
TCRP Research Report 249 Pre-Publication Draft—Subject to Revision

Bus Operator Barrier Design

GUIDELINES AND CONSIDERATIONS

Bus Operator Barrier Design: Guidelines and Considerations (2024)

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Contents

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SUMMARY

Summary of Bus Operator Barrier Design Guidance and Considerations

Our nation was reminded of the importance of security barriers for transit bus operators by the fatal attack on a Hillsborough Area Regional Transit Authority (HART) bus operator on May 18, 2019. The need for security barriers was reinforced by a serious attack on another HART bus operator later that same year. While these are two extreme examples, they are likely not unique, as many assaults against transit workers have been underreported in the past. Transit Cooperative Research Program (TCRP) Synthesis 93 defines “assault” broadly to include overt physical and verbal acts by a passenger that interfere with the transit worker’s ability to complete their scheduled run or other duties safely, or that adversely affect the safety of the transit employee and customers. As stated in the 2015 TCRP Synthesis 93 and Transit Advisory Committee for Safety (TRACS) 14-01 Report, “the vast majority of assaults against transit workers are nonfatal: 81% of assaults against bus operators are verbal and 60% involve spitting at the worker, while 2% involve weapons.” While many of these assaults go unreported and do not lead to arrest, they still have a strong psychological impact on bus operators. A secure barrier that eliminates physical contact or reduces the fear of assault could significantly improve the lives and job satisfaction of bus operators, allowing them to focus on customer service and safe vehicle operation.

The risks to bus operator health and safety are not limited to physical and verbal assaults. Another important but more pernicious risk to bus operator health is viral and bacterial infection. The COVID-19 pandemic in 2020 and 2021 clearly demonstrated this risk to everyone including bus operators. As reported in the October 6, 2020, editorial of *Issues in Science and Technology* entitled “COVID-19 Revealed an Invisible Hazard on American Buses,” over 10,000 transit workers in the U.S. contracted COVID-19, and 89 members of the Amalgamated Transit Union died during the preceding 8 months. Some agencies quickly adopted droplet barriers and soon recognized the challenges that other transit agencies who have installed security barriers have faced for some time: a barrier mounted between the bus operator and the curb side of the bus can limit visibility inside and outside the vehicle to view passengers in the rear and create glare on a barrier surface between the bus operator and the curb-side rearview mirror. Accordingly, transit agencies adopted barriers with manually sliding sections, requiring the bus operator to close the barrier before opening the front door at every stop and to reopen it before departing. Among the challenges that transit bus operators have faced for years is the change in temperature around the bus operator workstation due to the open layout of the front of the buses and the frequent need for the front entry door to be opened for passenger boarding and deboarding. These risks to bus operator security, health, comfort, driving visibility, and the high repetition of transit bus tasks need to be considered when determining how to design a bus operator barrier.

Objective

The goal of the project was to produce information and guidance for North American public transportation agencies, standards committees, and government and non-government policy-making organizations on designing, procuring, and installing bus operator barriers to prioritize the health and safety of essential operators and the public they serve.

Approach

The approach of the research was to survey the transit bus industry, collect reference materials on the designs of barriers and designs of heavy low-floor transit buses, produce a summary of design criteria, and produce three concept barrier configurations that may mitigate the risks to transit bus operator safety and health. This guidance was developed in consideration of assault prevention, air quality and ventilation, and thermal considerations; bus operator visibility, protection, security, safety, health, mobility, and comfort, American with Disabilities Act (ADA) compliance for bus access and mobility; and emergency egress. To ensure the guidance is practical and can be applied by public transportation agencies of varying sizes, means, and operational parameters, the guidance considered both retrofit barrier designs for aftermarket as well as new purchase integration of current and novel bus operator workstation designs. To meet the need of addressing current transit bus operator workstation designs the research team developed two concept barriers within a recent generation transit bus computer model provided by a major North American transit bus manufacturer. To meet the need to address future transit bus designs, the project team worked with the Bus of the Future team that was awarded by the FTA to develop a bus operator workstation compartment that would meet bus driver health and safety needs with a novel solution. This included a concept bus operator barrier that completely separates the bus operator workstation from the passenger area and/or the passenger front entryway.

Design Criteria

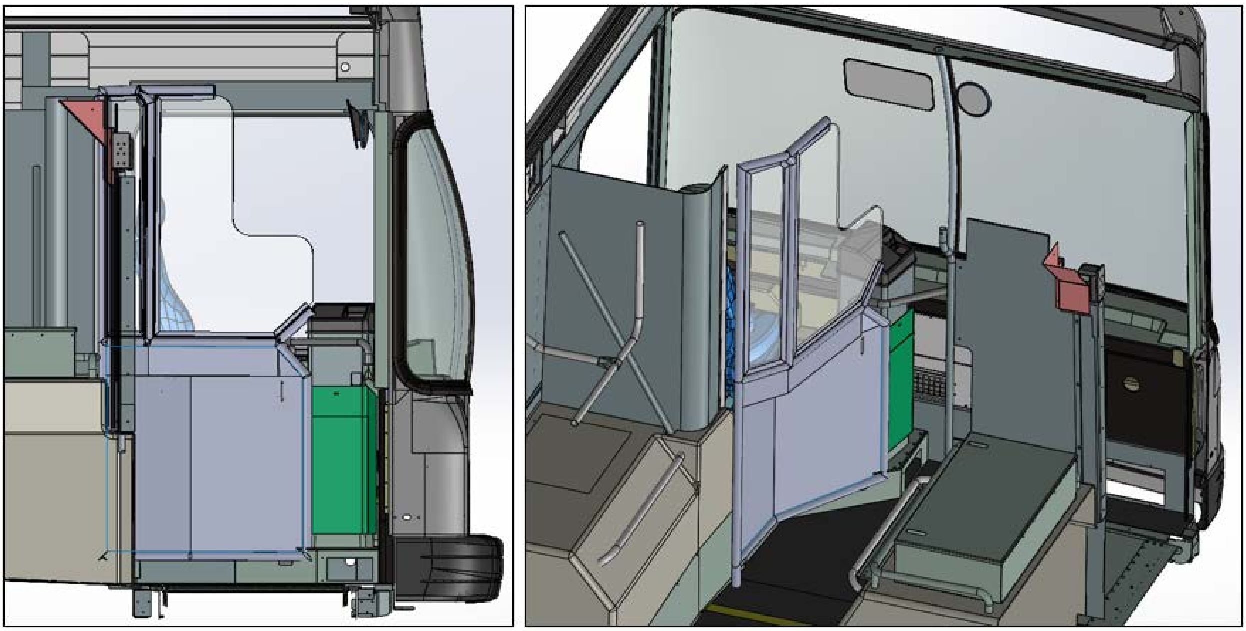
Design criteria was collected from the following sources: APTA, the European Bus System of the Future (EBSF), ISO, and the TCRP. The criteria collection for bus operator barrier design built on a previous exercise of criteria collection produced in TCRP Report 185. The collection of these criteria was applied in the selection of design variables that impact bus operator barriers. Criteria from other sources such as the MIL-STD-1472G, SAE, Code of Federal Regulation Parts 37 and 38 (ADA), and FMVSS were also collected. Based on these criteria a bus operator barrier requirement matrix was developed and organized by area or component and features of that component. The areas and components are listed below, and the matrix is available in Appendix A.

- Operator workstation
- Steering wheel
- Fare box
- Bus floor
- Ventilation, climate
- Driver area barrier
- Driver’s side window
- ADA wheelchair
- Side windows
- Bus operator barrier, door
- Seat
- Pedals
- Door control [passenger entry]
- Driver’s area
- Ventilation, air flow
- Modesty panels
- Passenger doors
- General safety
- Bus operator barrier
- Mirror

Key Findings

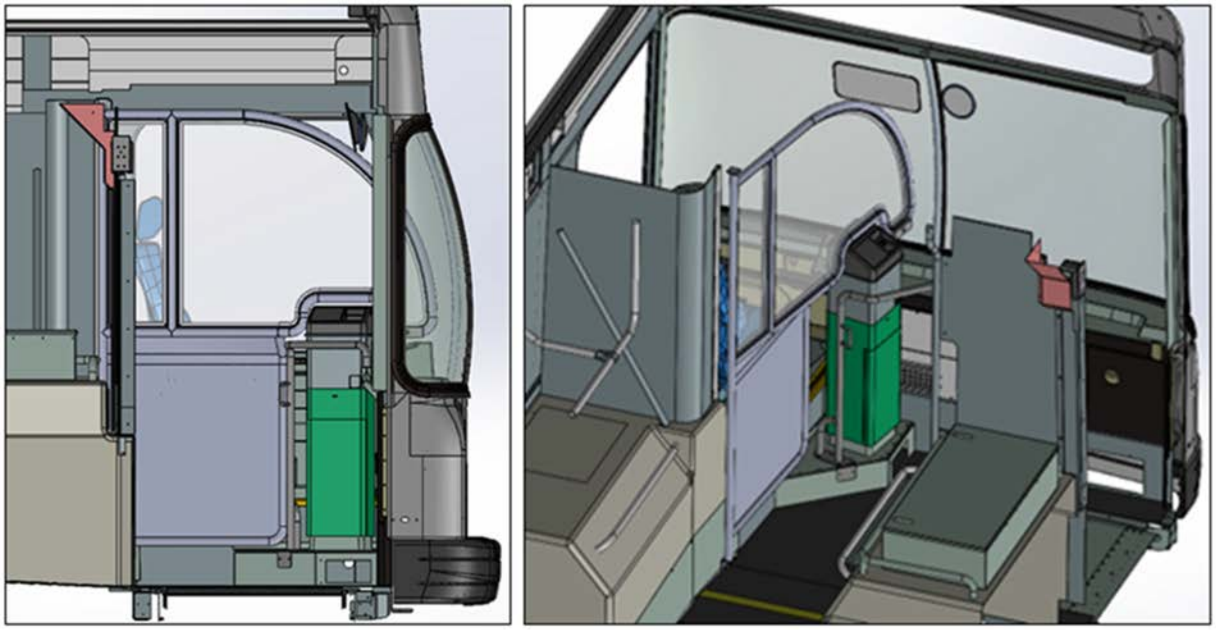
The research team at VTTI applied the information collected from the TCRP Panel, guidelines, standards, previous research, and the survey to develop a target risk mitigation approach for the three bus barrier concepts. The designs and estimated risk mitigation outcomes are provided.

Retrofit or Integrated Bus Barrier Design, Concept A



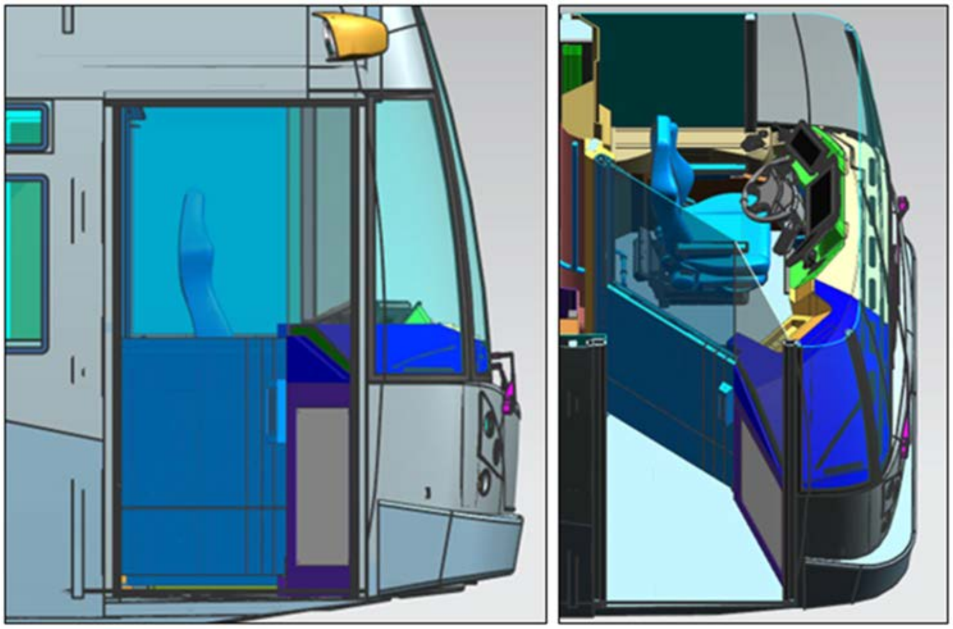
- Physical, Spitting and Other Attacks: Concept A was estimated to provide high mitigation of direct physical contact by limiting reach by passenger; low mitigation of shooting weapon around barrier; and low mitigation of spitting around/over barrier.
- Air Quality: Concept A was estimated to provide no mitigation of coughing/sneezing risk and no mitigation of air quality risk.
- Temperature: Concept A was estimated to provide low mitigation of cold temperatures since the barrier may reduce cold gusts through the passenger entryway door but no change to temperature and humidity.
- ADA: Concept A was estimated to provide clearance for passengers with disabilities based on the minimal dimensions for the ADA clearance box.
- Usability: Concept A was estimated to provide medium mitigation of risk to bus operator reach and repetition since the door does not have to be moved at every stop for driving visibility, but it is operated manually. The bus operator may latch or release under normal operation to perform passenger service; the bus operator may latch or release for emergency egress.
- Visibility: Concept A was estimated to provide high mitigation of obstruction/glare for visibility of exterior mirrors and interior passenger mirrors; however, obstruction/glare from the barrier may exist when the bus operator looks at the passenger front entry door.

Retrofit or Integrated Bus Barrier Design, Concept B



- Physical, Spitting and Other Attacks: Concept B was estimated to eliminate direct physical attack by passenger reach, to provide medium mitigation of shooting a weapon around the barrier, and to provide high mitigation of spitting since passengers cannot lean around the barrier.
- Air Quality: Concept B was estimated to provide medium mitigation of coughing/sneezing risk due to the size of the barrier. It was estimated to provide medium mitigation of air quality risk, depending on implementation of additional partitions between front entry and passenger compartments to limit gaps and increase higher pressure on the front side of the barrier.
- Temperature: Concept B was estimated to provide medium mitigation of cold temperatures since the barrier may reduce cold gusts through passenger entry door but there would be no change to temperature and humidity.
- ADA: Concept B was estimated to pass the clearance for passengers with disabilities based on the minimal dimensions for the ADA clearance box.
- Usability: Concept B was estimated to be implemented with automatic operation based on passenger front entry door state using a powered pneumatic armature and electro-magnetic latches at both positions for boarding and driving. A power override by the bus operator under normal operation would allow the bus operator to perform passenger service. The concept includes a physical hinge release for non-powered emergency egress.
- Visibility: Concept B was estimated to provide high mitigation of obstruction/glare risk for visibility of exterior mirrors and interior passenger mirrors due to barrier open latching position while driving. This concept was also estimated to provide high mitigation of risk for obstruction/glare when looking at the passenger front entry door due to the barrier door automatically latching open while driving.

Novel “Bus of the Future” Bus Barrier Design, Concept C



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- Physical, Spitting and Other Attacks: Concept C was estimated to eliminate direct physical attack by creating a separate floor to ceiling bus operator workstation compartment. The concept may potentially mitigate attack by shooting weapon with the appearance of no access. The concept eliminates spitting attack.
- Air Quality: Concept C was estimated to eliminate coughing/sneezing risk due to the separate bus operator workstation compartment. The concept was estimated to provide high mitigation of air quality risk, assuming positive pressure can be created on the bus operator side.
- Temperature: Concept C was estimated to eliminate cold temperature risk. The risk due to hot temperatures and humidity may not be mitigated and may be increased by the separate compartment due to the need for a separate bus operator workstation HVAC system.
- ADA: Concept C was estimated not to pass clearance for passengers with disabilities based on the minimal dimensions for the ADA clearance in the passenger front entryway. Concept C passes clearance for passengers with disabilities based on the dimensions for the ADA clearance box in the mid/rear door entry.
- Usability: Concept C was estimated to be implemented with automatic operation based on the state of the passenger front entryway door using a powered pneumatic armature and electro-magnetic latches at both positions for boarding and driving.
- Visibility: Concept C was estimated to provide high mitigation of obstruction/glare risk for visibility of the curb-side exterior mirror due to the orientation of the stationary barrier, which does not interfere with the bus operator’s view. Another alternative that may provide high mitigation of risk for obstruction/glare over exterior mirrors is the use of cameras and displays to replace rearview mirrors. Additional defrost/defogging vents near the additional barrier door and barrier stationary glazing surfaces may be needed to avoid obstructed vision due to glass fogging.

