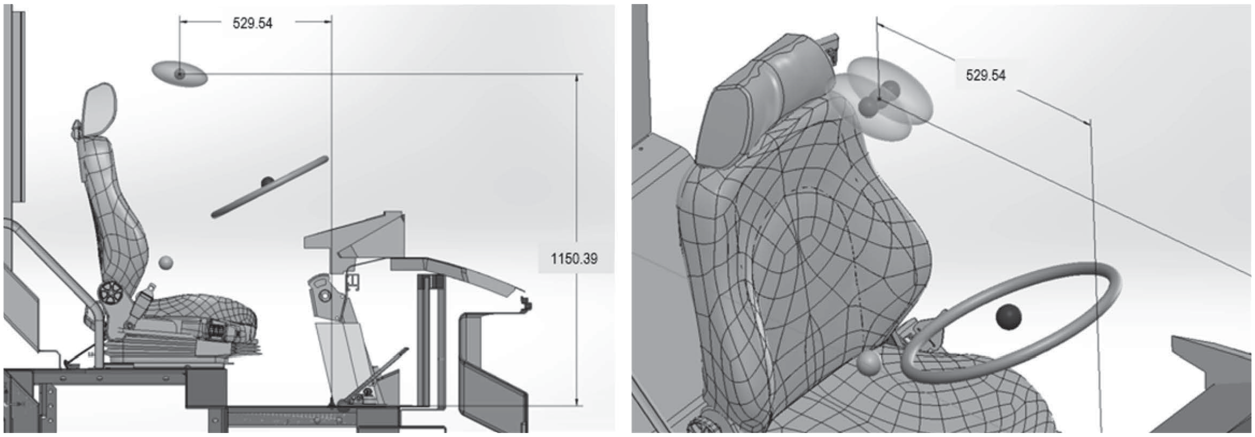

Figure B-10. Eyellipses in 3-D form as developed by SAE J941, Appendix E. Mid-eye centroid dimensions are relative to the AHP.

The eyellipse envelopes can be useful for many visibility analyses. The most pertinent application for a transit bus is the demonstration of the upward and downward forward-visibility tangent 2-D curves or 3-D sheet bodies. The result of the CAD guidance eyellipses in the suggested package demonstrates that the APTA downward visibility target should be visible to most operators. Likewise, the APTA upward visibility minimum angle of 15^{o} above horizontal passes easily under the top edge of the windshield opening (see Figure B-11).

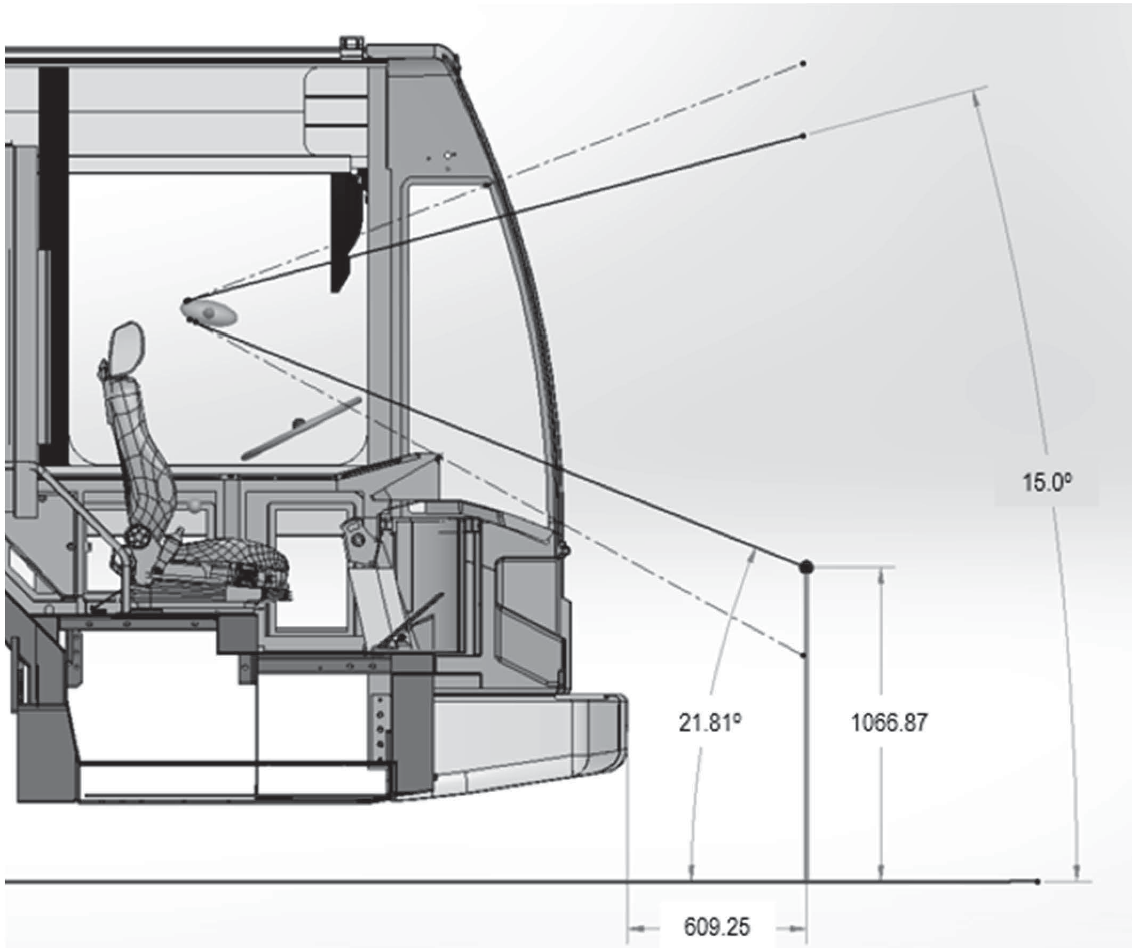

Figure B-11. The visibility sheets extend between the eyellipse tangents and down to the APTA visibility target or up to the APTA visibility angle above horizontal. The dotted lines demonstrate a current production example of visibility performance that meets and exceeds both requirements.

Application of Other Bus Operator Packaging Processes

A guideline for in-vehicle display systems was developed by the Japan Automobile Manufacturers Association (JAMA 2004). One feature of this guideline is a requirement for the maximum downward viewing angle for vehicle displays. This requirement states that at least half of each display must be visible at or above the angle prescribed in the guideline. This lower limit is described for most automotive vehicles as being 30° below horizontal. However, the guideline also provides the following formula to increase the inclination of the viewing limit according to eye point height when the reference eye point is above 1,700 mm from the ground.

$$\text{Inclination [deg]} = 0.013 \times \text{eye point from ground [mm]} + 15$$

The eye point being described in the formula is referred to as the Japanese Industrial Standard (JIS) eye point, which can be determined by constant offset dimensions from the SAE eyellipse mid-eye centroid as follows (Driver Focus–Telematics Working Group [2006]):

- SAE Eyellipse to JIS Eye Point Constant
- ΔX = 22.9 mm rearward
- ΔZ = 8.4 mm up

This JIS eye point was determined to be located at the following dimensions:

- Xc: 1162.5 mm
- Yc: 750.2 mm
- Zc: 1158.7 mm

The height of this point is determined by adding the height above the AHP and the AHP to ground delta. The resulting height of the JIS was equal to 1,937.3 mm above ground. The resulting angle for the suggested workstation was 40.3° below horizontal. The resulting display downward viewing limit is demonstrated in Figure B-12, which falls approximately on the mid-length of the center gauge panel display in the model.

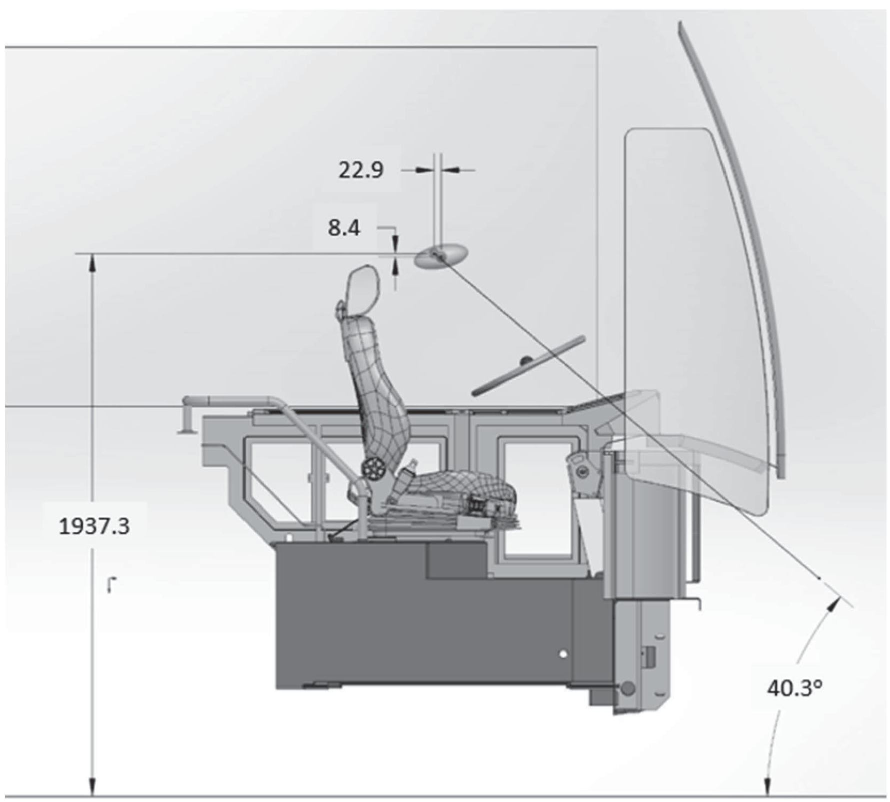

Figure B-12. The JAMA downward display visibility limit starts at the JIS point and runs along the JAMA-calculated angle below horizontal. The JIS point to mid-eye centroid dimensions and display angle (40.3°) are illustrated.