CHAPTER 1

Introduction

Our nation was reminded of the importance of security barriers for transit bus operators by the fatal attack on a Hillsborough Area Regional Transit Authority (HART) bus operator on May 18, 2019. The need for security barriers was reinforced by a serious attack on another HART bus operator later that same year. While these are two extreme examples, they are likely not unique, as many assaults against transit workers have been underreported in the past. Transit Cooperative Research Program (TCRP) Synthesis 93 defines "assault" broadly to include overt physical and verbal acts by a passenger that interfere with the transit worker's ability to complete their scheduled run or other duties safely, or that adversely affect the safety of the transit employee and customers.[1] As stated in the 2015 TCRP Synthesis 93 and Transit Advisory Committee for Safety (TRACS) 14-01 Report, "the vast majority of assaults against transit workers are nonfatal: 81% of assaults against bus operators are verbal and 60% involve spitting at the worker, while 2% involve weapons."[2] While many of these assaults go unreported and do not lead to arrest, they still have a strong psychological impact on bus operators. A secure barrier that eliminates physical contact or reduces the fear of assault could significantly improve the lives and job satisfaction of bus operators, allowing them to focus on customer service and safe vehicle operation.

Another important but more pernicious risk to bus operator health is viral and bacterial infection. The COVID-19 pandemic in 2020 and 2021 taught the world that viral infections can easily turn into widespread events with significant consequences to everyone's lives. A pandemic can disrupt essential services, such as public transit, a critical service that keeps people moving, including between critical medical facilities and health support systems. As reported in the October 6, 2020, editorial of *Issues in Science and Technology* entitled "COVID-19 Revealed an Invisible Hazard on American Buses," over 10,000 transit workers in the U.S. contracted COVID-19, and 89 members of the Amalgamated Transit Union died during the preceding 8 months.[3] Transit buses provide a convenient and predictable mode of transportation for the public, who can choose to enter and exit the bus at or between the many street stops based on perceived risk; however, the bus operator must remain in the same air space for much of their work day, regardless of whether an infected person is on board. Furthermore, the bus operator workstations in U.S. buses are designed to primarily obtain heat and cooling from the passenger heating, ventilation, and air conditioning (HVAC) system, for which the intake is located either in the rear of the bus or above the rider area. For this reason, new ventilation solutions that separate and filter the air for the bus operators are needed for transit buses. The Virginia Tech Transportation Institute (VTTI) completed a Federal Transit Administration (FTA)/Center for Urban Transportation Research (CUTR) investigation into transit bus ventilation, finding that the driver window is the lowest point of pressure when the vehicle is in motion, and simply opening the operator-side window can increase the exposure of the bus operator to air from the passenger seating area.[4,5] VTTI also found that HVAC-equipped transit buses commonly include no option for a mixture of fresh air in the bus operator windshield defrost system or in the passenger HVAC system. While this study generated recommendations for simple, temporary solutions for multiple HVAC configurations, other long-term solutions should be explored.

Early in the COVID-19 pandemic, droplet transmission through exhaled air, rather than surface contact, was identified as the primary path of virus transmission between people. Airborne transmission via small droplets and particles that can linger in the air was later recognized as well.[6] Based on guidance from the Centers for Disease Control and Prevention (CDC) regarding risks for transmission, many transit agencies limited all passenger entry to the rear door until a barrier could be installed in order to reduce the direct transfer of large droplets between passengers and bus operators. Early adopters of these droplet barriers recognized the challenges that other transit agencies who have installed security barriers have faced for some time: a barrier mounted between the bus operator and the curb side of the bus can limit visibility inside and outside the vehicle to view passengers in the rear and create glare on a barrier surface between the bus operator and the curb-side rearview mirror. Accordingly, transit agencies adopted barriers with manually sliding sections, requiring the bus operator to close the barrier before opening the front door at every stop and to reopen it before departing. When considering the CDC hierarchy of risk control, this requirement turned a promising engineering control into an administrative control that requires bus operators to remember to close the barrier to protect themselves. Agencies that chose to adopt barriers providing automated security and droplet protection recognized the added challenge of securing the barrier; that is, egress and functional release options were needed to allow operators to open the barrier door in cases of an emergency or when assisting persons with mobility impairments and disabilities.

Among the challenges that transit bus operators have faced for years is the change in temperature around the bus operator workstation due to the open layout of the front of the buses and the frequent need for the front entry door to be opened for passenger boarding and deboarding. Features have been added over the years to improve climate and HVAC controls for bus operators. In cold climates and seasons, bus operators have the option to use the heating units provided to support windshield, driver, and curb-side defogging and defrosting to increase the temperature in the bus operator workstation to reduce cold stress. However, in hot and humid conditions, bus operators rely on the primary bus passenger HVAC, which can often be sourced from the interior and back of the bus through overhead ducts, to provide air conditioning and cool the bus operator workstation. Some transit buses are equipped with additional overhead HVAC booster fans to increase the volume of air pulled from the primary bus HVAC through the overhead ducts. Some buses are also equipped with dash mounted fans to assist with defogging of windows and are used by operators to assist in cooling the bus operator workstation.

These risks to bus operator security, health, comfort, driving visibility, and the high repetition of transit bus tasks need to be considered when determining how to design a bus operator barrier. To address these risks, the objective of this research was to provide practical guidance to public transportation agencies on designing, procuring, and installing bus operator barriers to prioritize the health and safety of essential operators and the public they serve. This guidance was developed in consideration of assault prevention, air quality and ventilation, and thermal considerations; bus operator visibility, protection, security, safety, health, mobility, and comfort, American with Disabilities Act (ADA) compliance for bus access and mobility; and emergency egress. To ensure the guidance is practical and can be applied by public transportation agencies of varying sizes, means, and operational parameters, the guidance considered both retrofit barrier designs for aftermarket or new purchase integration and novel bus operator workstation designs.

CHAPTER 2

Approach to Bus Operator Barrier Designs

The goal of the project was to produce information and guidance for North American public transportation agencies, standards committees, and government and non-government policy-making organizations on designing, procuring, and installing bus operator barriers to prioritize the health and safety of essential operators and the public they serve. The approach was to survey the transit bus industry, collect reference materials on the designs of barriers and designs of heavy low-floor transit buses, produce a summary of design criteria, and produce three concept barrier configurations that may mitigate the risks to transit bus operator safety and health. The risks to bus operator health and safety that were specified by the TCRP Advisory Panel for this research effort are:

- Physical attack
- Spitting attack
- Air quality
- Temperature extremes
- ADA accessibility
- Usability and ergonomics
- Driving visibility

These risks that were considered in bus operator barrier designs are also affected by costs to manufacture, install/integrate, and maintain. Therefore, relative cost and complexity were considered as categories in the identification of the three concept bus operator barrier designs that would be produced. A range of transit agency needs and priorities should also be considered by stakeholders developing guidance and regulations. Transit agency personnel with roles as managers, technicians, and operators are likely to each have different preferences for types of bus operator barrier configurations. Some may prefer a higher prioritization for customer service and engagement and therefore desire a lower profile barrier, while others may prefer more security or even complete separation of the bus operator workstation compartment.

Besides preferences between bus operator barrier designs, the approach to developing all three bus operator barrier designs account for federal transportation requirements and standards that help ensure minimum safety and accessibility for the public and also affect procurement and funding bus purchases that depend on these standards. Passengers with ambulatory impairments should be provided handholds and stanchions to assist with navigating entryways and aisles. Additionally, persons with disabilities who use mobility devices must be provided adequate clearance through doorways and aisles.

Another important consideration when adding a barrier in the bus operator workstation is material strength and transparency. Standards and recommended practices exist to define the safety, durability, and transmittance of parts of the barrier that must be viewed during driving. Selection of the materials used in a barrier, especially barriers that remain in place during driving operations, should take these requirements into consideration.

Multiple design guidelines exist that provide criteria that either directly or indirectly impact bus operator barrier designs. These are available from the American Public Transportation Association (APTA), published from the European Bus System of the Future, International Organization for Standardization (ISO), and TCRP under the Transportation Research Board and National Academies of Sciences.

The approach for this project includes combining these sources of information to develop three concept bus operator barrier design configurations that address risks for bus operators while being grounded in the standards and transit bus designs that are common today and those that hold promise for tomorrow. To meet the need to address future transit bus designs, the project team worked with the Bus of the Future team that was awarded by the FTA to develop a bus operator workstation compartment that would meet bus driver health and safety needs with a novel solution. This included a concept bus operator barrier that completely separates the bus operator workstation from the passenger area and/or the passenger front entryway. The Bus of the Future team was led by the International Transportation Learning Center (ITLC) in partnership with RLS & Associates, Amalgamated Transit Union, and Styl&Tech. The research team worked directly with RLS & Associates on this TCRP project.

Survey on Transit Bus Barriers

The purpose of the survey was to collect preferences and needs for bus operator barriers, identify the design boundaries for bus operator barrier configurations for retrofit on existing buses, and collect traditional and novel barrier designs that have recently been used by transit agencies. VTTI conducted the survey with the assistance of the ITLC for recruitment. The information collected in the survey was intended to support the goals of the project to produce information and guidance to stakeholders of North American public transit bus operations. Representatives from North American transit agencies and/or unions were sought to complete the survey. Outreach was made through direct emails, transit industry newsletters, and during conferences.

Respondents completed the survey through an online method on QuestionPro. It was estimated that the survey would take approximately 20–25 minutes to complete. Prior to completing the survey, respondents were asked to review a Study Information Sheet, explaining the purpose and use of the survey, which, when completed, implied consent. The survey research protocol was approved by the Virginia Tech Institutional Review Board. Data collected in the survey included:

- basic demographics related to the respondent’s job and work history;
- bus operator barrier use, purpose, requirements;
- descriptions of bus operator barrier designs in use and operational features;
- barrier maintenance requirements;
- barrier costs;
- barrier effectiveness;
- implementation challenges;
- training;
- benefits and positive outcomes;
- return on investment;
- future design recommendations and suggestions; and
- option to email images of bus operator barriers in use at the survey respondent’s agency.

Guidelines, Standards, and Previous Research

North American and global recommended practices, guidelines, and standards were considered in the information collected to find related criteria for bus operator barrier designs.

Guidelines

Criteria and guidelines that pertain to the bus operator workstation and bus operator barriers were reviewed and collected from the following sources: APTA[7], the European Bus System of the Future[8], ISO[9], and TCRP.[10]

Standards

Minimum requirements for accessibility for persons with disabilities on transit buses are defined in 49 CFR Part 37; Transportation Services for Individuals with Disabilities (ADA), and Part 38; ADA Accessibility Specifications for Transportation Vehicles.

In recent years, especially since the COVID-19 pandemic, barriers of many types have been developed by and for transit agencies as they have sought to protect their bus operators from air quality risks or attack. That demand brought many ideas to the industry for bus operator barriers. Because these barriers interface with the bus operator near the workstation, the designs could be placed in locations that in the past were considered as glazing used during vehicle driving tasks. Therefore, developers of glazing materials and bus operator barriers sought to understand the impacts of related standards on glazing. An interpretation was requested of the US DOT National Highway Traffic Safety Administration (NHTSA) as to whether transparent material used in shielding on bus operator barriers needs to comply with Federal Motor Vehicle Safety Standard (FMVSS) No. 205. A letter dated June 4, 2020, stated that this, "…shield assembly, located immediately to the right of a driver, is an interior partition composed of motor vehicle glazing that must comply with FMVSS No. 205."[11] The letter continues to discuss the applications of FMVSS No. 205 to motor vehicles prior to first purchase and to aftermarket glazing for use in motor vehicles. Additional details note that the manufacturer that cuts the glazing is responsible for certifying the glazing, but the assembler of an aftermarket [bus operator] barrier, as the manufacturer, is responsible for ensuring that the product is free from safety-related defects. The letter goes on to denote that, "Any portion of the glazing [in the bus operator barrier] that the driver would see through in in order to view windows requisite for driving visibility would also be considered requisite for driving visibility."[12]

Therefore, glazing (e.g., glass windows) materials used in bus operator barriers must meet 49 CFR 571.205 FMVSS Standard No. 205; Glazing materials. This federal regulation references other standards and practices that, among other tests, cover strength, safety, and transmittance of glazing such as SAE J3097/ANSI Z26.1-MAY2019, "Standard for Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operating on Land Highways - Safety Standard" and J673-JUL2021, "Automotive Safety Glazing Materials."

Visibility through glass during inclement weather and under differential external/internal humidity and moisture levels is covered by a standard and recommended practices for defog and defrosting: 49 CFR 571.103 FMVSS Standard No. 103; Windshield defrosting and defogging systems,[13] and SAE J381-JUN2020, "Windshield Defrosting Systems Test Procedure and Performance Requirements - Trucks, Buses, and Multipurpose Vehicles."[14]

These are a selection of standards that were collected and reviewed to understand how they impact the design and integration of bus operator barriers on transit buses. Consulting with bus procurement guidelines and federal agencies is recommended to ensure all relevant standards are considered prior to purchase and installation.

Previous Research

VTTI researchers on this team completed a series of projects in recent years that investigated transit bus barriers and produced guidelines and recommendations that were applied to this effort for implementing retrofit barriers in existing buses and new workstation designs. These project reports include TCRP Report 185: Bus Operator Workstation Design for Improving Occupational Health and Safety,[15] Transit Bus Mirror Configuration Pilot Project, Final Report,[16] and FTA Standards Development Program: Transit Bus Operator Temporary Barrier to Reduce COVID-19 Exposure.[17] VTTI applied knowledge and expertise gained during these highly relevant projects to the development of bus operator barrier designs.

TCRP Report 185: Bus Operator Workstation Design for Improving Occupational Health and Safety

In TCRP Report 185, VTTI produced a global summary of bus operator workstation design requirements (see Figure 1) and developed a universal file formatted CAD model to serve transit agencies during procurement (see Figure 2). This report demonstrated the design constraints present in current production transit buses in North America.

Design Variables		Report 25 Guidelines	APTA Specification Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Updated for Report 25
Door Control	Location	N/A	Shall be located in the operator's area within the hand reach envelope described in SAE Recommended Practice J287, "Driver Hand Control Reach." Shall provide tactile feedback to indicate commanded door position and resist inadvertent door actuation.	N/A	N/A	Represented by 3-D CAD Models
Bus Floor	Height above ground	N/A	No more than 406 mm	N/A	N/A	No
Driver Platform	Height	N/A	Allows a seated bus operator to see a target positioned 610 mm in front of the bumper and 1067 mm above the ground. The height of the platform shall also allow the bus operator's vertical upward view is less than 15°.	300 (±50) mm above the bus floor and be reachable by a single step. If the platform height is greater than 350 mm, steps with equal height shall be provided with a maximum height of 250 mm and a minimum height of 125 mm.	Clear and unrestricted access to the bus operator's workplace shall be ensured, with a passage width of at least 500 mm.	Yes

Figure 1. Global bus operator workstation design guidelines compiled by VTTI for TCRP Report 185.

Figure 2. A bus operator workstation design guideline model created by VTTI for TCRP Report 185. The guideline includes forward, upward, and downward visibility performance; bus operator reach and clearance zones; and standard design guidance applied from the APTA Standard Procurement Guide.

A bus operator workstation model was built as a simulation feasibility exercise to compare the guideline criteria to a transit bus that was already in production in North America at that time (see Figure 3). This project used this background and again worked with a transit bus manufacturer to demonstrate the concept bus operator barrier designs inside a current production electric vehicle bus model.

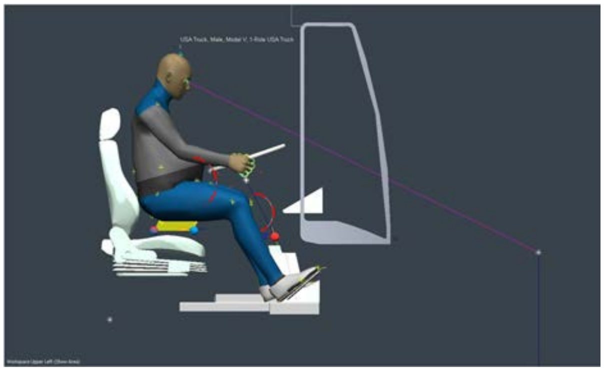

Figure 3. Image from the simulation modeling-based feasibility testing for a production bus operator workstation design for TCRP Report 185.

Transit Bus Mirror Configuration Pilot Project, Final Report

In this previous research, four transit buses were measured using a six-axis computer measurement machine and a laser light scanning device to produce 3D CAD reverse-engineering transit bus operator workstation and visibility boundary models (see Figure 4) at the New York City Transit, Department of Buses (NYCT DOB) maintenance facility. During this research, the VTTI team also measured and modeled the security barriers installed in each of the four transit bus configurations (see Figure 5 and Figure ***6***). The research team applied information from these designs to identify typical components and design elements that were considered in the concept bus operator barrier designs.

Figure 4. VTTI scanned a transit bus at the NYCT DOB to produce a reverse engineering model for FTA Report No. 0219.

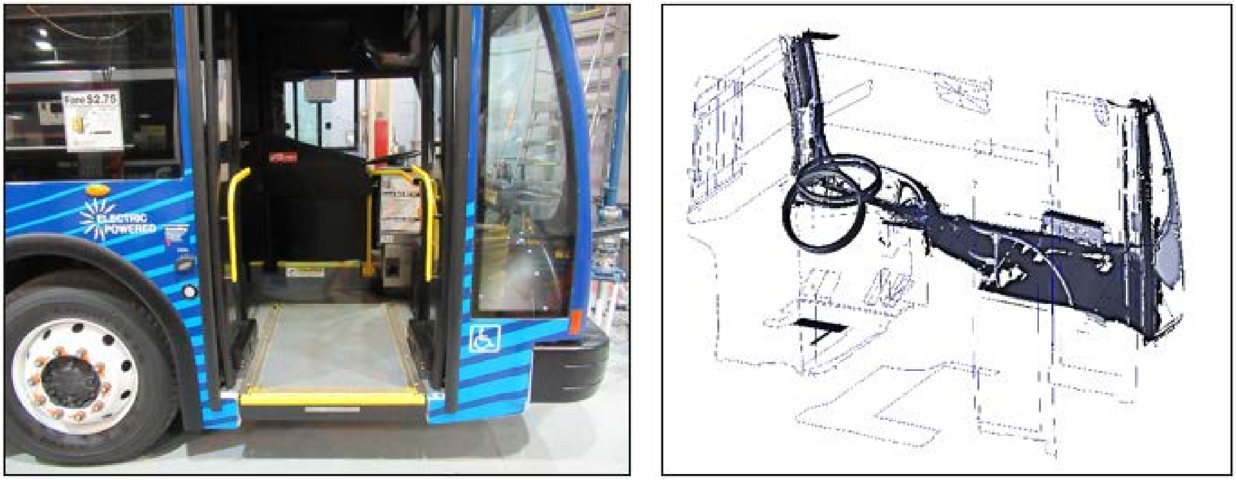

Figure 5. NYCT DOB Proterra bus (left) and 3D-scanned model (right) of the bus operator workstation barrier for FTA Report No. 0219.

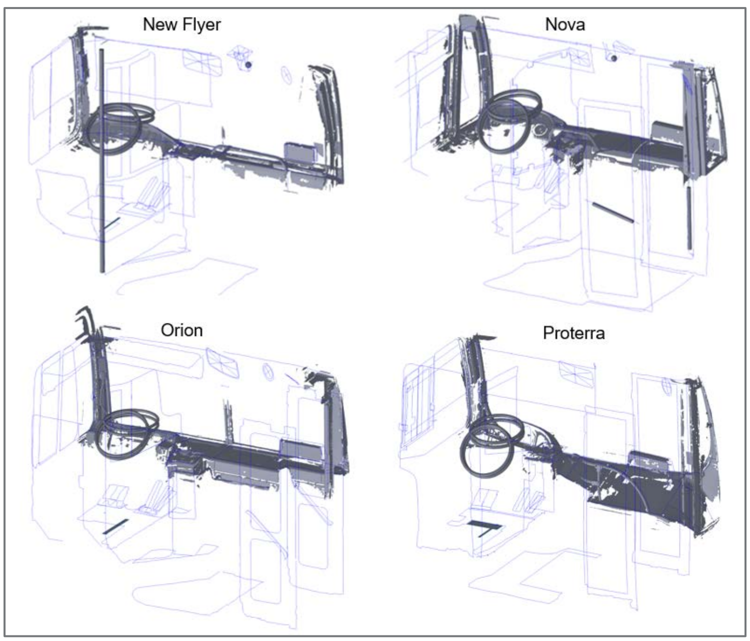

Figure 6***. Four 3D CAD models of the transit bus operator workstation, bus operator visibility and mirrors, and passenger front entry zone for FTA Report No. 0219.***

Using the 3D bus operator workstation models, VTTI used human simulation tools to create comparisons of the bus visibility benchmarking performance comparisons between buses (see Figure 7) and applied the performance measures to develop direct and mirror visibility guidance that led to a novel mirror design for demonstration in NYC. VTTI applied the sight lines and visibility performance data as guidelines for the development of the bus operator barrier designs.

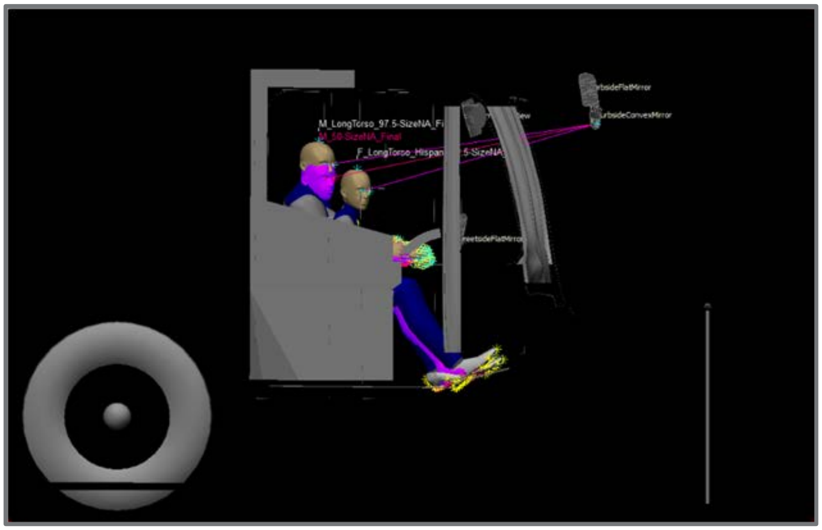

Figure 7. Image from the human simulation modeling of a Proterra curbside mirror visibility around the bus operator barrier for FTA Report No. 0219.

FTA Standards Development Program: Transit Bus Operator Temporary Barrier to Reduce COVID-19 Exposure

During the COVID-19 pandemic, researchers at VTTI performed field testing with three different transit bus HVAC configurations and evaluated the ventilation performance (see Figure 8) during static and dynamic operation of three high-volume in-service transit buses in North America (i.e., New Flyer and Gillig; rear/mid and rear HVAC intakes). VTTI cooperated with two local transit agencies in Blacksburg and Roanoke, Virginia to apply barriers to buses for testing between service periods. A concept barrier designed by VTTI was tested to determine if it could create a negative pressure zone at the front of the barrier, thereby reducing the open-air mixture between the bus operator workstation and the passenger area (see Figure 9).

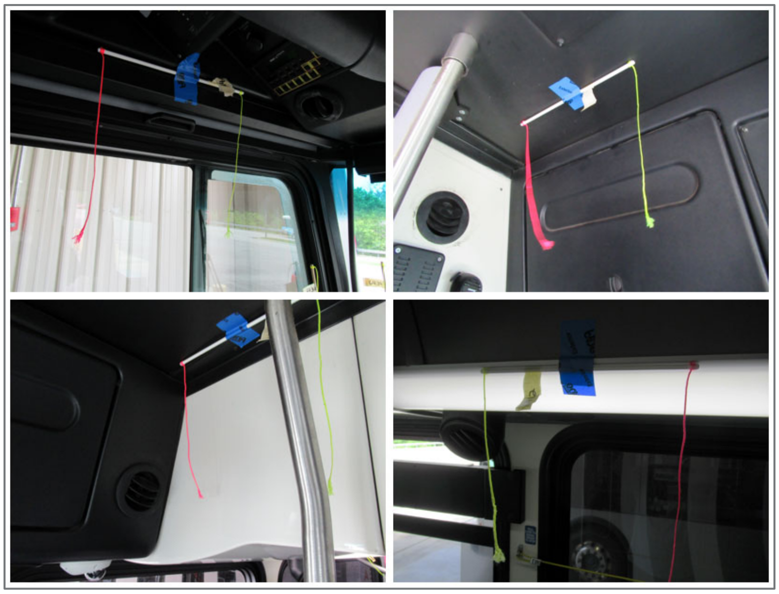

Figure 8. Four images of the ventilation duct outlets in the bus operator workstation and passenger front entryway area instrumented with telltale strings to identify changes in air flow for FTA Report No. 0224.

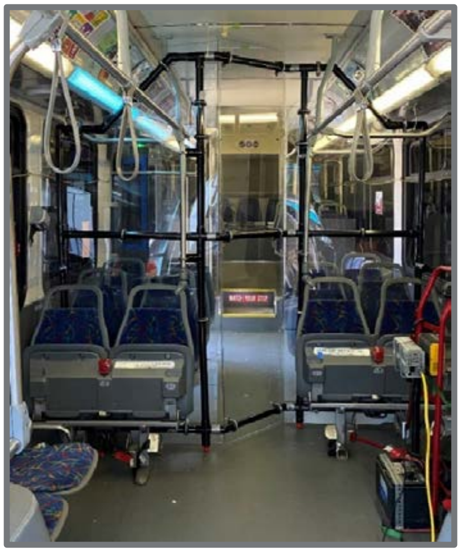

Figure 9. A prototype mid-bus barrier developed and installed in a transit bus for air flow testing on the Virginia Smart Roads test bed for FTA Report No. 0224.

Testing revealed that the temporary barrier was successful in buses equipped with rear-intake passenger HVAC configurations. The research team produced a technical brief and a 3D CAD model of the temporary barrier that was made available for public download and implementation. This research led to recommendations to transit agencies on practical principles they could use to reduce exposure for bus operators and bus passengers (see Figure 10 and Figure 11).

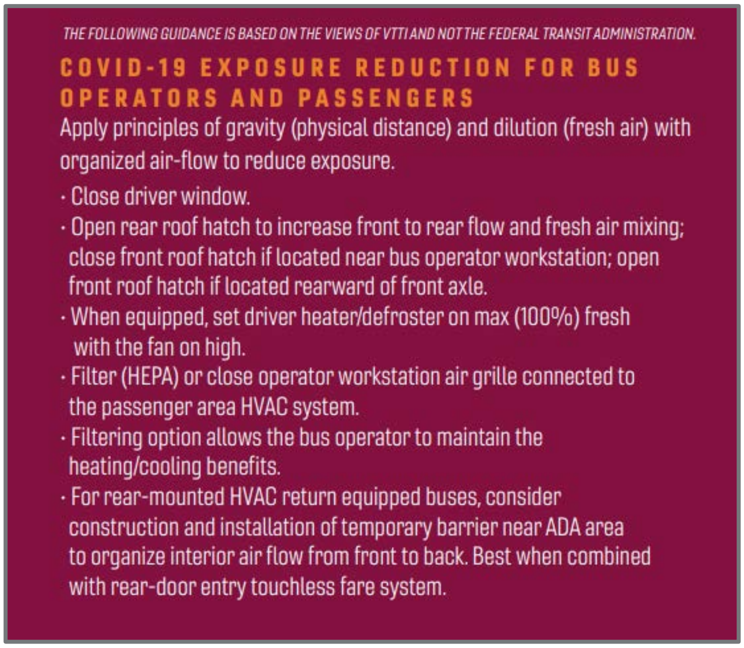

Figure 10. Implementation guidelines for temporary ventilation controls to increase and distribute indoor fresh air for FTA Report No. 0224.

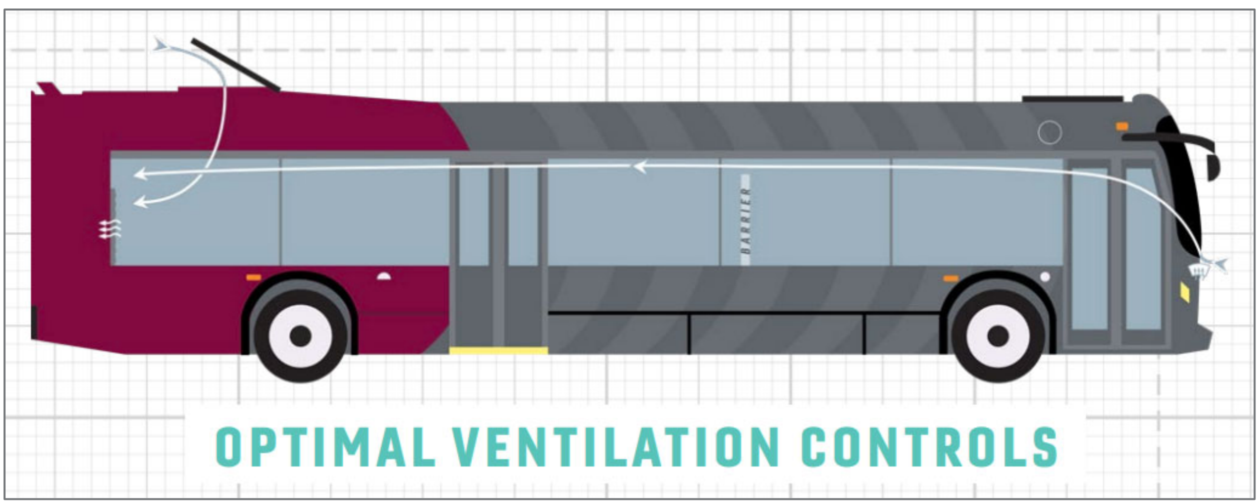

Figure 11. Implementation guidance on optimal temporary engineering ventilation controls to increase and distribute indoor fresh air for FTA Report No. 0224.

The findings of this research illustrate the complex variables that must be considered when developing guidelines for transit bus operator workstation security and health, and the design of barriers intended to support both. The addition of barriers can lead to changes in the airflow that may improve or degrade existing HVAC systems. Other performance, such as heating, cooling, and defrosting/defogging, can also be impacted. That performance can affect the thermal comfort of the bus operator. Additional glazing and surfaces between the bus operator and side glass or onboard passengers may also affect the bus operator's ability to see the roadway or to monitor and serve passengers. Bus operator barriers may require additional air treatment to manage different temperatures and humidity levels on each side of the barrier. This research also highlighted the challenge of managing air quality on buses. For example, some barrier designs may reduce risks to bus operators of passengers sneezing on them, but viral risks have recently been recognized to extend beyond droplet contact. This research observed the influences of air pressure on the exterior of the bus while the bus is in motion, which impact the air pressure and air flow inside the bus. Likewise, low flow airflow zones inside the bus were observed when all exterior windows and hatches or defrost ducts were closed. This effect on pressure varied by bus configuration. Some bus HVAC systems had little to no controlled fresh air intake, especially those that had rear-mounted HVAC units. Other buses with roof-mounted HVAC units always operated with 20 percent fresh air intake. Future designs of rear and roof mounted units may come with a combination of fresh air intake solutions. The primary takeaway was that it is important to select a solution that considers the complete vehicle and HVAC system and the differences between bus configurations when designing and implementing bus operator barriers.