Another useful envelope is suggested by the APTA guideline regarding front and side sun visors/shades. The guideline suggests that "the visor when deployed, shall be effective in the operator's field of view angles more than 5° above the horizontal." The guideline also states that the "deployment of the visor shall not restrict vision of the rearview mirrors." This requirement would create a conflict were it not for the recent addition in the 2013 version of the guideline allowing for the alternative of roller type sunscreens. That alternative makes no mention of the coverage of view angles. Therefore, the Engineering CAD Model will include optional sun visor 5° upward view angle sheet bodies that run tangent from the eyellipses forward through the windshield and sideways through the operator-side glass. These sheet bodies can provide a useful reference for the development of sun visors or sunscreens while highlighting the balance that must be struck with top-mounted rearview mirrors as demonstrated in Figure B-13.

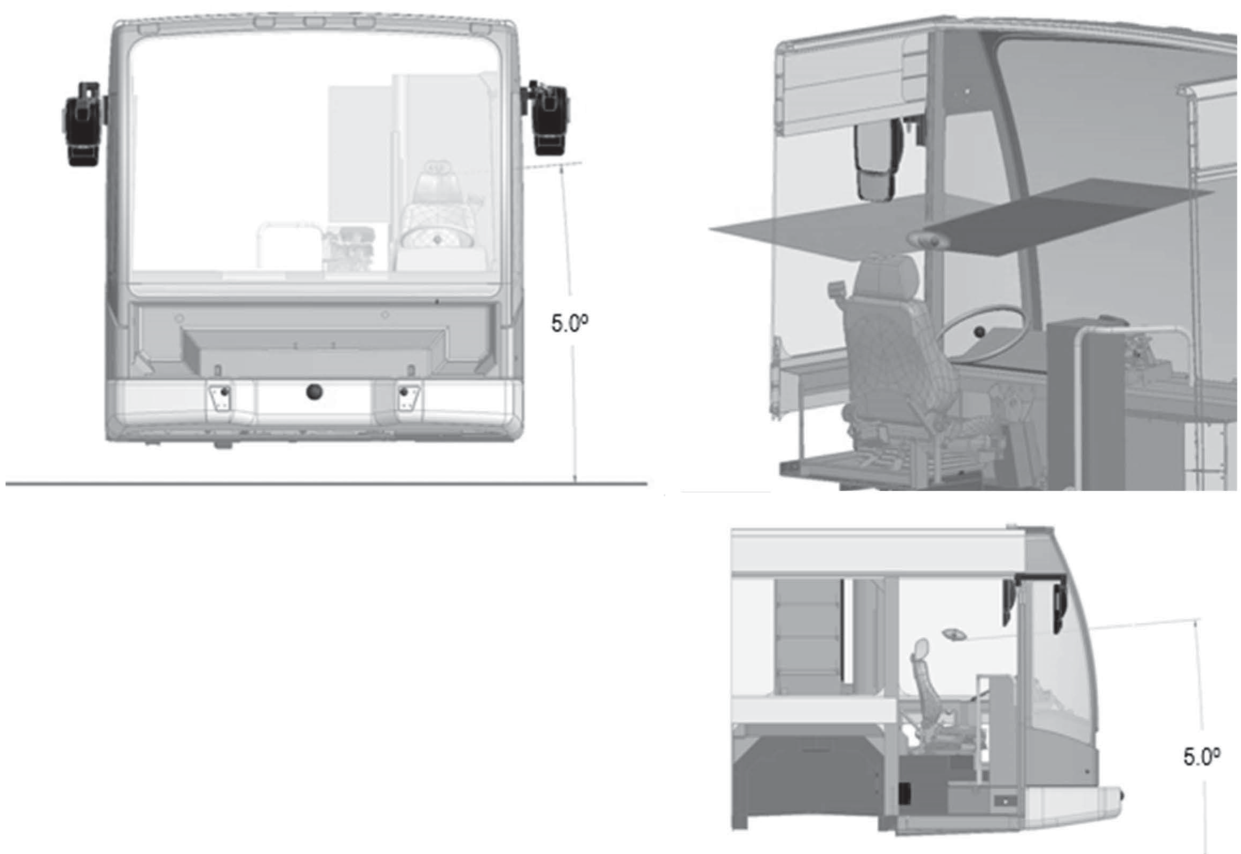

Figure B-13. These forward and operator-side glass sheet bodies demonstrate the APTA minimum requirement for sun shade/visor performance, 5° above horizontal.

An envelope was developed for the Engineering CAD Model and is demonstrated in Figure B-14. This envelope was developed using the human modeling software. Reach surfaces were developed for all six manikins that will be discussed in the section on digital human modeling validation (see Chapter 5 – Human Modeling Validation of Bus Operator Workstation Design Guidelines). The reach surfaces were constructed referencing the clavicle to index fingertip for each arm, left and right.

The result of these six surface section curves at Zc: 600 is visible in Figure B-15. The final reach curve was selected by comparing the six manikins based on their varying seat positions and arm reach distances. The reach curve for manikin Female U was the worst-case forward reach. Based on that result an additional reach envelope was developed for the same manikin from the clavicle to hand grasp (see Figure B-16). The worst-case forward reach was selected as the primary control reach curve along with the maximum reach curve for controls requiring the whole hand grasp, as demonstrated in Figure B-17. Both were applied in the Engineering CAD Model.

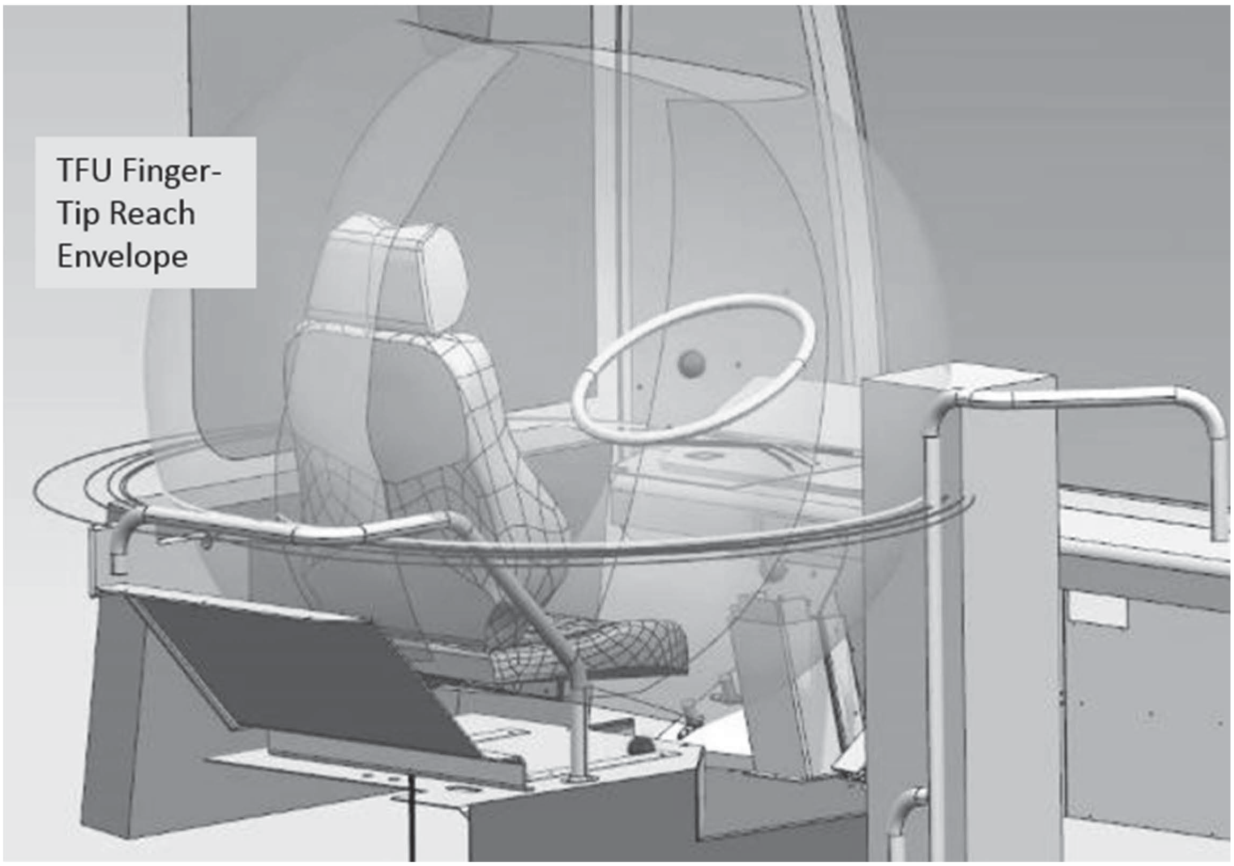

Figure B-14. The reach surface envelope developed from manikin Female U represents maximum reach rotating from clavicle and extends to the index fingertip for left and right arms.