"Bus of the Future" Redesign of Transit Bus Operator Compartment to Improve Safety, Operational Efficiency, and Passenger Accessibility Program

The TCRP Bus Operator Barrier Design project was performed in collaboration with members of the team who worked on the "Bus of the Future" project. This project was funded by the FTA in 2020 and the research was performed by the ITLC to find ways to protect operators from assault and improve their view of the road through innovative designs.[18] The team was composed of experts from the Amalgamated Transit Union, Styl&Tech, AC Transit, RLS & Associates, and Vision Systems. The research objectives were to improve on ineffective transit bus barriers, improve operator visibility, and create a separate operator workstation. The separate operator workstation was intended to maximize security, provide a sealed compartment that might be capable of positive air pressure on the operator side of the barriers, provide bus operator access through a pneumatic-powered barrier door with glazing, and provide options to eliminate barrier reflections.

The team developed a bus operator workstation and concept bus operator barriers on a previously existing chassis that is not in production at this time. This bus chassis provided the team with the opportunity to check feasibility of the concept against an example transit bus configuration. The resulting workstation concept is demonstrated in Figure 12.

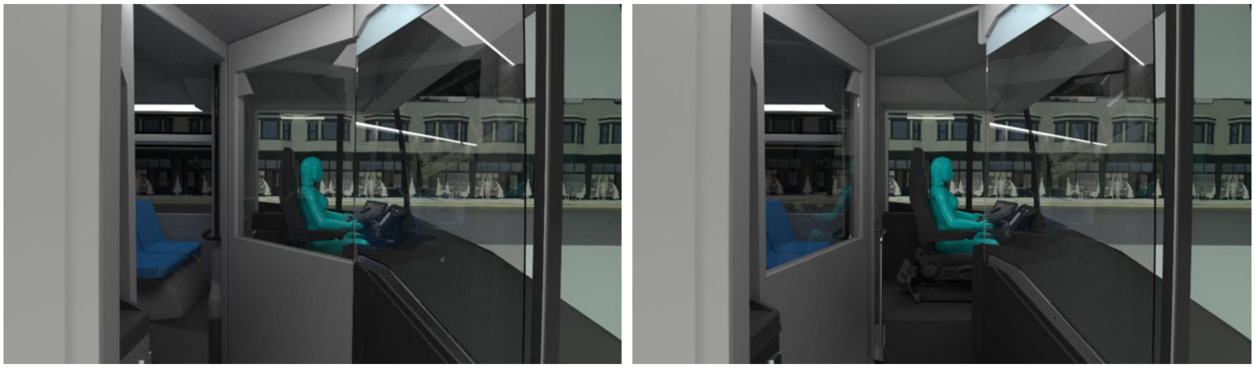

Figure 12. Concept "Bus of the Future" separate bus operator workstation with integrated door in the passenger entry mode position (left) and bus driving mode position (right). Used with permission from ITLC and STYL&TECH.

The security and separation of the air space was a priority for the design. The concept created a separate boundary at the typical standee line that allowed the bus operator workstation door to be opened and closed and securely sealed the front of the bus either from the entire passenger front entryway or the entire passenger compartment (see Figure 13).

Figure 13. Concept "Bus of the Future" passenger compartment with a perspective looking at the bus operator workstation with the door in the passenger entry mode position (left) and bus driving mode position (right). Used with permission from ITLC and STYL&TECH.

Another priority for the design was to avoid creating new obstructions due to the bus operator barrier and door and furthermore to improve visibility for driving, passenger boarding/deboarding, and passenger service. To accomplish this, the two positions of the door were intended to allow the bus operator to drive the bus without any new surfaces between the operator and the windshield or the passenger front entry door, which is considered to support visibility for driving and boarding operations similar to the driver side window on the street side of the bus. The additional static barriers added to the front of the bus were designed to avoid creating additional obstructions from the perspective of the bus operator while looking at the curb-side A-pillar, meaning the bus vertical structure on the front side of the front passenger entry door (see Figure 14). The bus operator workstation design also included concept cameras and displays positioned to avoid obstructing forward visibility and improving the size of objects and clarity of images usually viewed in the exterior side rear-view mirrors (see Figure 15).

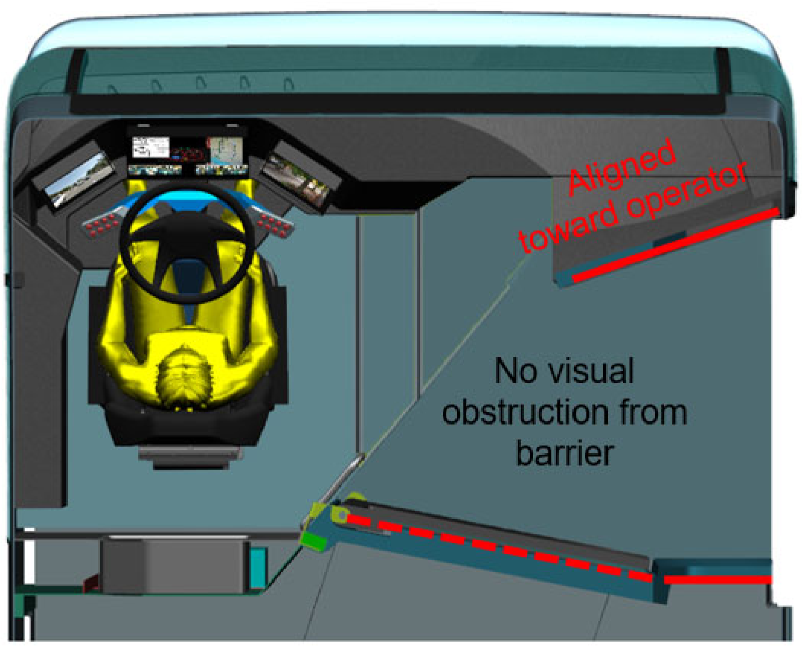

Figure 14. Concept "Bus of the Future" bus operator workstation compartment from top view demonstrating the bus operator barrier door in the driving mode position and angle of static barrier near the curb-side A-pillar aligned with the viewing angle of the bus operator. Used with permission from ITLC and STYL&TECH.

Figure 15. Concept "Bus of the Future" bus operator workstation with a view from the driver's perspective looking down at the displays in front of the steering wheel, which show views through the rearview cameras which replace the exterior side mirrors. Used with permission from ITLC and STYL&TECH.

The "Bus of the Future" team collaborated with the TCRP C-25 project team to provide information and design detail to support the illustration of one of the three concept bus operator barriers demonstrated in this project.

Design Criteria

Design criteria was collected from the following sources: APTA, the European Bus System of the Future (EBSF), ISO, and the TCRP. The criteria collection for bus operator barrier design built on a previous exercise of criteria collection produced in TCRP Report 185.[19] One of the tools that was developed with this report was Design Tool 1 – International Transit Bus Operator Workstation Guideline Matrix. This design criteria matrix was collected from three non-TCRP sources (i.e., APTA, ISO, and EBSF) and TCRP Report 25[20] to produce a full list of bus operator workstation design variables. The collection of these criteria was applied in the selection of design variables that impact bus operator barriers. Criteria from other sources such as the MIL-STD-1472G[21], SAE, Code of Federal Regulation Parts 37 and 38 (ADA), FMVSS, and some miscellaneous sources (e.g., NHTSA Letter of Clarification on Driver Shield for Buses and Vans) were also included in the collection.

The design variables included in the bus operator barrier requirement matrix were organized by area or component and features of that component. The areas and components are listed below. All features are provided in Appendix A.

- Operator workstation
- Steering wheel
- Fare box
- Bus floor
- Ventilation, climate
- Driver area barrier
- Driver's side window
- ADA wheelchair
- Side windows
- Bus operator barrier, door
- Seat
- Pedals
- Door control [passenger entry]
- Driver's area
- Ventilation, air flow
- Modesty panels
- Passenger doors
- General safety
- Bus operator barrier
- Mirror

Feature design variables were enumerated with each component design variable. Some examples of these feature variables for the "bus operator barrier" component variable are general, panels, materials-strength, materials-fire safety, materials-transparency, and passenger service-fare. Each of the individual feature variables was classified as to the level of interface with a bus operator barrier design along one of multiple levels: primary, secondary, tertiary, clearance, and reference only. Examples of these levels and features are examined below.

A feature variable criterion that has direct impact on the design of a bus operator barrier was classified as "primary." For example, the FMVSS criterion for feature variable "materials-strength" under the variable "bus operator barrier" states: "According to NHTSA, any transparent material to the right of a driver is an interior partition motor vehicle glazing that must comply with FMVSS No. 205, Glazing materials. FMVSS No. 205 requires by reference that the material comply with ANSI/SAE Z26.1-1996 fracture test." Therefore, this criterion directly impacts the strength requirement of selected glazing used in the bus operator barrier design.

A feature variable criterion that has a second-degree indirect interface with the design of a bus operator barrier was classified as "secondary." For example, the FMVSS criterion for feature variable "Controls and Temperature Uniformity" under the variable "ventilation, climate" states:

> Per FMVSS No. 103, S4. Except as provided in paragraph (b) of this section [applicable to non-continental US bus manufacturing], each passenger car shall meet the requirements specified in S4.1, S4.2, and S4.3, and each multipurpose passenger vehicle, truck, and bus shall meet the requirements specified in S4.1. S4.1 states that each vehicle shall have a windshield defrosting and defogging system. Criteria should be applied from SAE J381-JUN2020 Recommended Practice for defrosting performance of windshield target and defrosting performance of side window project mirror perimeter.

This criterion indirectly impacts the bus operator barrier due to criteria for the HVAC defrosting and defogging performance of glazing on the bus operator barrier between the bus operator and windshield, curb-side mirror, or passenger entry door glass, which could affect driving visibility.

A feature variable criterion that has a third-degree indirect interface with the design of the bus operator barrier was classified as "tertiary." For example, the EBSF criterion for feature variable "spacing" under the variable "pedals" states: "Accelerator pedal: longitudinal spacing with bodywork (min. 50 mm); lateral spacing with bodywork (min. 30 mm)." This pedal positioning and spacing determines the position of the bus operator in the workstation. The bus operator barrier is intended to maximize coverage of the bus operator for security. Clearances around the bus operator's feet and shoes on the pedals could affect dash panels and the size and position of the bus operator barrier relative to the bus operator workstation pedals and dash near the workstation. This area near the workstation often includes the fare box as well. The position and size of the fare box are related to these criteria for bus operator workstation clearance and closeout.

A feature variable criterion that has a clearance interface with the design of the bus operator barrier was classified as "clearance." For example, the ISO 16121 criterion for feature variable "workplace width" under the variable "operator workstation" states: "The bus operator compartment should allow for clearance to the operator's shoulders and elbows (min. 800 mm cross-bus)." The bus operator needs to have sufficient clearance for their arms and elbows to move in the seat and adjust the steering wheel rotation while driving. Therefore, this clearance should be afforded in the bus operator barrier design. It is not a primary level criterion because this criterion is not a property of the barrier itself, but this clearance remains very important.

Some feature variable criteria did not have a direct, indirect, or clearance interface with the design of bus operator barriers. However, the criteria are informative as a "reference" to designers and implementers when developing a solution. For example, the APTA criterion for feature variable "strength" under the variable "modesty panels" states: "The modesty panel and its mounting shall withstand a static force of 250 lbs. applied to a 4 × 4-inch area in the center of the panel without permanent visible deformation." This criterion may be useful as a security and strength test for surfaces that are not glazed and not impacted by FMVSS No. 205 criteria, but which still need to withstand damage from intentional force directed at the bus operator.

Design for Risk Mitigation

The bus operator barrier designs were conceived based on the priorities requested by the TCRP Panel, including assault prevention, air quality and ventilation, thermal considerations; bus operator visibility, protection, security, safety, health, mobility, and comfort, ADA compliance for bus access and mobility; and emergency egress. Three concept bus operator barrier configurations were developed to mitigate these risks to bus operators while recognizing that transit agencies will seek a range of options based on cost, complexity, and prioritization of risks for new and existing buses. The first two concepts "A" and "B" were developed focusing on existing bus production in North America. These two concepts were intended to be capable of being integrated and manufactured in first purchase production or after-market transit buses. However, the third concept "C" was based on the expectation that the bus operator workstation would be integrated with the entire bus body at first purchase production in future buses.

The research team at VTTI applied the information collected from the TCRP Panel, guidelines, standards, previous research, and the survey to develop a target risk mitigation approach for the three bus barrier concepts. The target assignment of risk mitigation to bus operator barrier design concept and relative cost/complexity is provided in Table 1.

Table 1. Bus operator barrier design concepts, type, relative cost/complexity, and risk control mitigation.

			Risk Controls						
Concept	**Type**	**Cost**	**Physical**	**Spitting**	**Air**	**Temperature**	**ADA**	**Usability**	**Visibility**
A	Retrofit/ Integrated	Low	medium	low	low	low	high	medium	medium
B	Retrofit/ Integrated	Moderate	high	medium	medium (pressure)	medium	high	high	high
C	Integrated	High	high	high	high (filtration)	high	high (mid-door)	high	high

Concept A Risk Mitigation Targets

- Type: Retrofit/integrated
  - This concept was intended to be retrofit on existing buses or integrated into first purchase buses. The barrier was primarily composed of one panel that also serves as the door for the bus operator to access the bus operator workstation.
- Cost: Low
  - The barrier was intended to be relatively low cost and complexity to develop, manufacture, and install.

- Physical attack mitigation: Medium
  - The barrier was made large enough to limit most physical attacks by reaching towards the bus operator at a medium risk mitigation.
- Spitting attack mitigation: Low
  - The barrier does not extend to the windshield and therefore will provide low risk mitigation for spitting attack, since passengers who intend to expectorate on the bus operator may be able to get around the barrier.
- Air quality mitigation: Low
  - The barrier does not extend to the windshield and therefore will provide low risk mitigation for air quality since air mixture and air flow will not be affected by the barrier.
- Temperature mitigation: Low
  - The barrier does not extend to the windshield and therefore will provide low risk mitigation for temperature.
- ADA accessibility mitigation: High
  - The barrier design was intended to avoid interference with handholds for passengers with ambulatory impairments, and the barrier was also intended to avoid interference with the minimum ADA wheelchair access and targeted a high-risk mitigation.
- Usability mitigation: Medium
  - The barrier is operated manually by the bus operator and does not need to be adjusted between passenger-entry and driving mode positions, which leads to a medium usability risk mitigation target.
- Visibility mitigation: Medium
  - Due to the fixed location of the barrier during passenger boarding and driving modes of revenue operations, the glazing of the barrier must not extend into the line of sight for the range of all driver eyepoints when looking at the curb-side mirror. The glazing was intended to extend to a height that may be in the line of sight to the front entry door to limit physical attacks and therefore targeted a medium visibility risk mitigation due to the possibility of glare on the glazing when looking at the passenger front entry door.

Concept B Risk Mitigation Targets

- Type: Retrofit/integrated
  - This concept was intended to be retrofit on existing buses or integrated into first purchase buses. The barrier was designed to be assembled with a door panel and additional panels to create closeouts between the passenger front entry door area and the front right wheel panel on the curbside of the bus.
- Cost: Moderate
  - The barrier was intended to be relatively moderate cost to develop, manufacture, and install. This is due to the automatic features that will be integrated with other bus controls, and the additional closeout panels between the passenger front entryway and the passenger compartment may increase costs above the first concept barrier.
- Physical attack mitigation: High
  - The barrier extends to the windshield but not the interior roof of the bus and therefore was intended to provide high risk mitigation for physical attack.
- Spitting attack mitigation: Medium
  - The barrier extends to the windshield but not the interior roof of the bus and therefore was intended to provide medium risk mitigation for spitting attack.
- Air quality mitigation: Medium (air pressure capable)
  - The closeouts between the passenger front entryway and the passenger compartment along with the size of the barrier were intended to minimize gaps to 1-inch. This design is intended to provide a high-pressure zone on the front of the bus operator barrier if HVAC/defrost fan controls and exterior bus

openings are managed to enable this flow away from the bus operator. Therefore, a medium risk mitigation was targeted for air quality.

- Temperature mitigation: Medium
  - The size of the barrier was intended to limit cold air flow from the passenger front entry door, but it was not intended to maintain a sealed and separate climate zone for heating and air conditioning temperature management around the workstation. Therefore, the concept targeted a medium risk mitigation for temperature.
- ADA accessibility mitigation: High
  - The barrier design was intended to avoid interference with handholds for passengers with ambulatory impairments, and the barrier was also intended to avoid interference with the minimum ADA wheelchair access thus targeting high risk mitigation.
- Usability mitigation: High
  - The barrier door was intended to be pneumatic-powered and automatically move between passenger-entry and driving mode positions with electro-magnetic latching at each position, which leads to a high usability risk mitigation. This operation requires additional complexity to tie the system to the passenger entry door setting. Additionally, a manual override should be included in this design to allow the bus operator to move the barrier door while the passenger entry door is closed during periods of customer service. An emergency egress latch is also necessary in case the bus is involved in a collision and the door needs to be physically released without shutting down the bus's power from inside the bus.
- Visibility mitigation: High
  - Due to the automatically adjusting position of the barrier during the driving mode, the glazing of the barrier can extend into the line of sight for the range of driver eyepoints when looking at the curb-side rear view mirror and front entry door and still target a high visibility risk mitigation.

Concept C Risk Mitigation Targets

- Type: Integrated only
  - This concept was intended to be developed and integrated into first purchase buses on a new bus body and chassis. The concept was composed of both a door panel with drop glass and additional stationary panels to seal and separate the workstation from the bus passenger front entryway or from the passenger compartment.
- Cost: High
  - Because the barrier was intended to be developed as part of a new body and chassis design, the cost to develop, manufacture, and install was anticipated to be high.
- Physical attack mitigation: High
  - Because the barrier completely separates the bus operator from the passenger front entryway and passenger compartment, this concept was intended to provide high risk mitigation for physical attack, unless the driver decides to leave the drop glass lowered.
- Spitting attack mitigation: High
  - Because the barrier completely separates the bus operator from the passenger front entryway and passenger compartment, this concept was intended to provide high risk mitigation for spitting attack, unless the driver decides to leave the drop glass lowered. This sealed doorway may also target an additional risk mitigation reducing stress on bus operators from verbal abuse or attack.
- Air quality mitigation: High
  - This concept was intended to provide a high-pressure zone on the front of the bus operator barrier in at least the bus operator workstation closed position. Therefore, a high-risk mitigation was targeted for air quality.
- Temperature mitigation: High

  - Because the design was intended to seal the airspace between the bus operator and the passenger front entryway or passenger compartment, separate climate zones were intended for heating and air conditioning. This could lead to a need to defrost and defog these additional glazing surfaces with HVAC ducts near the barrier door and glazing. These opportunities come with added complexity and cost to the bus HVAC and defrost systems.
- ADA accessibility mitigation: High (mid/rear door)
  - The barrier design was intended to convert the primary entry door to the mid or rear positions for all passengers or at least persons with ambulatory or ADA accessibility challenges. With this conversion in mind and assuming the docking operations in the future could be modified to provide for ADA mid/rear door entry, the target for ADA risk mitigation was high. If these assumptions cannot be met, then other solutions for separating the bus operator workstation would need to be developed or lower risk mitigation would need to be targeted in future production design exercises.
- Usability mitigation: High
  - Like Concept B, the barrier was intended to be pneumatic-powered and automatically move between passenger-entry and driving mode positions with electro-magnetic latching at each position, which leads to a high usability risk mitigation. Production designs may include a separate door control feature like the passenger entry door, allowing bus operators to leave the door in either position. This operation requires additional complexity to tie the system to the passenger entry door setting or develop a separate barrier door control. Additionally, a manual override was intended to be included in this design to allow the bus operator to move the barrier door while the passenger entry door is closed during periods of customer service. An emergency egress latch is also necessary in case the bus is involved in a collision and the door needs to be physically released without shutting down the bus's power from inside the bus.
- Visibility mitigation: High
  - This concept barrier door also includes a drop-glass feature, allowing the driver the choice to keep the glazing lowered during driving and customer service periods. According to the "Bus of the Future" team, the stationary barrier panels near the curb-side entry area and A-pillar were designed to be in the line of sight of the existing A-pillar to avoid additional visibility obstructions beyond those present due to bus body structure. The bus operator workstation design also included rearview mirror cameras and integrated displays; therefore, this design targeted high visibility risk mitigation. If all these features could be executed and implemented well in final production, this bus operator workstation would be considered best in class for visibility.

CHAPTER 3

Findings

Survey Results

The data captured with this survey was intended to inform the transit industry and its stakeholders about the current use of bus operator barriers and to inform future guidelines and barrier designs, including the bus operator barriers being designed as part of this project. It should be noted that survey respondents were not required to answer all questions. Respondents may have chosen to skip certain questions due to lack of data or knowledge on that topic and some questions directed the respondents to skip questions based on their responses to another question. In those cases, total responses per question were less than the total number of respondents who at least started the survey.

Survey Demographics

A total of 77 respondents submitted survey results from across North America. The survey was distributed in Fall of 2022 through Winter 2023. Forty-nine (49) respondents identified their organization or agency affiliation. Seven (7) respondents did not identify their affiliation. Other respondents skipped this question. Out of the 49 who identified, two of the survey respondents were from Canada while the other 47 were from across the United States. Table 2 provides a list of transit agencies and organizations represented in the survey.

Table 2. Transit agencies completing bus operator barrier survey (n = 56).

Agency	Surveys Completed
ABC	1
Broward County Transit (Florida)	1
Central Ohio Transit Authority	1
Central Virginia Alliance for Community Living	1
Chicago Transit Authority	1
DC Metro	2
Detroit Department of Transportation	2
El Dorado County Transit	1
Fairfax County Department of Transportation (Virginia)	2
First Transit Inc.	1
Greater Peoria Mass Transit	2
JTRAN (City of Jackson, MS)	1
Lake Erie Transportation Commission (Monroe, MI)	1
Lane Transit District (Lane County, OR)	12
Lowell Regional Transit Authority (Massachusetts)	1

Agency	Surveys Completed
MARTA (Atlanta, GA)	1
New York City Transit	3
Omnitrans (San Bernadino, CA)	2
Pierce Transit (Pierce County, WS)	1
Pittsburgh Regional Transit	2
Regional Transportation Agency of Central Maryland	1
SABIC	1
San Diego Metropolitan Transit System	1
San Francisco Municipal Transit Agency	1
SEPTA (Philadelphia, PA)	1
Toronto Transit Commission	2
Transit Workers Union	2
TriMet (Portland, OR)	1
No organization listed	7

Survey respondents were asked to provide their current job title, role, and/or position at their current transit agency of employment. Job roles were broken into four basic categories with each category having different job titles or positions for respondents to choose from. The four basic job role categories were:

- Administration, Upper Management, and Executive Leadership (Agency Level)
- Maintenance Operations (Depot, Division, Department Level)
- Transportation Operations (Depot, Division, Department Level)
- Engineering, Procurement, and Non-operations (Agency Level)

Figure 16 provides the percentage of the 77 survey respondents for job title, role, or position within their respective transit agency.

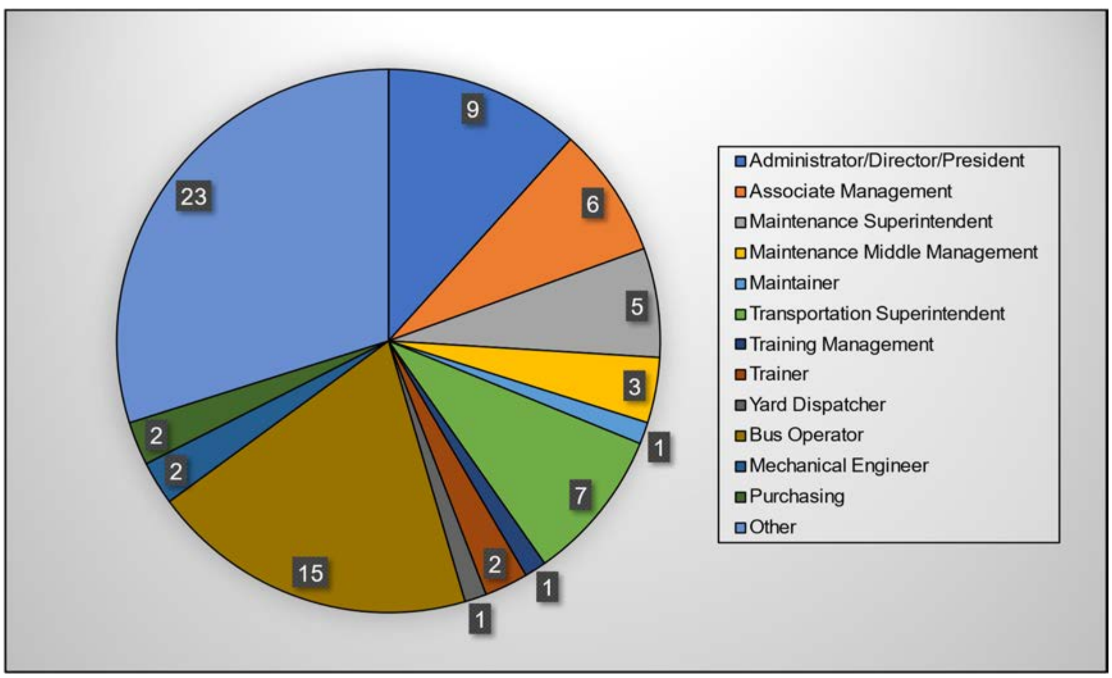

Figure 16. Total survey respondents by job role/title/position (n = 77).

Across 53 survey respondents, the mean years of experience in their current job title, role, or position was 9.7 years with a high of 34 years and low of 1 year. Table 3 breaks out mean years of experience by job category. Additionally, among 45 survey respondents 11 (24%) identified as being a union representative.

Table 3. Mean years of experience by job category (n = 53).

Job Category	Average Years of Experience
Administration, Upper Management, and Executive Leadership	8.4
Maintenance Operations	6.3
Transportation Operations	14.7
Engineering, Procurement, and Non-operations	3.5

Agency Barrier Use

The next set of survey questions captured overall use of bus operator barriers, the main purpose of the bus operator barrier for their respective transit agency, and whether barrier use would continue as the COVID-19 pandemic has begun to wane.

The results among 54 respondents showed that 52 (96%) of these respondents indicated their transit agency was currently using bus operator barriers. Among 51 respondents, only 16 (31%) indicated their transit agency was utilizing bus operator barriers prior to the COVID-19 pandemic. As a follow-up question for transit agencies utilizing bus operator barriers prior to the COVID-19 pandemic, these respondents were asked to identify the primary reason for their use. Table 4 provides a breakdown of bus operator barrier use factors among 16 respondents.

Table 4. Bus operator barrier use factors prior to COVID-19 pandemic (n = 16).

Primary Reason for Bus Operator Barrier	Total Responses
Prevention of Physical Assault	11
Bus Operator Health (e.g., sneeze guard)	1
Both	2
Other	2

Among respondents indicating their transit agency did not utilize bus operator barriers prior to the COVID-19 pandemic, all 34 indicated their agency planned to continue utilizing the bus operator barriers even as the COVID-19 pandemic has begun to wane, and restrictions are lifted.

Requirements may vary between transit agencies on required use of the bus operator barriers by their operators. To assess this requirement, survey respondents were asked to indicate whether the bus operator barrier was required to be actively used during revenue generating operations. A total of 50 respondents chose to answer this question, with 46 (92%) reporting they are required to actively use the bus operator barrier during revenue generating runs while four (8%) were not required to actively use the barrier.

Finally, for respondents who indicated their transit agency is not currently utilizing bus operator barriers, three reported that their agency has either considered or is currently considering the use of bus operator barriers. The primary reasons respondents gave why these agencies have not implemented bus operator barriers were:

- no record of assaults,
- concern for emergency evacuation of the operator, and
- would like more research to determine the quality and effectiveness of barriers.

Barrier Design and Process

The survey requested information about the design elements of current bus operator barriers in use, including the selection and evaluation, redesign, continued use, ADA compliance, and emergency egress. Survey respondents were asked to describe the type of barriers in use by their respective transit agency. A wide range of barrier materials and designs were provided and are listed below:

- Vinyl shower curtain
- Full plexiglass enclosure
- Full polycarbonate enclosure
- Steel half barrier door
- Full barrier with steel lower half and sliding plexiglass upper half
- Full barrier with steel lower and glass upper half with powered windows and separate fan controls
- Some indicated the upper half can be opened separately from the lower half

Various personnel are often involved in the selection and evaluation of bus operator barriers. A total of 34 respondents answered this question. Figure 17 provides a breakdown of the categories of responses for personnel involved in the selection and evaluation for their transit agency's bus operator barrier.

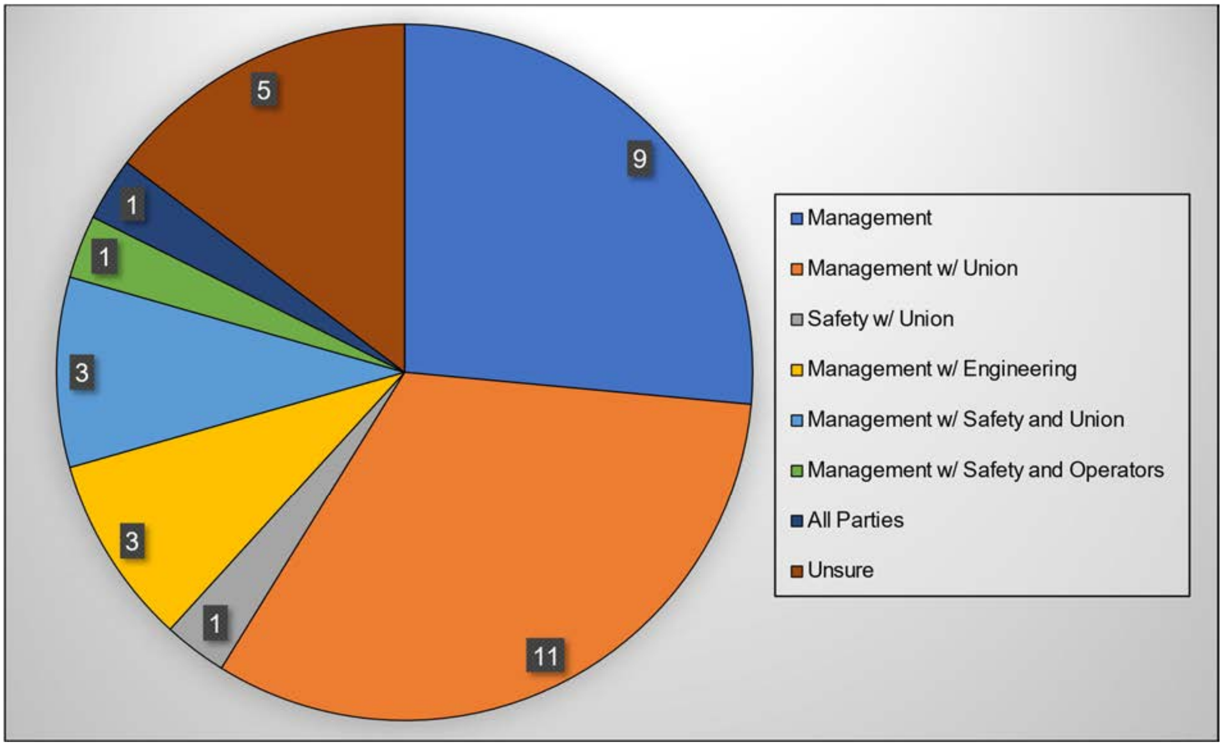

Figure 17. Personnel Involved for Selection and Evaluation of Bus Operator Barriers (n = 34)

More detail on the barriers was provided by respondents. Among 37 respondents, 15 (41%) indicated there had been a redesign since the initial installation of their bus operator barriers. Among 39 respondents, 38 (97%) indicated that bus operator barriers are still in use today at their respective transit agency.