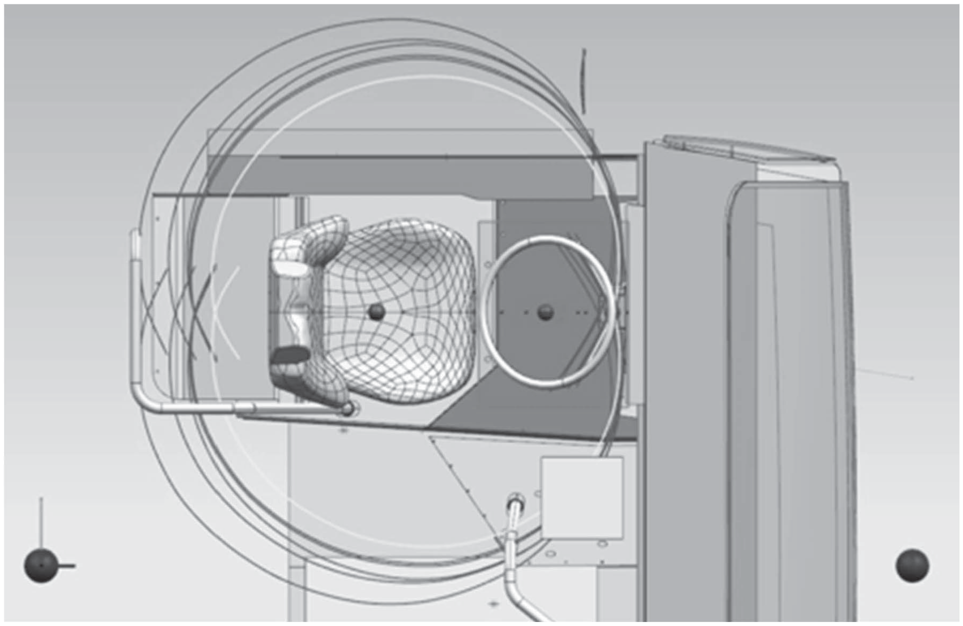

Figure B-15. All manikin reach surfaces were sectioned on the surface at Zc: 600 and compared.

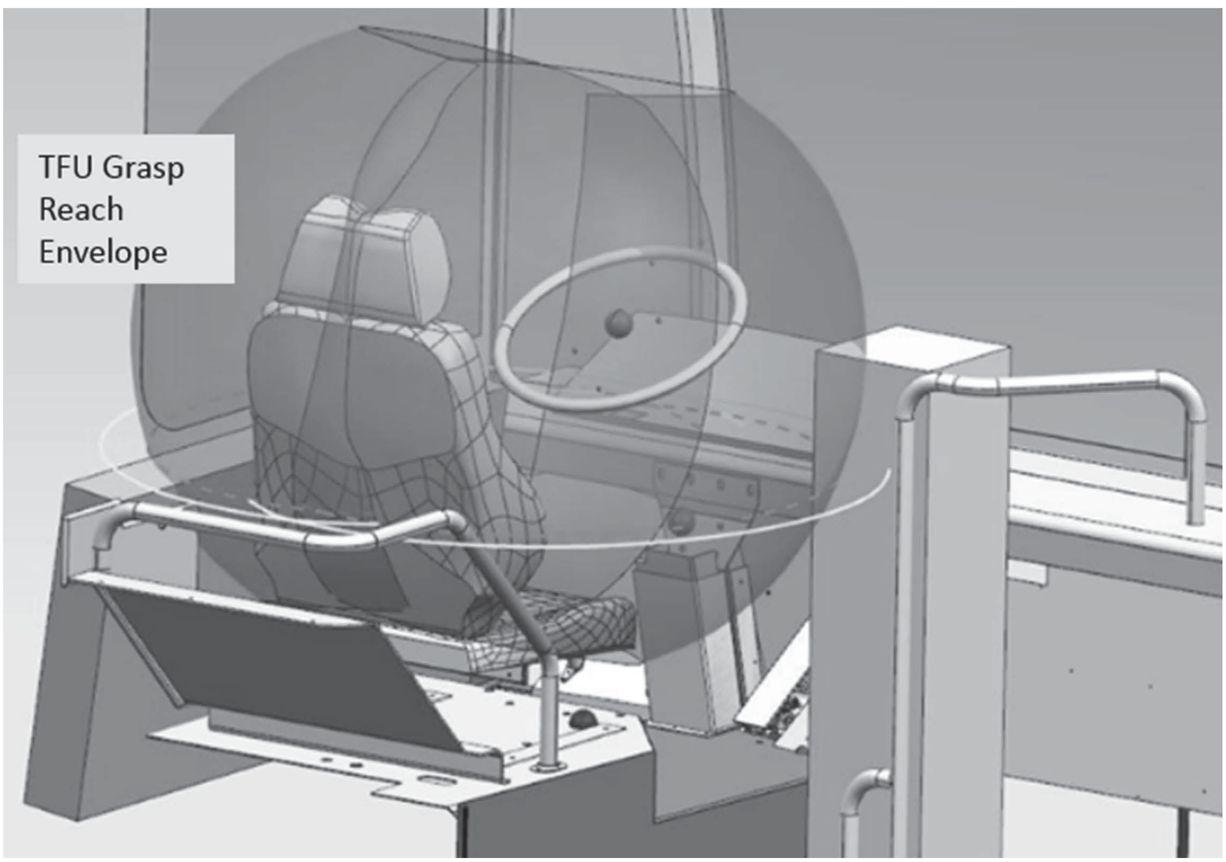

Figure B-16. The reach surface envelope developed from manikin Female U represents maximum reach rotating from clavicle and extends to hand grasp for left and right arms.

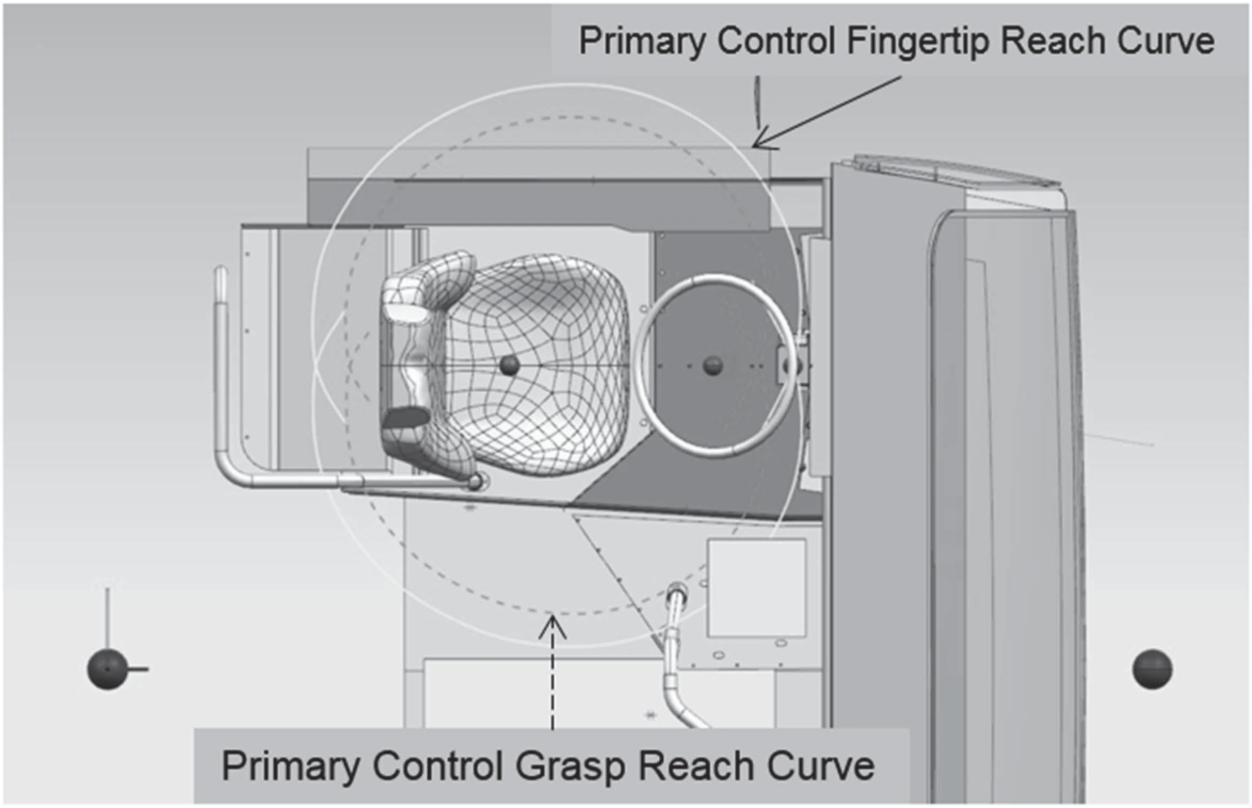

Figure B-17. The reach curve section on the surface at Zc: 600 for manikin Female U. The solid curve provides the maximum reach for primary controls that are required for safe operation of the vehicle in motion. Hand grasp controls should be kept within the dotted curve.

Clearance envelopes are necessary around the bus operator's pedals to provide unrestricted access to move the shoe and foot up and down on the accelerator pedal, transition to the brake pedal, and activate the brake smoothly without interruption. The ISO 16121-1 guideline provides a requirement that has been included in these guidelines. The right foot well envelope requires clearance across the accelerator and brake pedals with additional clearance on both sides. Per the ISO requirement, the foot well envelope provides at least 350 mm forward of the AHP (see Figure B-18).

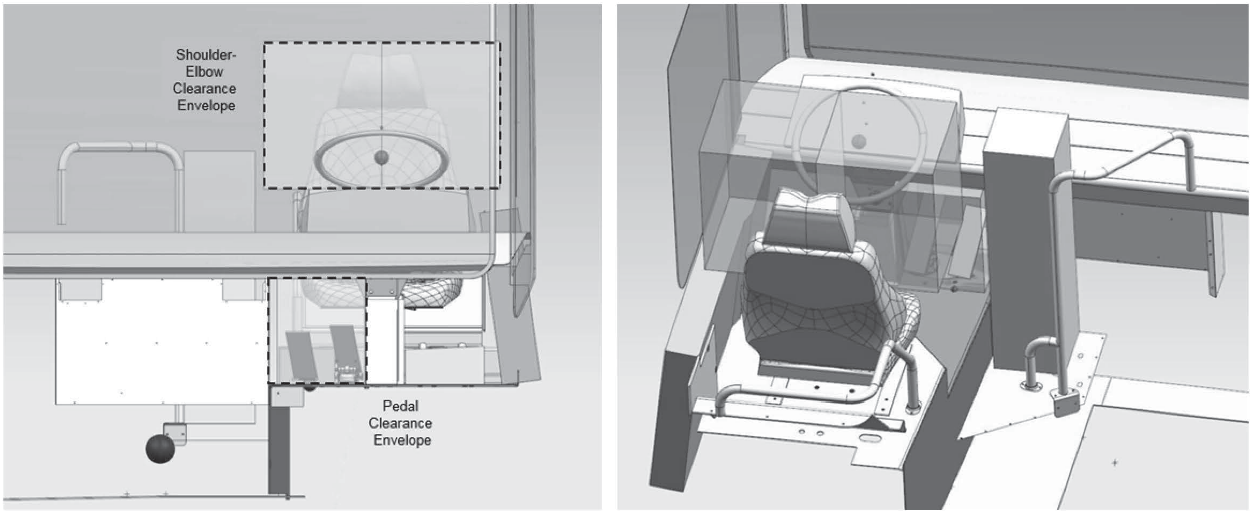

Figure B-18. Bus operator clearance envelopes for pedal and shoulder-elbow clearance per ISO 16121-1:2012. The left image provides a forward view of the front of the bus operator workstation. The right image provides a rear-isometric view of the same envelopes.