Interestingly, one respondent out of 38 respondents indicated their bus operator barrier had automated opening and closing while a second respondent indicated their barriers were both manual and automated. All other respondents indicated manual operation of their barriers.

All but one respondent out of 38 indicated that the front passenger doors are still operable and accessible by able-bodied passengers; however, 29 (74%) of 39 respondents indicated their bus operator barrier was ADA compliant in terms of allowing passenger flow and mobility devices through front door access. Nine of the 39 respondents did not know if the barrier was compliant.

Two factors very important to the bus operators themselves were emergency egress and visibility or glare concerns. Only 23 (59%) out of 39 respondents indicated their bus operator barrier had emergency egress while 16 (41%) reported there was no emergency egress. As for the visibility and glare concerns, a slight majority, 21 (54%) out of 39 respondents, indicated that their bus operator barrier did take into consideration their visibility and glare concerns while 18 (46%) indicated their barrier did not consider these factors.

Barrier Samples

Respondents of the survey were asked to share images of their barriers for reference in the study. Only two respondents chose to upload images. One response showed that transparent vinyl sheets were hung above the standee line between the passenger compartment and the passenger front entryway (see Figure 18). The second image was a CAD model rendering demonstrating a complex and pneumatically powered bus operator barrier door with panels that can be adjusted by the bus operator (see Figure 19).

Figure 18. Sample image (1) provided by a survey respondent.

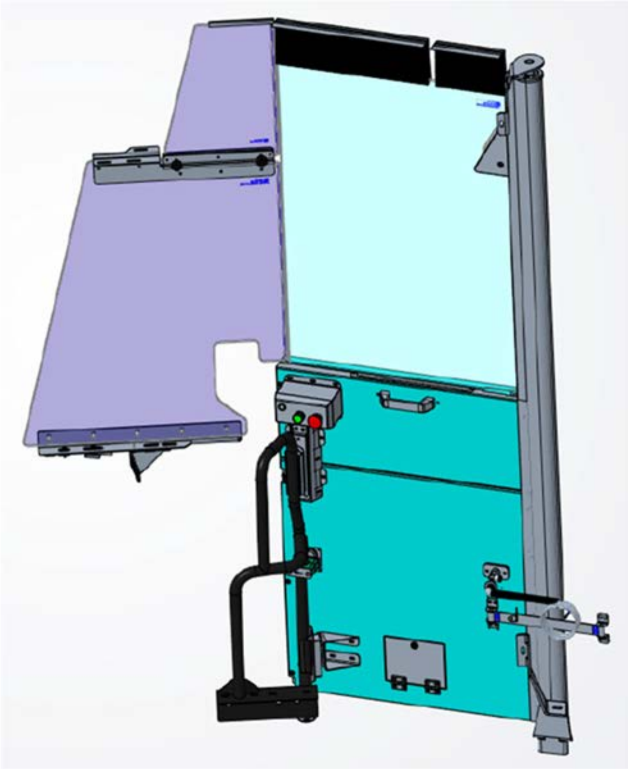

Figure 19. Sample image (2) provided by a survey respondent.

Maintenance

To ensure bus operator barriers are functioning correctly, proper maintenance is critical. Survey respondents were asked to indicate the maintenance cycles, if known, of the current bus operator barriers in use at their agency. A total of 37 responses were received for this question. Table 5 provides the reported maintenance cycles.

Table 5. Bus operator barrier maintenance cycle (n = 37).

Maintenance Cycle	Total Responses
1 Time per Year	3
2–3 Times per Year	8
4 or More Times per Year	5
Never	1
I Don't Know	20

Survey respondents were provided with an open-ended opportunity to describe the most common types of required maintenance conducted on their bus operator barriers. Maintenance needs were described among 31 responses. Figure 20 provides categories among those maintenance needs for bus operator barriers.

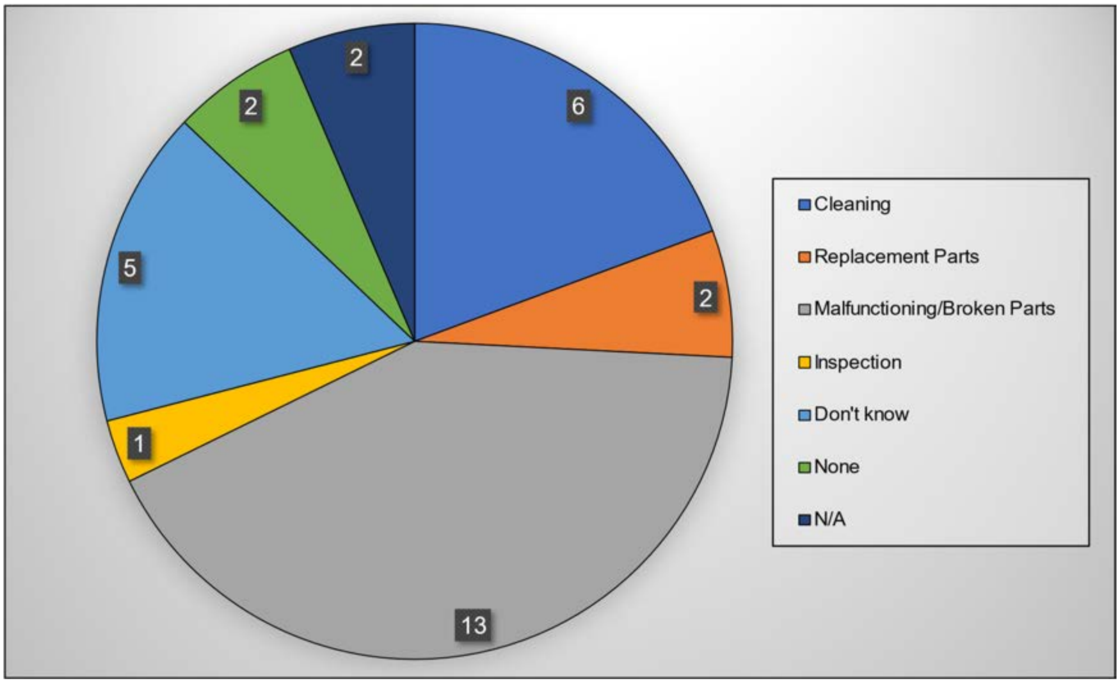

Figure 20. Categories of required bus operator barrier maintenance (n = 31).

Costs

Respondents were asked to provide the initial cost of bus operator barriers, average yearly maintenance costs per bus operator barriers, average life cycle of the barriers, and whether the bus operator barriers were designed in-house, by the bus manufacturer, or by a third-party vendor.

Many respondents (20) among the 31 received indicated they did not know or were unsure of the initial costs per bus operator barrier. Of the 11 respondents who provided a cost estimate, retrofit barrier costs ranged from $25 (i.e., shower curtain) to $7,000 per barrier, while factory installed barriers on new buses ranged from $3,000 to $7,500 per barrier.

Respondents also provided information on the design of the bus operator barriers. Among the 33 responses received, eight (24%) reported the barriers were designed in-house, 13 (39%) reported the barriers were designed by a third-party vendor, six (18%) reported the barriers were designed by some combination of both in-house and third-party, and six (18%) reported being unsure.

The survey also sought information regarding the average yearly maintenance costs per bus operator barrier as well as the average life cycle of these barriers. Among 29 respondents, 19 indicated they did not know the average yearly maintenance cost per barrier; however, 10 respondents reported average maintenance costs ranging from $0–1000 per barrier per year. Similarly for the average life cycle of bus operator barriers, among 30 respondents 22 were unsure. Of the eight respondents providing estimates of the average life cycle, the life cycle ranged from 1 to 13 years with four respondents reporting the bus operator barrier lasts the life of the bus.

Effectiveness and Desired Features

Effectiveness

Respondents were asked to report any challenges they encountered when implementing the bus operator barriers. Note: respondents could indicate more than one challenge. A total of 30 respondents answered this question with 39 responses. Figure 21 provides a breakdown of the implementation challenges.

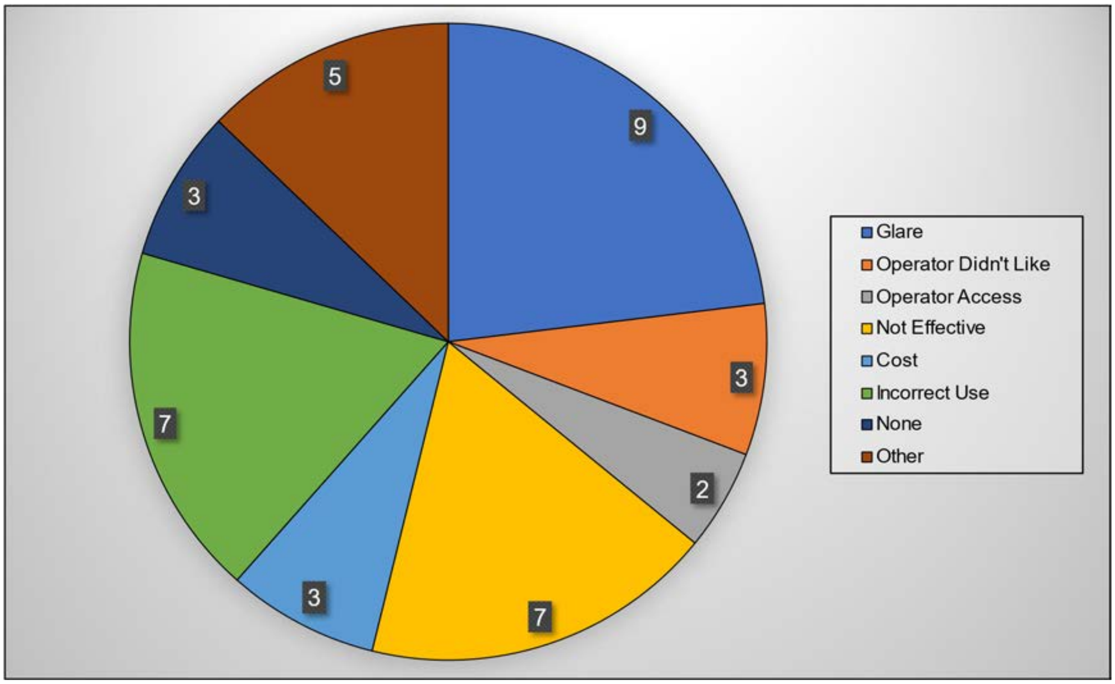

Figure 21. Bus operator barrier implementation challenges. Thirty respondents provided 39 barrier implementation challenge responses.

When it came to training on the use of the bus operator barrier, a total of 33 respondents answered this question. Slightly less than half (16) of respondents indicated training was provided to bus operators regarding barrier use and maintenance. No training was indicated by 14 respondents and three did not know. A follow-up to this question asked respondents to describe this training. No responses were received.

Thirty-one respondents reported on benefits and outcomes, with the largest benefit and positive outcome being a reduction in assaults, as reported 10 (32%) times. Some respondents reported multiple benefits. Improved operator protection or confidence was reported six (19%) times. Other reported benefits included reduced operator sick days (1), reduced operator injury (1), general benefits (1), and airborne pathogen was contained (2). Negative responses included increased assaults (2) and increased workers comp (1) while six responses of unknown and five responses of no benefits were also reported.

Among 33 respondents, a majority (22) of respondents indicated that operators did complain about barriers and 11 responded that bus operators do not complain. As to passengers, a small number (2) of the 33 respondents reported passengers complaining about bus operator barriers. While both of these questions asked for descriptions explaining the complaints, no responses were provided.

Return-on-investment (ROI) is often a critical factor for implementation. Of the 28 respondents to this question, 20 indicated they did not know if there was an ROI on the use of the barriers and three indicated it was not applicable. Among respondents who described ROI factors, responses included reduced assaults

(1), reduced workers comp claims (1), and preventing operator sickness (3) as factors that would calculate into their transit agency's ROI calculation.

On the overall success of bus operator barriers, 12 of 31 respondents indicated that barrier use had been successful, 13 indicated barrier use was partly successful, and 6 indicated barrier use was unsuccessful for their organization. An overwhelming majority, 32 of 33 respondents, reported their organization plans to continue the use of bus operator barriers, while only one indicated their organizations would not continue use.

Desired Features

Respondents were asked to describe their ideal bus operator barrier, considering personal experience and lessons learned. The most common response from the 25 respondents was full operator barrier/protection (11). Some respondents provided multiple attributes. Other responses included anti-glare (5), better ventilation or air movement (2), full/partial open/protection option/auto lock barrier (2), adjustable window slider (1), temperature control (1), OEM build and install (1), emergency latch for emergency escape (1), and an intercom for communication between operator and passengers (1). One respondent commented that because visibility was more important than a false sense of safety, not using a barrier would be ideal. Responses also included "none," "unknown," and "not appliable," which were reported by one respondent each.

Barrier Designs

Three bus operator barrier designs were developed based on the issues present in the North American transit bus industry today and the range of preferences and needs identified by the survey. The designs seek to address the risk mitigation targets defined in the approach. The three concept designs are illustrated below.

As demonstrated in Figure 22, Concept A was based on existing bus operator barrier design framework used today in NYC. See discussion in the section of this report entitled, "Previous Research." Data collected from multiple bus and barrier configurations were considered in this design. Concept A was modeled in an existing battery electric low floor transit bus provided by GILLIG, LLC to demonstrate the size, scale, and feasibility of the concept in a current production bus. This barrier concept was not developed by GILLIG, LLC and should not be considered a final assembly that could be immediately manufactured or installed in any specific bus configuration.

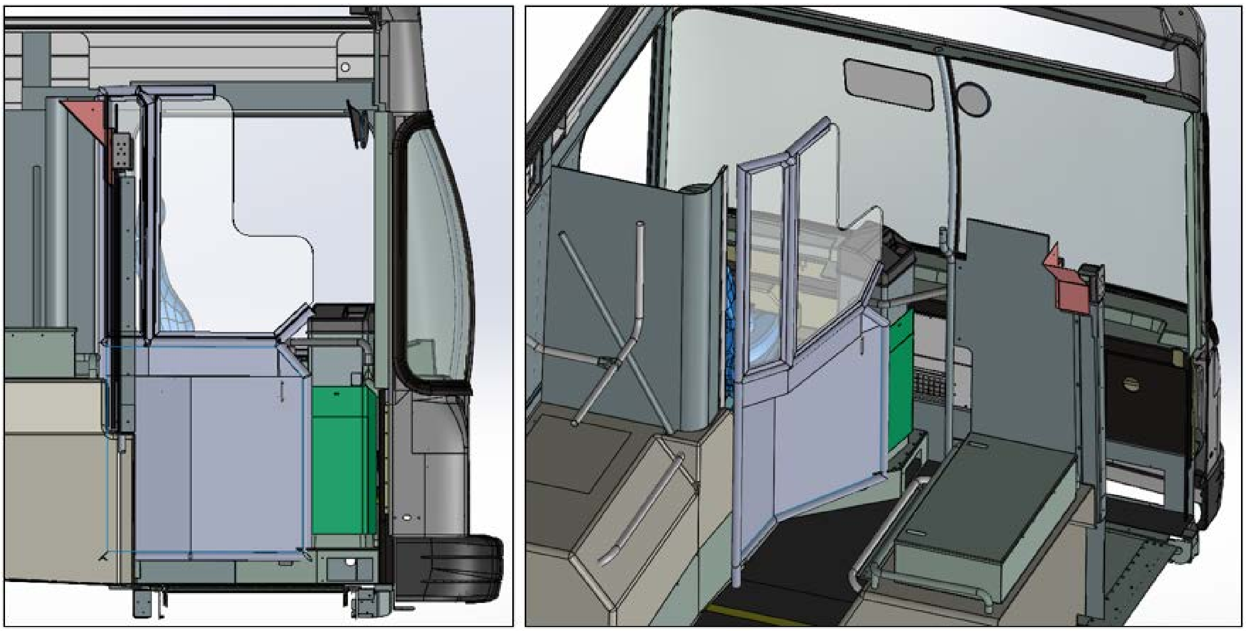

Figure 22. Concept A bus operator barrier.

As demonstrated in Figure 23, Concept B was based on a novel idea to maximize the barrier size between the bus operator and the passenger front entryway with the intention that the bus barrier door would move with the front entry door at every stop to provide protection for the bus operator while stopped and to provide an unobstructed view via transparent glazing while driving after the passenger front entry door is closed. Concept B was modeled in an existing battery electric low floor transit bus provided by GILLIG, LLC to demonstrate the size, scale, and feasibility of the concept in a current production bus. This barrier concept was not developed by GILLIG, LLC and should not be considered a final assembly that could be immediately manufactured or installed in any specific bus configuration.

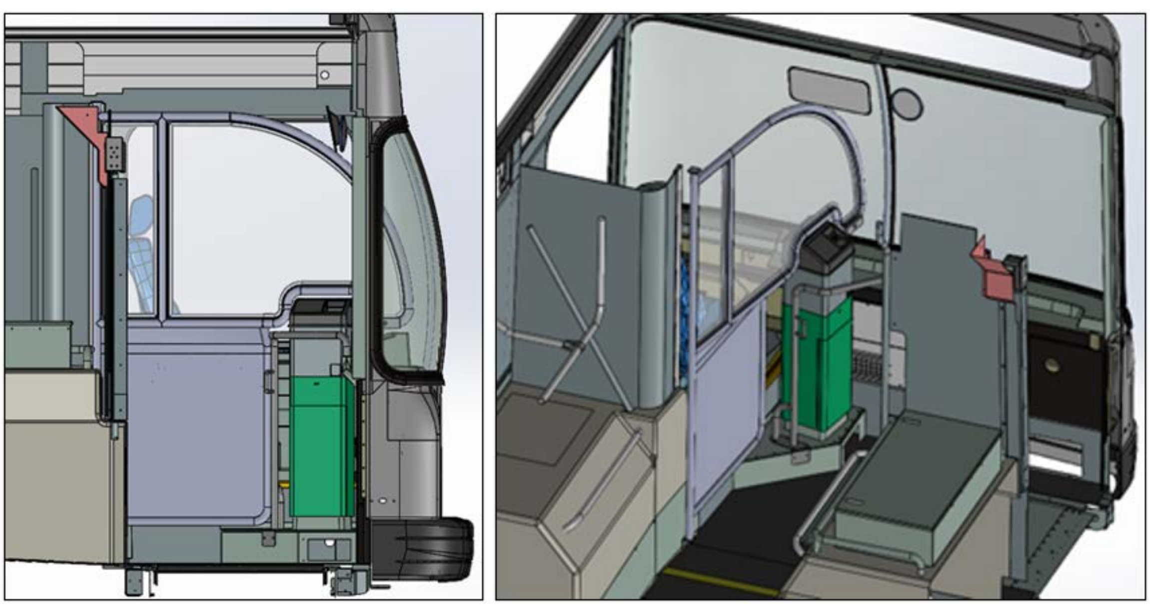

Figure 23. Concept B bus operator barrier.

As demonstrated in Figure 24, Concept C was based on a novel barrier and bus body/chassis idea to completely separate the bus operator from the passenger front entryway and passenger compartment with the intention that the bus barrier door would move automatically with the front entry door at every stop (like Concept B), provide protection for the bus operator while stopped, and provide an unobstructed view while driving after the passenger front entry door is closed. Concept C was modeled inside a Van Hool low floor transit bus that is no longer in production to demonstrate the size, scale, and feasibility of the concept in a realistic low floor transit bus vehicle architecture. This barrier concept and the bus operator workstation model would require further bus body and chassis prototype development before the Concept C bus operator barrier could be developed for full production.

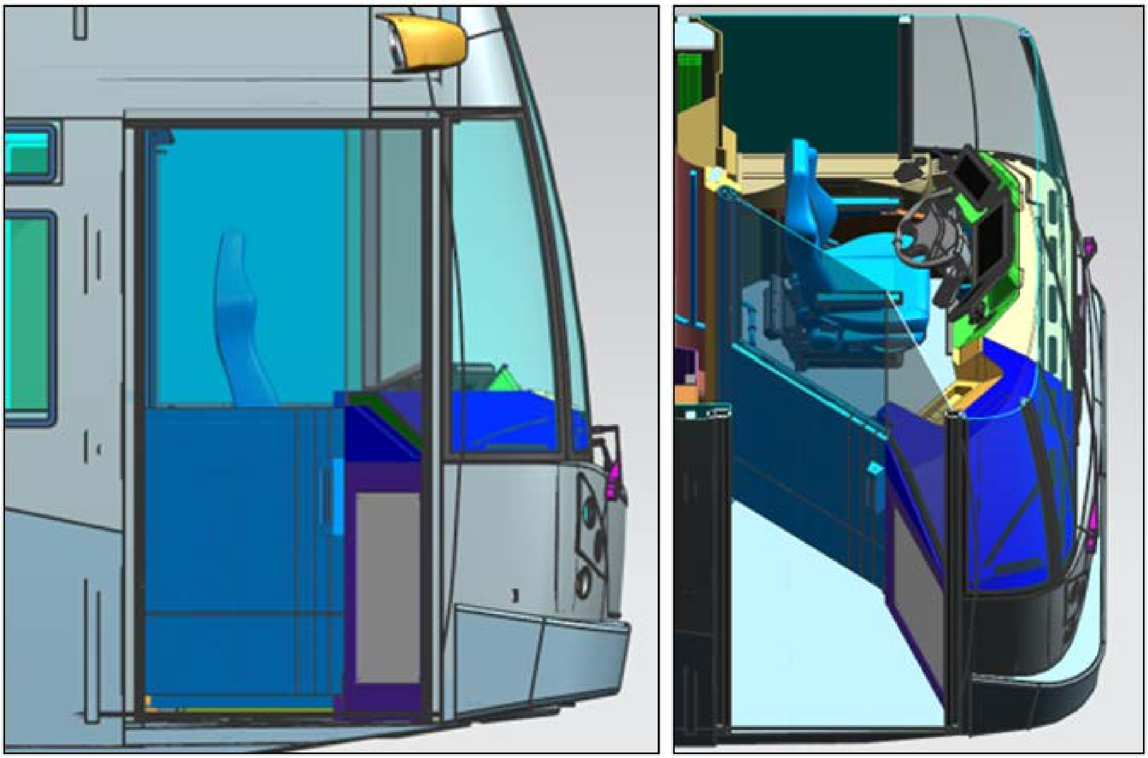

Figure 24. Concept C bus operator barrier. Used with permission from ITLC and STYL&TECH.

Requirement Matrix Concept Status

Design criteria that pertain to bus operator barriers were organized according to component/area variables and feature variables as described in the section titled "Approach to Bus Operator Barrier Designs, Design Criteria." The full criteria list is provided in the requirement matrix in Appendix A. During the development of the bus operator barrier Concept A and B by the research team, these criteria were applied to guide the attributes of the concepts. The design effort in the "Bus of the Future" project occurred before the collection of criteria for this project was complete. However, draft versions of the requirement matrix were shared with the "Bus of the Future" project team.

The application of the requirement matrix included two steps for each of the bus barrier concepts. First each criterion was evaluated against each concept. If a criterion applied to the concept (i.e., A, B, C) then that concept (letter) was identified with that criterion. For example, the feature variable "Glare, General" in the variable "Driver's Area" references a criterion from APTA that the glare should "…minimize to the extent possible." This criterion applies to Concept A because even though glazing was designed to avoid interference from the bus operator's vision with the curbside rearview exterior mirror, the glazing is fixed during bus driving and may interfere or collect glare over the view of the passenger front entry door used to see that side of the bus for driving. However, the Concept B bus operator barrier is intended to automatically adjust position to latch against the passenger compartment partition and will not interfere with the bus operator's view of the mirror or passenger entry door. For this example, Concept C was also included as a priority for this criterion in case the bus operator chooses to keep the barrier door latched near the bus operator workstation, which could interfere with the bus operator's view of the passenger entryway door and collect glare.

The second step in the application of the requirement matrix was to define the status or anticipated satisfaction of that criterion based on the final design of each bus operator barrier concept. Using the same example above, the status for the feature variable "Glare, General" for Concept A was, "Potential issue, material selection is crucial." The status for this feature variable for Concept B was, "Alleviated by closing barrier door to rear for driving." The status for this feature variable for Concept C was, "Barrier glazing can be lowered to reduce glare. Glare from the barrier can be alleviated by closing barrier door to rear for driving. Fixed glazing is parallel to the line of sight to minimize obstruction. It should reach to vehicle 'B-post' to ensure a direct view to the windshield and side window." Status and descriptions for each criterion and concept bus operator barrier are provided in the requirement matrix for use by designers and implementers.

Risk Mitigation Evaluation

Each of the bus operator barrier concepts was evaluated against the target risk mitigation attributes. The findings of this evaluation are organized by concept and risk attribute.

Concept A Risk Mitigation

Physical, Spitting and Other Attacks

As demonstrated in Figure 25, Concept A was estimated to provide high mitigation of direct physical contact by limiting reach by passenger; low mitigation of shooting weapon around barrier; and low mitigation of spitting around/over barrier. Passengers may be able to reach around the door and release the operator-side latch.

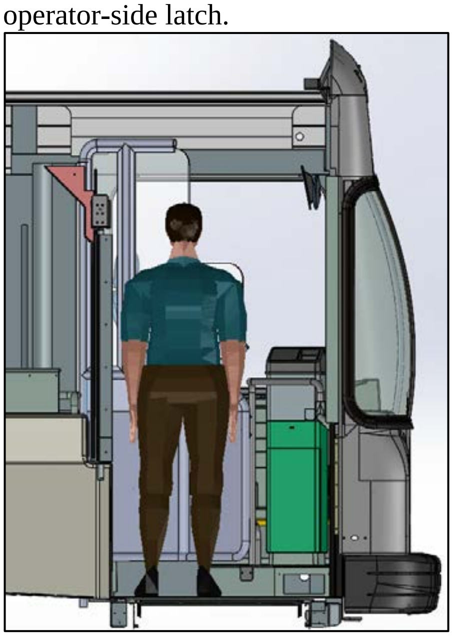

Figure 25. Large male standing next to Concept A bus operator barrier.

Air Quality

As demonstrated in Figure 26, Concept A was estimated to provide no mitigation of coughing/sneezing risk and no mitigation of air quality risk.

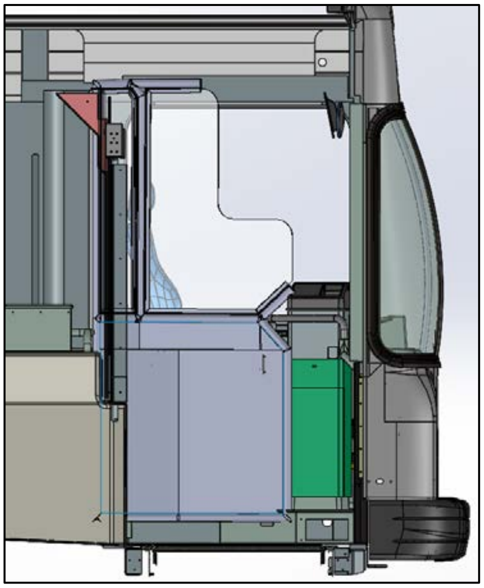

Figure 26. Side view of Concept A bus operator barrier latched at bus operator workstation demonstrating large gaps to windshield and roof for air exchange.

Temperature

Concept A was estimated to provide low mitigation of cold temperatures since the barrier may reduce cold gusts through the passenger entryway door but no change to temperature and humidity. The gap between the barrier and windshield may limit the potential benefit.

ADA

As demonstrated in Figure 27, Concept A was estimated to pass clearance for passengers with disabilities based on the minimal dimensions for the ADA clearance box. This concept maintains the current common configuration for the front entry ramp.

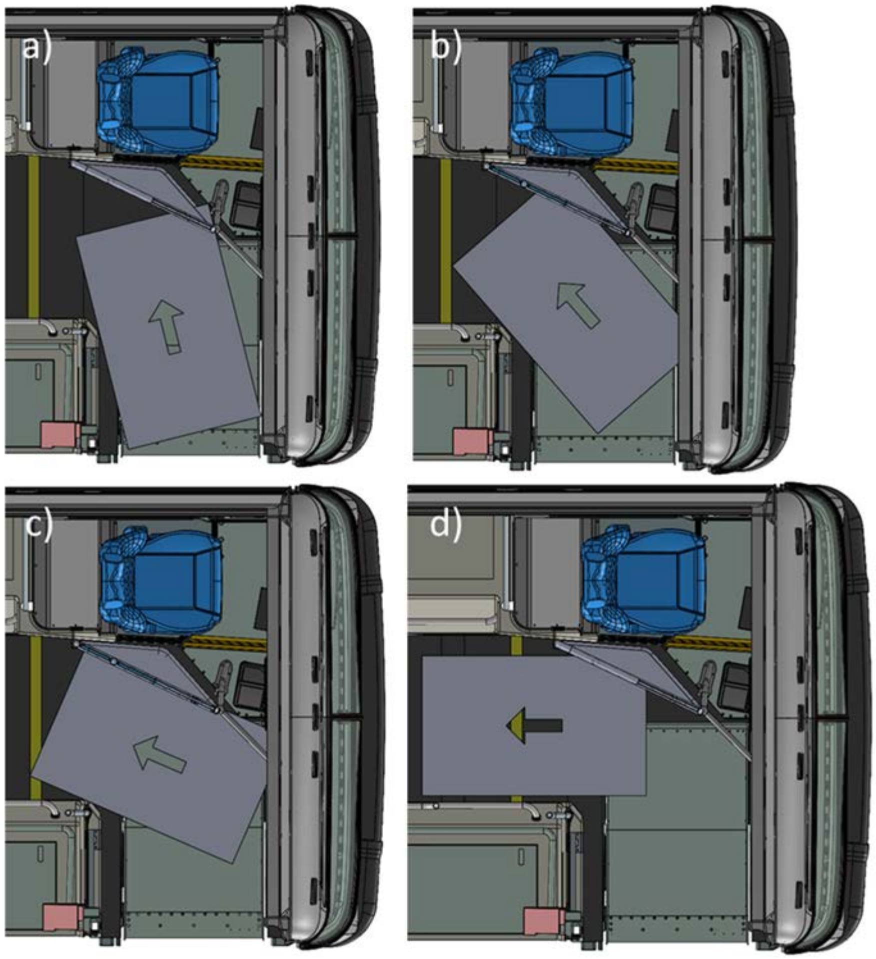

Figure 27. Top view of minimum ADA wheelchair clearance demonstrated on Concept A at multiple entry stages.

Usability

Concept A was estimated to provide medium mitigation of risk to bus operator reach and repetition since the door does not have to be moved at every stop for driving visibility. The barrier door is operated manually and does not change based on the state of the front entry door. The bus operator may latch or release under normal operation to perform passenger service; the bus operator may latch or release for emergency egress.

Visibility

As demonstrated in Figure 28, Concept A was estimated to provide high mitigation of obstruction/glare for visibility of exterior mirrors and interior passenger mirrors; however, obstruction/glare from the barrier may exist when the bus operator looks at the passenger front entry door. The barrier door is not intended to latch in the open position, except optionally at a mechanical position for service and maintenance outside of revenue activities.