Clearance envelopes are also necessary for bus operators around their shoulders and elbows to provide sufficient clearance to rotate the steering wheel, reach for controls on the instrument panels, and turn within the seat when viewing the road environment. ISO 16121-1 also provides a requirement for this clearance that has been included in these guidelines. A rectangular envelope is centered around the bus operator seat, requiring a minimum of 400 mm on each side and a total clearance of 800 mm, as demonstrated in Figure B-18.

Clearance around the steering wheel to all surrounding controls and the instrument panel is important for bus operators to provide smooth control of the bus while turning. This clearance should be provided in all steering wheel tilt and telescope adjustment positions. A minimum hand clearance of 38 mm has been constructed for this guideline based on typical hand with glove clearances required for manual labor and around vehicle access grab handles. An image of this clearance is provided in Figure B-19.

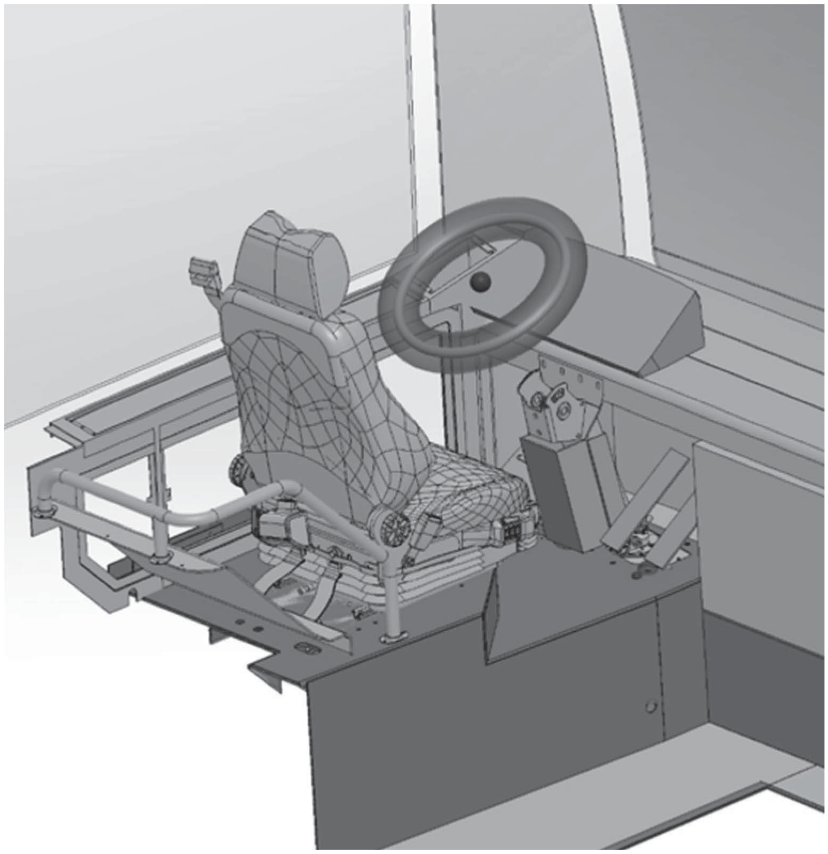

Figure B-19. Steering wheel hand clearance.

Bus Operator Workstation Suggested Access Envelopes

There are multiple elements that affect workstation access. One that is commonly provided for in at least the two physical transit buses that were benchmarked is a steering wheel tilt that is forward of vertical. This can increase the access clearance between the seat and steering wheel or seat floor and column. While this position is not practical for normal vehicle operations, it is a useful setting that has been maintained in the Engineering CAD Model. This position was set with the telescope at full up (+55 mm from mid-position) and the tilt at 5° forward of vertical as illustrated in Figure B-20.

Although this concept of forward-of-vertical steering column tilt is not a novel one for transit buses today, the new steering wheel adjustment range that has been suggested may make this access position difficult to produce. One solution might be to provide a separate pivot point and quick-release lever on the column that would allow the operator to quickly move the steering wheel out of a normal driving position and then return it to a preferred position easily upon return.

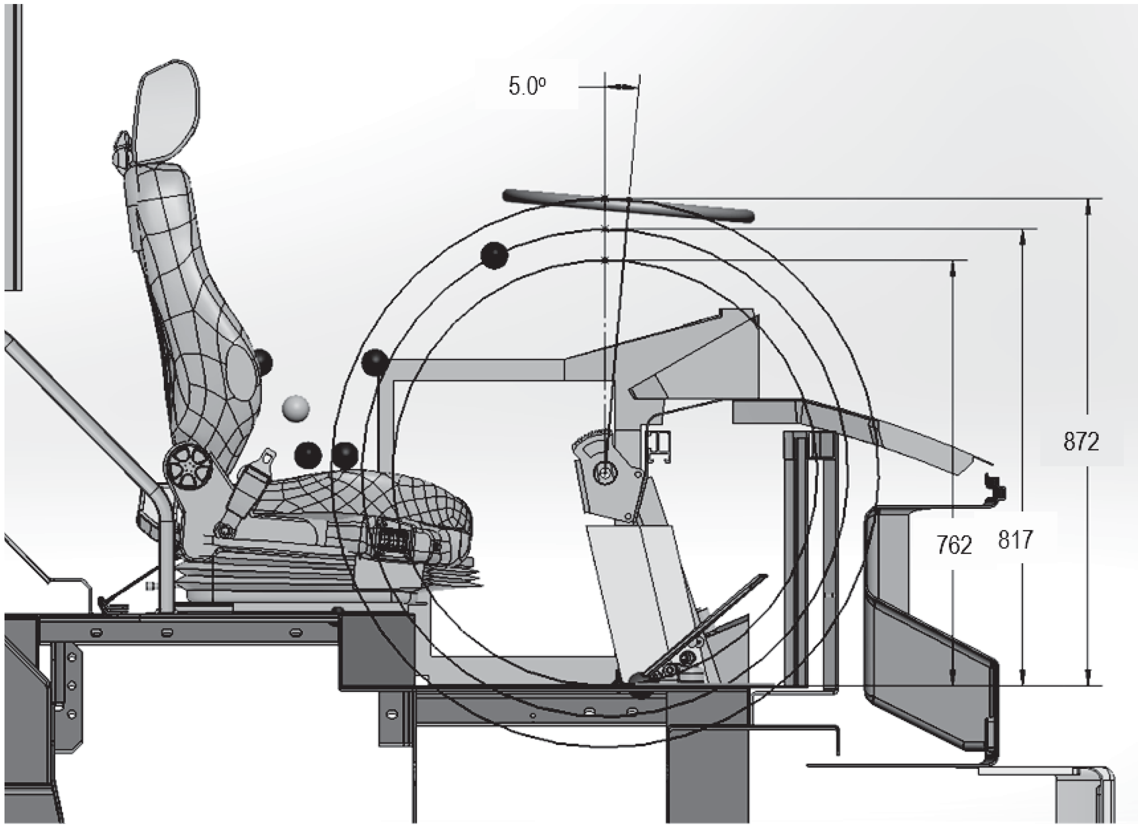

Figure B-20. An additional steering wheel position which tilts forward of vertical 5° with telescope at full upward extension is demonstrated to increase operator access into and out of the workstation area.

The step heights are another important element of operator workstation access. The floor height provided by the partnering manufacturer was used as an example in the model of how a balanced step height is suggested. The dimensions of that height from passenger floor to step and step to pedal floor may vary with other pedal floor heights. The guideline update provides maximum floor and step height dimensions.

The APTA guideline lists dimensions for the operator-side glass to protect the operator's direct line-of-sight view. These dimensions also provide a useful reference for an emergency access hatch for the operator. This might become more critical in the future as thermal or security enclosures are added around the operator workstation. Figure B-21 illustrates the APTA forward (840 mm rear of AHP) and upward (560 mm above AHP) limits for the glass. The SAE RP for access systems, SAE J185, suggests a minimum rectangular opening (470 × 650 mm) for this emergency access. This solution could be applied to the window opening within the operator's sliding side-glass feature.

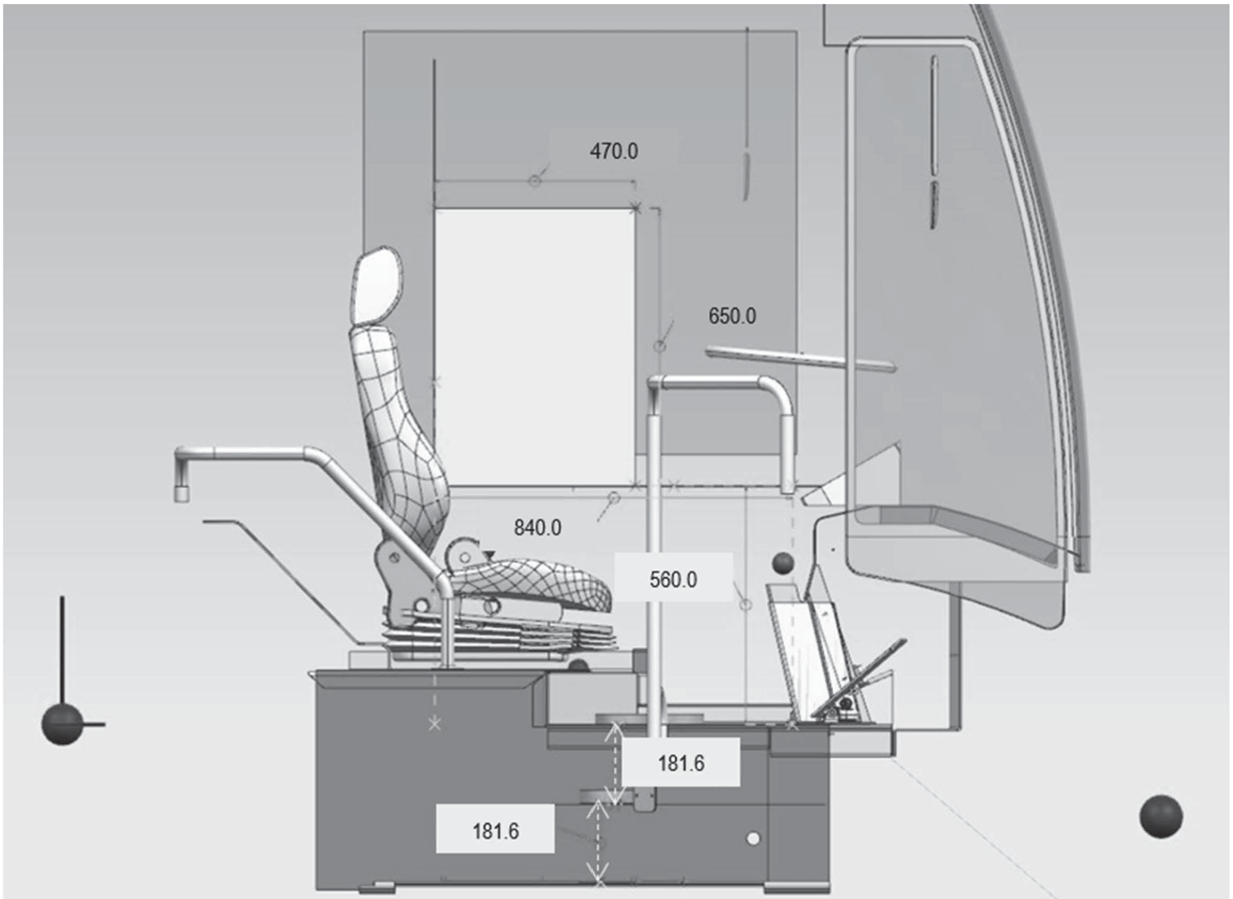

Figure B-21. Balanced step heights and optional consideration of emergency access hatch (SAE J185) through operator-side glass. The emergency access hatch has been positioned along the APTA operator-side glass rearward and upward guideline dimensions.

As mentioned above, an element that may find more common application in the future is a thermal and security enclosure. An access door object was developed in the Engineering CAD Model to support the installation of such an enclosure (see Figure B-22). The height and width dimensions were set according to SAE J185. The width was set at 680 mm, and the height was set to approximately 1,981 mm, which is greater than that suggested by the J185.

The taller height was a combination of the SAE J185 preferred clearance of 1,800 mm plus the 181 mm step height in the model. This consideration should provide for the increased headroom needed for operators when accessing the workstation through such an enclosure door. This clearance should account for the needs of tall females and males even when combined with taller steps, as evidenced by the NIOSH survey value for a 95th percentile Male Stature (with shoes): 1,900 mm.

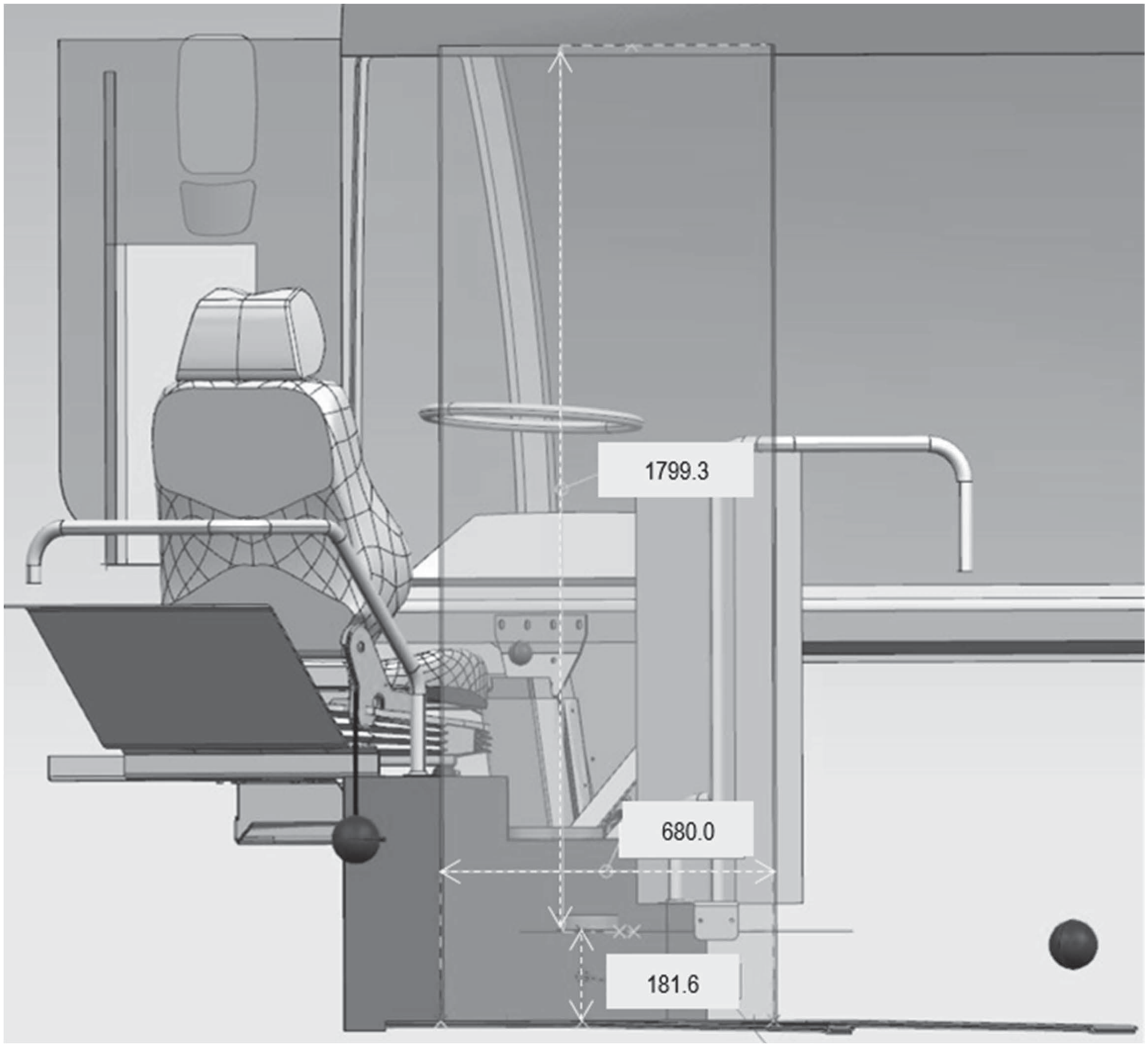

Figure B-22. A minimum door access opening (SAE J185) was constructed for optional consideration of workstation enclosure with thermal/security barrier. The door height was extended above the minimum criteria listed in SAE J185 for consideration of the step, which is 181 mm above the passenger floor.

The top view image shown in Figure B-23 clearly shows the need for stepping clearance on the step itself and the pedal floor. One 127 mm disc was located on the lower step as a minimum requirement. Two 127 mm discs were located on the pedal floor and against the side wall of the seat-mounting floor. Other clearances were referenced in this example to highlight the clearance path that operators must pass through in order to be seated, including seat backrest to 457 mm steering wheel at access position, grab handle to grab handle, and fare box to seat backrest-side bolster. The seat was positioned at full rearward among the suggested horizontal travel range. The passenger/operator grab handles provided in the image will not be distributed with the Engineering CAD Model since these specifications were provided by the bus manufacturing partner.

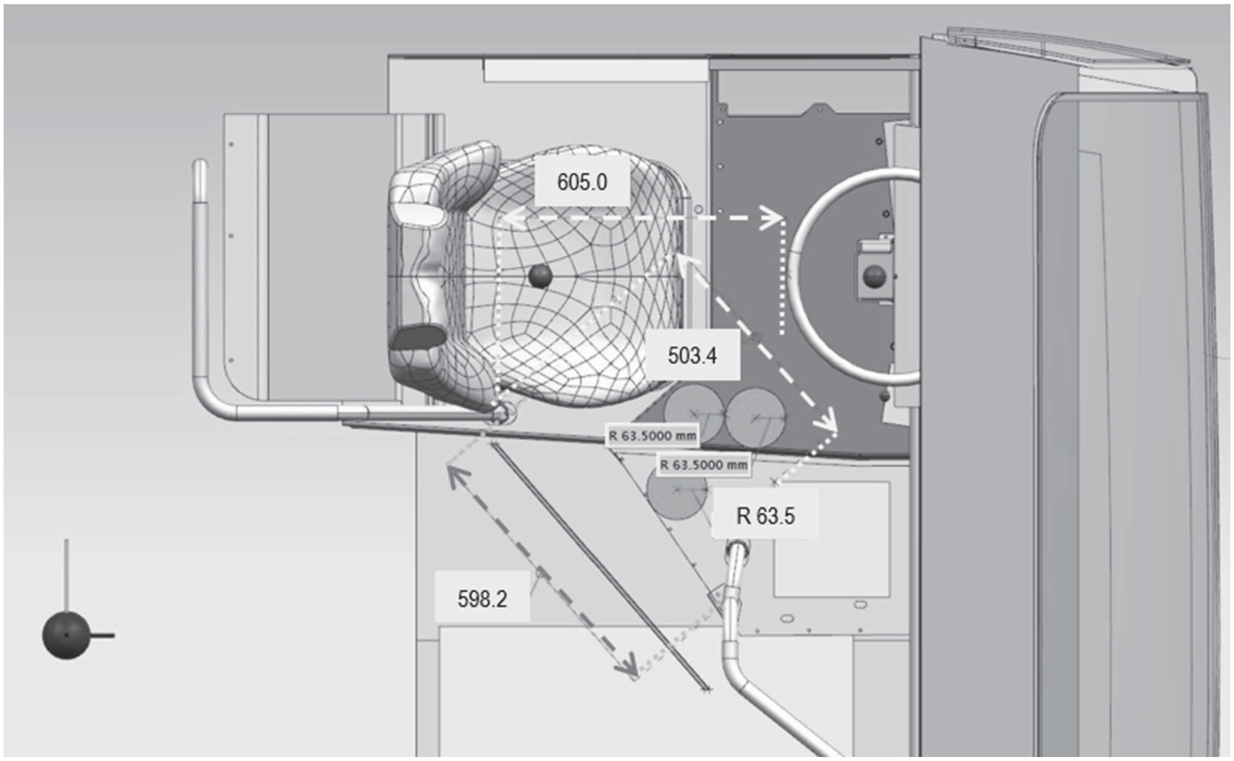

Figure B-23. Minimum step size (127 mm) discs (lower step – single, upper step/floor – double) are demonstrated. In addition, example dimensions of a current production bus operator workstation highlight the available clearances when combined with the suggested rearward seat position and the suggested operator-access steering wheel position.

APPENDIX C

Construction of Multivariate Manikins in Human Modeling Software

Introduction

The following information is provided in order to demonstrate the steps and specifications that were applied when developing manikins representative of a North American commercial vehicle operator population for human modeling validation of the Engineering CAD Model.

Manikin Development Role Definition

The body dimensions shown in Table C-1 are structured to be in order of priority from primary to secondary to tertiary. The priority also provides the procedure that other research or industry practitioners might use to replicate these manikins in a human modeling software. Prior to editing specific manikin dimensions at these three levels, the role and the anthropometric population were selected (see Figure C-1). The role was created to carry the "Heavy Truck XXL" posture model, which was developed between the human modeling software developer and a major European truck and bus vehicle manufacturer. The "Kapandji" range of motion was applied to the manikins' biomechanical limits. The population was created to apply the NIOSH survey data, so-named "Truck Driver (USA)," with the age group set to 18–65 (default) and in the current reference year, 2014.

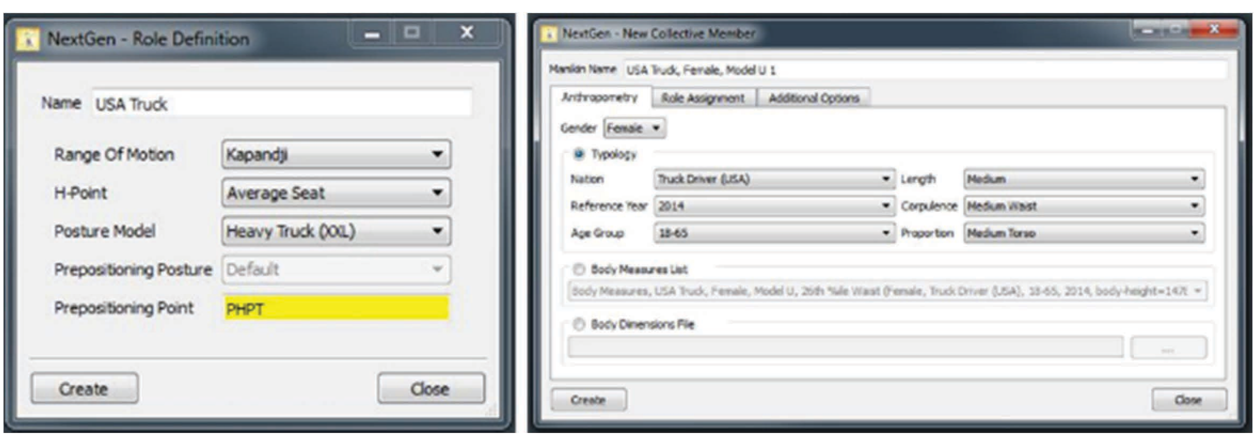

Figure C-1. Manikin sample vehicle packaging role and anthropometry population interfaces.

Manikin Development Primary Dimensions

Next the length, corpulence, and torso proportion dimensions for each manikin were set to match the values of the NIOSH model (e.g., Female U, see Figure C-2). The corpulence (waist circumference) was not provided in the NIOSH survey report. Therefore, this dimension had to be determined by iteration either until the tertiary "abdominal depth" manual dimension matched the NIOSH model or until it was within an allowable error tolerance, which has been discussed in more detail in Chapter 5 in the section regarding manikin modeling deviations.

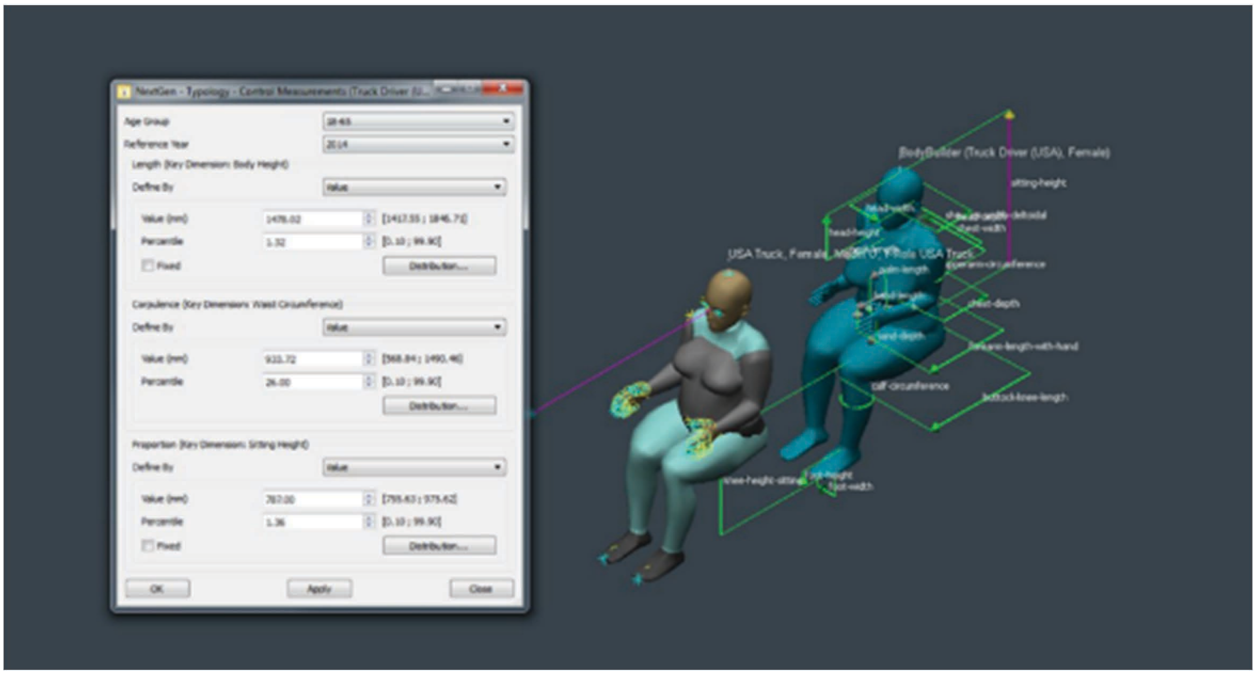

Figure C-2. Manikin body builder, primary "control" dimensional interface, Female U.

Manikin Development Secondary Dimensions

The interdependent secondary dimensions were set using the interface displayed in Figure C-3. The same process applied to the corpulence was also applied with manual measures of NIOSH "acromial height, sitting" and "eye height, sitting" in the human modeling software between iterations of the primary dimensions of "length (body height)" and "torso proportion (sitting height)." See Figure C-4 for an example of the manual measurement process on a manikin.

For reference, Table C-2 reproduces data excerpted from Table 2.5, anthropometric variable hierarchy and data—linear dimensions, in the TCRP Project F-4 Final Report that accompanied *TCRP Report 25*.

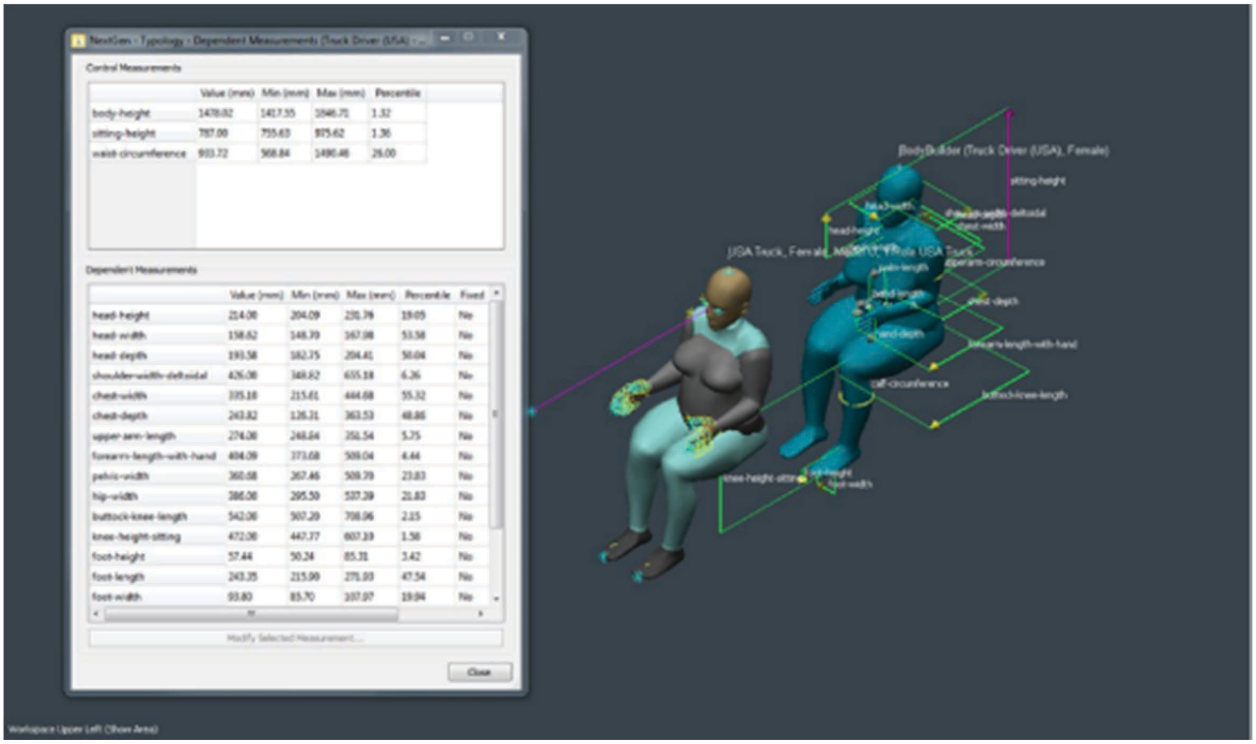

Figure C-3. Manikin body builder, secondary "dependent" dimensional interface, Female U.

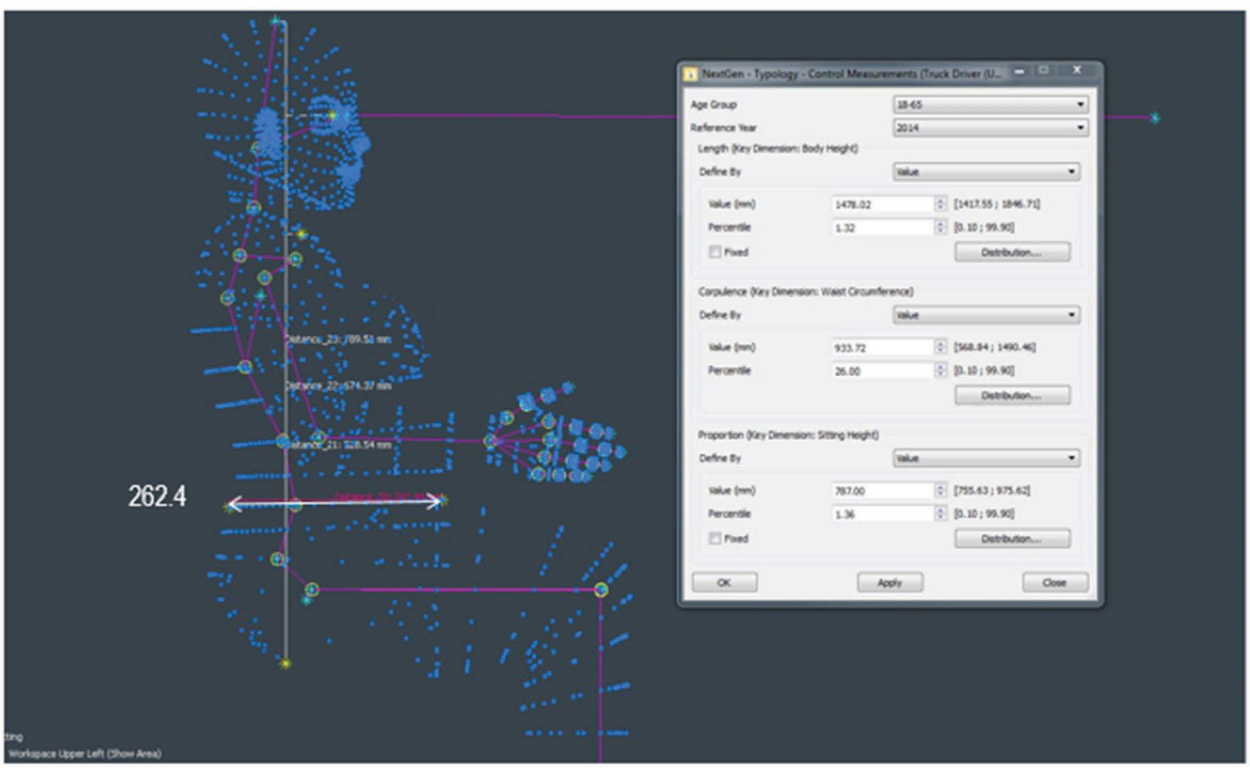

Figure C-4. Example of tertiary measurement iteration with primary dimensions, Female U.

Table C-1. Operator Cadre, Simulation Manikin Construction Dimensions (mm) versus NIOSH Survey Models

Variable Type	Source	Body Dimension (mm)	Allowable Error (mm)	Female (Stature/Waist %tile)			Male (Stature/Waist %tile)		
				1st / 26th	47th / 69th	98th / 95th	1st / 13th	42nd / 57th	97th / 96th
				Model U	Model O	Model V	Model U	Model O	Model V
Primary Independent	RAMSIS	Length (Body Height)	4	1478	1627	1776	1617	1756	1906
	NIOSH	Stature, No Shoes		1482	1627	1772	1617	1756	1906
	RAMSIS	Corpulence (Waist Circumf.)	11	934	1104	1275	928	1133	1379
	NIOSH	(Iterated through Abdominal Depth)		na	na	na	na	na	na
	RAMSIS	Torso Proportion (Sitting Height)	5	787	864	942	850	918	996
	NIOSH	Sitting Height		791	864	937	850	918	991
Secondary Dimensional Interdependent	RAMSIS	Upper-Arm Length	7	274	300	325	300	325	353
	NIOSH	Shoulder-Elbow Length		304	333	361	333	361	392
	NIOSH	† Shoulder-Elbow Length ∗ 90%		274	300	325	300	325	353
	RAMSIS	Forearm Length with Hand	6	404	440	476	448	486	527
	NIOSH	Elbow-Fingertip Length		403	440	477	448	486	528
	RAMSIS	Buttock-Knee Length	10	542	606	669	567	631	701
	NIOSH	Buttock-Knee Length		542	606	669	567	631	701
	RAMSIS	Knee Height, Sitting	8	472	526	580	513	568	629
	NIOSH	Knee Height, Sitting		472	526	580	513	568	629
	RAMSIS	Hip Width	8	386	460	534	360	425	502
	NIOSH	Hip Breadth, Sitting		386	460	534	360	425	502
	RAMSIS	Shoulder Width Deltoidal	1	426	499	572	468	535	612
	NIOSH	Bideltoid Breadth		426	499	572	468	535	612

† Simulation Upper-Arm Length measurement adjustment.

(*continued on next page*)

‡ Manikin dimension exceeds the model's sample measurement allowable error.

Table C-1 (Continued).

Variable Type	Source	Body Dimension (mm)	Allowable Error (mm)	Female (Stature/Waist %tile)			Male (Stature/Waist %tile)		
				1st / 26th	47th / 69th	98th / 95th	1st / 13th	42nd / 57th	97th / 96th
				Model U	Model O	Model V	Model U	Model O	Model V
Tertiary Resultant	RAMSIS	Manual Dimension	11	262	325	389	252	327	418
	NIOSH	Abdominal Depth (Nominal Manikin Skin Reference)		262	325	389	252	324	417
	RAMSIS	Manual Dimension	9	‡ **529**	578	634	‡ **569**	616	‡ **666**
	NIOSH	Acromial Height, Sitting (Nominal Manikin Skin Reference)		517	580	642	554	614	680
	RAMSIS	Manual Dimension	7	674	748	827	729	797	873
	NIOSH	Eye Height, Sitting (Nominal Manikin Skin Reference)		681	753	825	736	798	866

† Simulation Upper-Arm Length measurement adjustment.

‡ Manikin dimension exceeds the model's sample measurement allowable error.

Table C-2. Excerpt from TCRP Project F-4 (unpublished Final Report), Table 2.5: Anthropometric variable hierarchy and data—linear dimensions.

Anthropometric Variable			Code	Anthropometric Data (unit: cm or kg)		
1st Level	2nd Level	3rd Level		5th Percentile Female (cm)	50th Percentile (Person) (cm)	95th Percentile Male (cm)
Head	Depth	eye to body center line	HL1	7.6	8.1	8.6
	Length	top-of-head to eye	HL2	10.2	11.0	11.5
		eye to cervical pivot	HL3	11.1	11.2	11.3
Neck	Length	cervical pivot to shoulder pivot	HL4	11.7	13.5	15.3
Torso	Width	shoulder pivot width	HL5	29.2	33.4	37.6
		abdominal width (sitting)	HL6	17.5	24.7	31.8
	Depth	abdominal depth (sitting)	HL7	14.0	19.6	25.1
	Length	shoulder pivot to hip pivot	HL8	40.4	44.2	48.0
Pelvis	Width	hip pivot width (standing)	HL9	16.8	17.7	18.6
		hip width (sitting)	HL10	32.5	36.0	39.5
	Length	vertical length from hip pivot to SRP (sitting)	HL11	6.4	8.0	9.6
		horizontal length from hip pivot to SRP (sitting)	HL12	11.6	12.8	14.0
Upper Leg	Thickness	thigh thickness (sitting)	HL13	13.5	15.8	18.0
	Length	femoral link	HL14	36.2	40.7	45.2
Lower Leg	Length	shank link	HL15	35.1	39.8	44.5
Foot with Shoes	Width	shoe width	HL16	9.0	10.3	11.6
	Length	ankle pivot height from floor with shoes	HL17	10.3	11.1	11.9
		horizontal length from heel point to ankle joint	HL18	6.8	7.8	8.7
		horizontal length from ankle pivot to ball-of-foot	HL19	9.2	10.2	11.3
		shoe length	HL20	25.0	28.5	32.0
Upper Arm	Length	humeral link	HL21	25.0	27.5	30.0
Lower Arm	Length	forearm link	HL22	22.1	24.4	26.7
Hand	Length	wrist to hand-grip	HL23	6.9	7.5	8.1
		wrist to finger-grip	HL24	10.5	11.5	12.5
		hand length	HL25	16.5	18.5	20.5
	Diameter	Grip diameter (inside)	HL26	4.1	4.7	5.3
Stature with shoes (cm)			-	155.0	171.5	188.0
Body weight (kg)			-	48.0	73.0	98.0

Sources: Diffrient et al. (1981), Kroemer et al. (1994), SAE Handbook (1990), Sanders and McCormick (1994), Woodson (1981).

Annex to Appendices

This annex to the appendices summarizes key information provided in Appendices D, E, and F, which address the research methodology for TCRP Project C-22. The summary of Appendix D explains the interview and survey process that led to the suggested steps for bus operator workstation procurement and for training (described in Chapters 2 and 3) and lists the survey questions. The summary of Appendix E lists the questions posed in telephone interviews to industry experts. The summary of Appendix F gives a brief overview of the transit agencies interviewed for the research. The complete, unedited content of Appendices D, E, and F may be accessed from the TCRP Project C-22 webpage.

Summary of Appendix D: Transit Agency Procurement and Bus Operator Workstation Considerations: Research Methods and Results

Sampling

The research sample was designed to recruit input from transit agencies, ranging in size and geographic location, that addressed bus operator workstation health and safety in their procurement activities. The research target was to complete interviews with staff at ten transit agencies and at least five union representatives at the participating agencies. Initial contacts consisted of the transit agency members of the APTA Bus Safety Committee and three additional transit agencies that had been identified by industry experts as potential sources for good practice but which were not on the committee. Industry experts were identified from the research literature and via recommendations by other specialists in the field. Three international unions were asked to distribute a survey to their selection of local union affiliates. Based on the researchers' experience with union surveys, 25 responses were expected.

Recruitment

A total of 56 transit agencies were asked by email to describe their procurement practices in telephone interviews. Email or telephone contacts were made with twelve industry experts: three in bus cab ergonomics and manufacturing, two in transit procurement policy and practice, and seven in ergonomics and occupational health research. Some of these were made on referral by the initial targets.

The survey was distributed to local union representatives by an international union representing bus operators in the United States and Canada, and returned directly to the research team. One international union did not respond to the researchers' request to participate, and one was not able to distribute the survey. Email invitations to participate in a follow-up interview were sent directly to 13 local union presidents, who had either asked to be contacted on the union surveys or whose members worked at one of the interviewed transit agencies.

Data Collection and Processing

All interviews were carried out between February and May of 2015. Each transit agency telephone interview was based on a set of 14 questions. The industry experts were asked six questions. Interviews typically took between 45 and 90 minutes and were recorded using MP3 Skype Recorder software with the permission of the respondents. When recording was not possible for technical or time reasons, the interviewer made extensive manual notes during the interview using the questionnaire template. Interview data were transcribed and edited for clarity, and the content was coded using MaxQDA qualitative analysis software. Union survey data were entered into Microsoft Excel, cleaned, and tabulated.

Responses

Management representatives from twelve transit agencies responded to the email recruitment. Three declined to participate in the interview, although they were all interested in the research and provided synopses of their procurement processes. Seventeen telephone interviews were held with respondents from ten transit agencies, lasting an average of one hour. In five locations, both union and management participated; in four, only management was interviewed, and in one only the union was interviewed.

Twenty-five union surveys were completed. Union leaders representing bus operators at six transit agencies were interviewed, five from locations where management was also interviewed and one from a union that had reported a procurement team on their survey response. One local union represented members in two of the agencies but provided responses about only one of those. One transit agency was not unionized.

The four industry experts who agreed to be interviewed were a governmental researcher involved in participatory ergonomics, a former bus operator with extensive experience in bus operator health and safety, a participatory design specialist, and an experienced transit agency manager who is involved in procurement training development and with national procurement policy. Despite initial interest, the manufacturing contacts declined to be interviewed.

Transit Agency Characteristics

Five of the responding transit agencies were large (more than 250 transit buses in regular service), two were medium (50 to 249 buses), and two small (less than 50 buses). Larger agencies represented a slightly greater proportion of those interviewed (78%) than those who were initially recruited (55%). Although the transit agencies were recruited from throughout the United States, those agreeing to be interviewed were from the West (5), South (2), and East (2) of the United States; no Midwestern transit agencies responded. Each transit agency's respondents, procurement process, and bus operator's role are described in Appendix F: Description of Transit Agencies Interviewed.

As shown in Table D-1, the contacts made directly or via the APTA Bus Safety Committee represented operations, maintenance, safety, human resources, and executive teams. These contacts often referred the researchers to others in their agencies who they thought would be better able to contribute. Five of the interview respondents were in operations, four in engineering or technical services, four in maintenance, three in safety, and two in procurement.

Table D-1. Transit Agency Outreach and Respondent Areas

Area by Title	**Contacted** *N* **= 56**	**Participated in Interview** *N* **= 17**
Operations	27%	29%
Maintenance	4%	24%
Engineering/Technical	7%	24%
Safety	54%	12%
Procurement	0%	12%
Executive	7%	0%
Human Resources	2%	0%

Transit Union Surveys

The 26 union officers who returned surveys represented members at 36 transit agencies across Canada (four, 15% of the respondents) and the United States (seven respondents in the East and five each in the Midwest, South, and West). Most of the survey response content referred to their members at larger agencies (14), with 10 medium and two small.

An employer bus procurement or design group was reported by union officers at 16 of the 36 transit agencies. In 17 agencies, the union officer reported there was no group. In three of the agencies, the union did not know if there was a group.

Only four union respondents reported that their members serve on the procurement committees. Two unions are involved in procurement, design, or retrofit activities but are not on the committee, and 17 stated that they are not involved at all.

Interview Questions

Appendix D describes the responses to each interview question, with quotations illustrating the current practices described. To conserve space while giving an idea of the research methodology, this annex reproduces the survey questions. The complete Appendix D may be accessed from the TCRP Project C-22 webpage.

Interview Section 1: Who Is Involved in the Bus Procurement and Retrofitting Processes

Question 1. Please describe your bus design/procurement group: who participates?

Question 2. Is there a separate team or committee for bus assessment, refitting or retrofitting? What departments or individuals contribute to this stage?

Interview Section 2: How the Procurement Process Works to Enhance Operator Health and Safety.

Question 3. How does your group work?

Question 4. Can you summarize the practical steps your organization takes for new bus procurement and for retrofit?

Question 4.a. Practical steps for new bus procurement

Question 4.b. Practical steps for refit/retrofit of existing vehicles or when problems develop

Question 5. What are the strengths of your process and your group – what makes them effective?

Question 6. What external documents or sources have you used in procurement and retrofitting?

Interview Section 3: What Is Involved in the Training and Preparation of the Procurement Group

Question 7. Do group members receive any training to help them do their jobs better? If yes, please describe.

Question 8. Could you provide examples of any training plans or materials that you use?

Question 9. Are there members with specific qualifications, skills or knowledge that make your group more effective?

Interview Section 4: Barriers and Needs Encountered in the Bus Procurement or Refit Processes

Question 10. Is there anything that limits the effectiveness of your procurement, refit or retrofit processes?

Question 11. What could be done to improve the bus operator workstation procurement processes in your agency?

Question 12. In particular, what training would be helpful for your group?

Question 13. How can or could transit agencies assist each other in improving the procurement process?

Question 14. What could be done to improve the processes across the transit industry?

Summary of Appendix E: Industry Expert Interviews

Twelve industry experts were identified from the research literature and via recommendations by other specialists in the field. Emails were sent to request a telephone interview. Four agreed to be interviewed. The four interview subjects had experience in academic research, in transportation ergonomics, in bus operator health and workstation ergonomics, in participatory ergonomics, and in procurement practice, policy, and training.

Interview Questions

Question 1. Please describe your experience with the workplace design and procurement process. Have you worked with vehicle design? With transit agencies?

Question 2. Can you describe a project exemplifying an effective design and procurement process that enhances employee health, safety and wellness?

Question 3. Who have the experts observed participating in procurement?

Question 4. What is the ideal role of employees?

Question 5. What skills do you observe or recommend in design and procurement teams?

Question 6. What training have you observed that supports effective groups? If not maximal, what additional skills and training do you recommend?

Question 7. What kind of communication and decision-making processes have you observed that enhance effective design and procurement within companies, and what would you recommend?

Appendix E summarizes the responses to these questions.

Summary of Appendix F: Description of Transit Agencies Interviewed

Information about procurement practices at 10 agencies was collected in 15 interviews, 10 with transit agency staff and 5 with union representatives. Seven of the transit agencies represented provide bus and rail or subway service, and three provide bus service only. County-wide and regional transit agencies made up 40 percent of the total, and two each were state-wide, small city, and metro area transit agencies.

Four of the 10 transit agencies reported that there was no real committee working on bus procurement and that the process was coordinated by one or two people. This occurred in small and in large locations. Others described well-established teams either made up of representatives from all stakeholder groups or involving them as needed. In most but not all locations, bus operators and safety staff were consulted at some point during the bus procurement process.

Appendix F provides additional information about each transit agency.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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