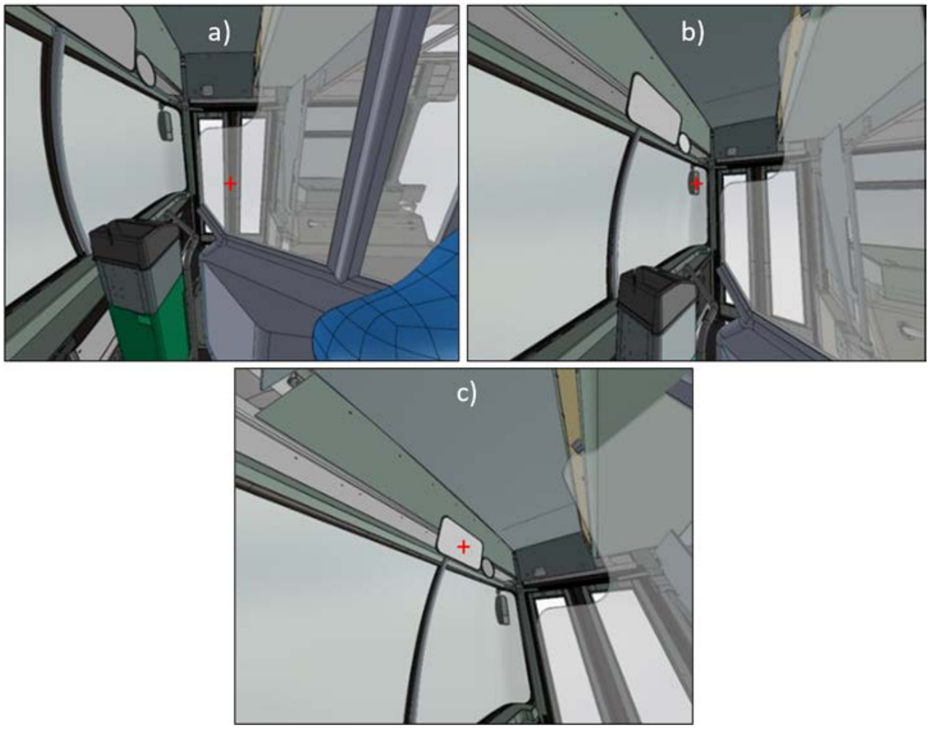

Figure 28. Bus operator perspective view with Concept A while looking at the a) passenger front entry door, b) curbside rearview mirror, and c) passenger compartment rearview mirror.

Concept B Risk Mitigation

Physical, Spitting and Other Attacks

As demonstrated in Figure 29, Concept B was estimated to eliminate direct physical attack by passenger reach. Concept B was estimated to provide medium mitigation of shooting a weapon around the barrier. It was estimated to provide high mitigation of spitting since passengers cannot lean around the barrier, but potential exists for spitting over the top of the barrier. The passenger cannot easily reach around the barrier door and release the latch. The emergency egress hinge release is not reachable by a passenger.

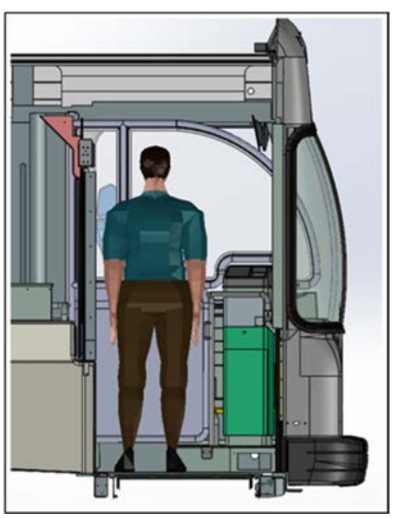

Figure 29. Side view of a large male standing next to Concept B bus operator barrier.

Air Quality

As demonstrated in Figure 30, Concept B was estimated to provide medium mitigation of coughing/sneezing risk due to the size of the barrier. It was estimated to provide medium mitigation of air quality risk, depending on implementation of additional partitions between front entry and passenger compartments to limit gaps and increase higher pressure on the front side of the barrier. The targeted gaps of 1-inch were not achieved without modifications and additions to the passenger compartment partition. The pressure differential is also dependent on the use of external bus openings (e.g., windows and hatches) on the bus that may reduce potential air flow benefits. Filtered fresh air inlets in the bus HVAC defrost or bus operator workstation may increase these potential benefits by mixing fresh air with internal air.

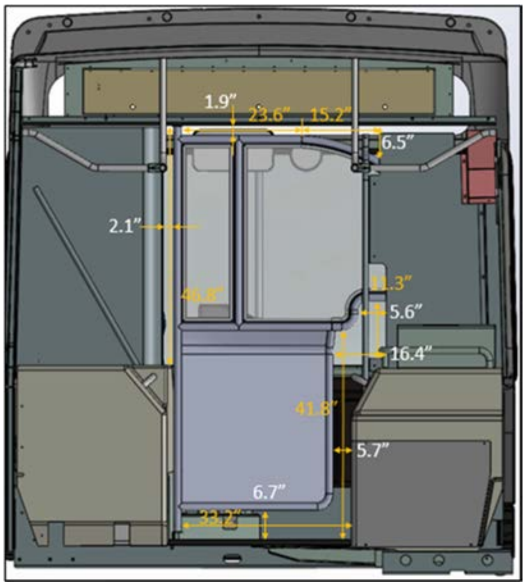

Figure 30. Rear view of Concept B bus operator barrier latched at passenger compartment partition demonstrating small gaps to for air exchange.

Temperature

Concept B was estimated to provide medium mitigation of cold temperatures since the barrier may reduce cold gusts through passenger entry door but there would be no change to temperature and humidity. The extended length of the barrier towards the windshield may increase the potential benefit compared to Concept A.

ADA

As demonstrated in Figure 31, Concept B was estimated to pass the clearance for passengers with disabilities based on the minimal dimensions for the ADA clearance box. The concept maintains the current common configuration for a front entry ramp.

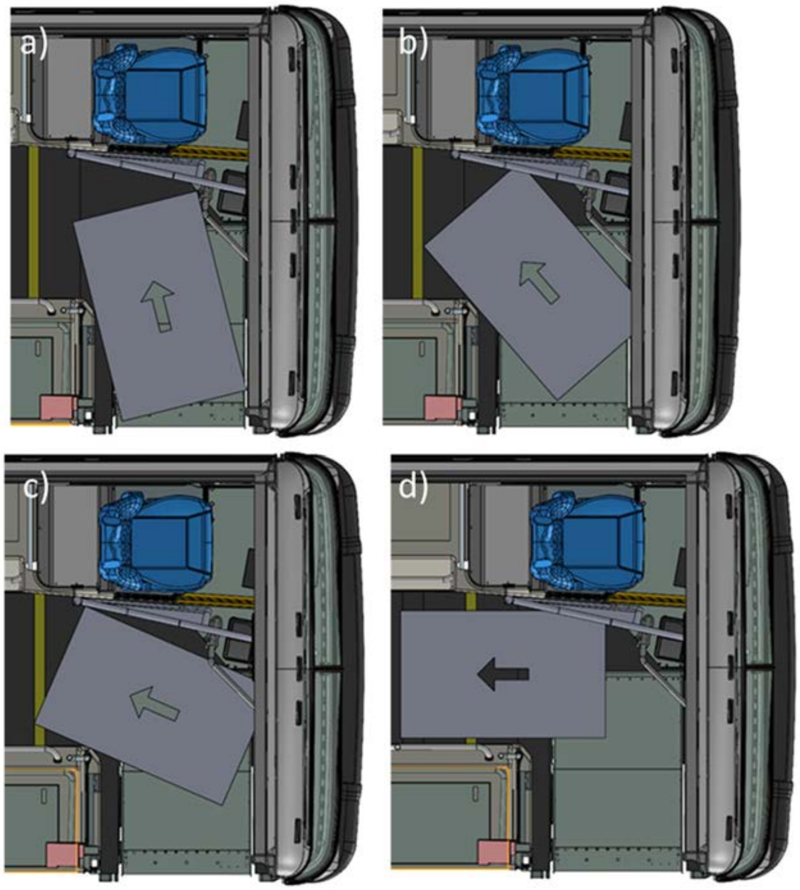

Figure 31. Top view of minimum ADA wheelchair clearance demonstrated on Concept B at multiple entry stages.

Usability

As demonstrated in Figure 32, Concept B was estimated to be implemented with automatic operation based on passenger front entry door state using a powered pneumatic armature and electro-magnetic latches (see Figure 33) at both positions for boarding and driving. A power override by the bus operator under normal operation would allow the bus operator to perform passenger service. The concept includes a physical hinge release for non-powered emergency egress.

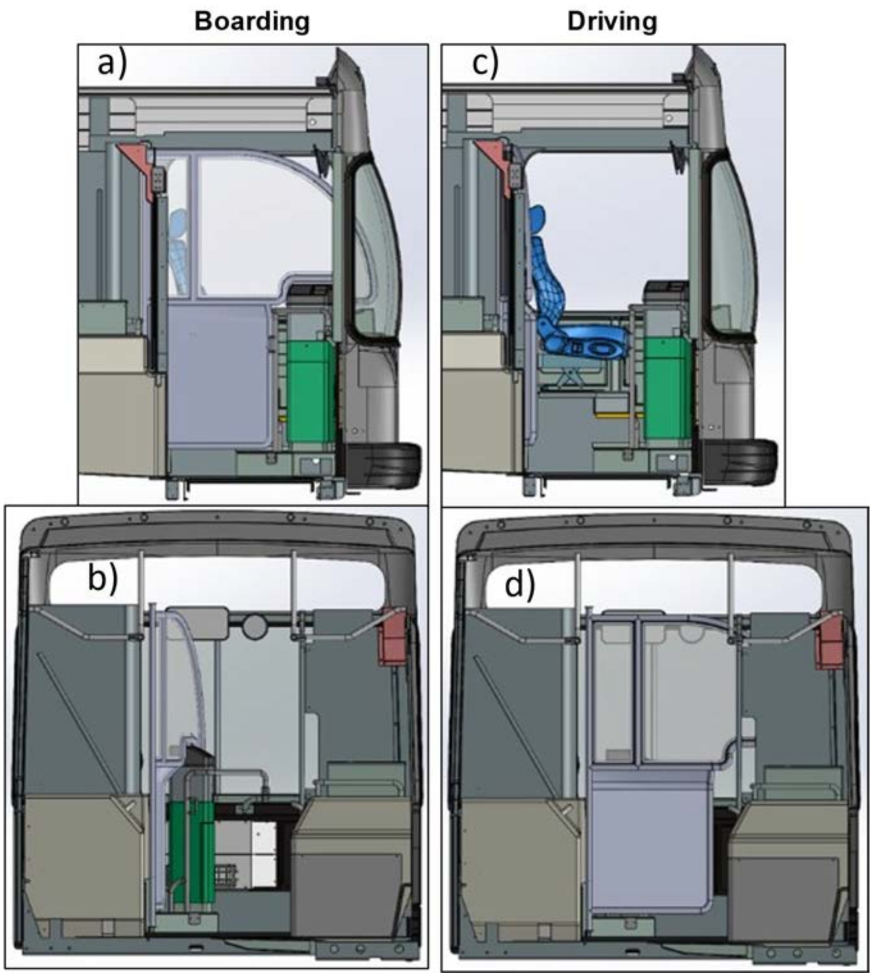

Figure 32. Demonstration of two positions for Concept B at boarding position in a) side view and b) rear view; and at driving position in c) side view and d) rear view.

Figure 33. Demonstration of the pneumatically powered door mechanism (left) and electromagnetic lock at driving position (right).

Visibility

As demonstrated in Figure 34, Concept B was estimated to provide high mitigation of obstruction/glare risk for visibility of exterior mirrors and interior passenger mirrors due to barrier open latching position during driving. This concept was also estimated to provide high mitigation of risk for obstruction/glare when looking at the passenger front entry door due to the barrier door automatically latching open while driving.

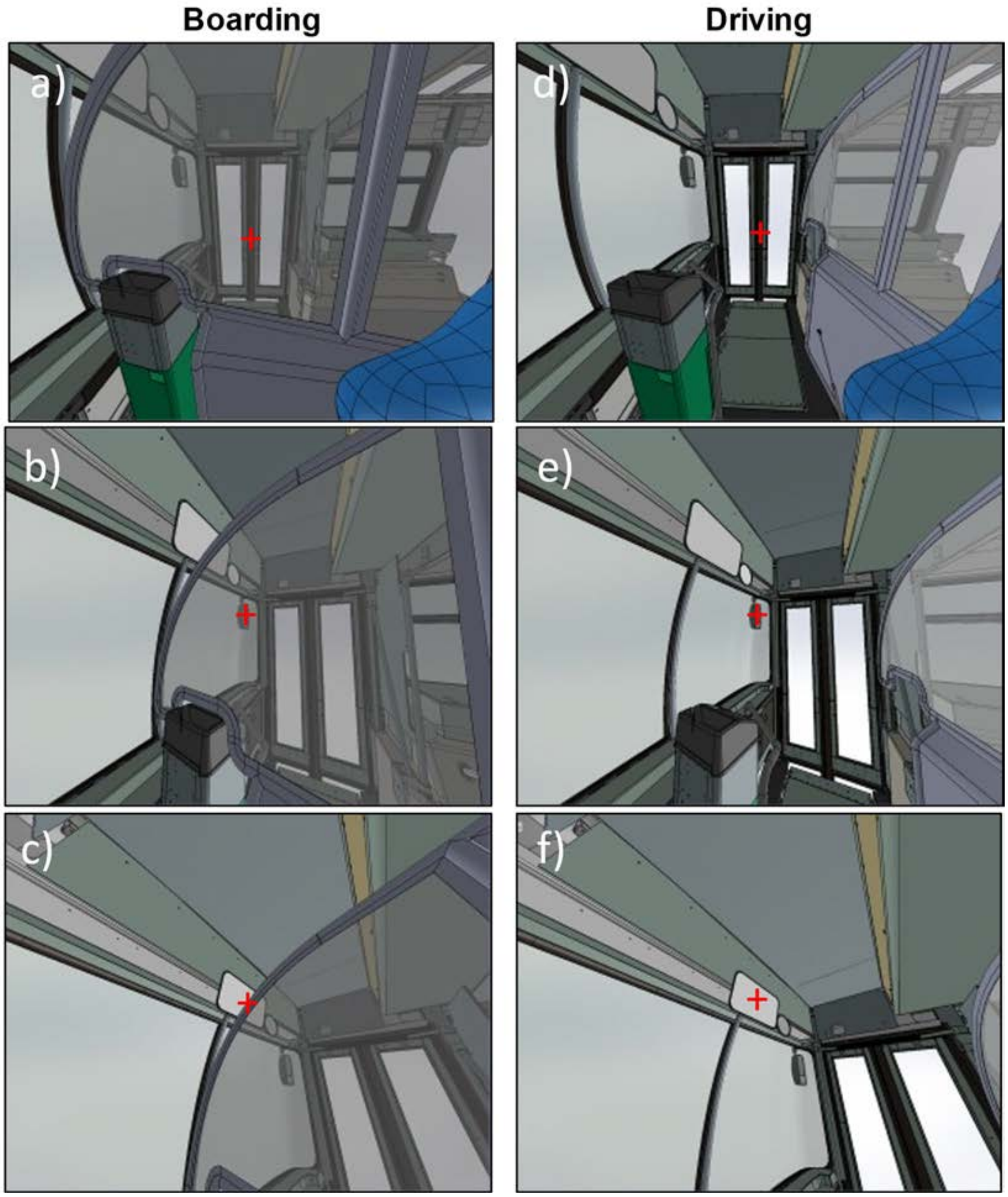

Figure 34. Bus operator perspective view with Concept B at boarding position (left) while looking at the a) passenger front entry door, b) curbside rearview mirror, and c) passenger compartment rearview mirror; and at driving position (right) while looking at the d) passenger front entry door, e) curbside rearview mirror, and f) passenger compartment rearview mirror.

Concept C Risk Mitigation

Physical, Spitting and Other Attacks

As demonstrated in Figure 35, Concept C was estimated to eliminate direct physical attack by creating a separate floor to ceiling bus operator workstation compartment. The concept may potentially mitigate attack by shooting weapon with the appearance of no access. The concept eliminates spitting attack. The door release would not be accessible by passengers.

Figure 35. Side view of a large male standing next to Concept C bus operator barrier. Used with permission from ITLC and STYL&TECH.

Air Quality

As demonstrated in Figure 36, Concept C was estimated to eliminate coughing/sneezing risk due to the separate bus operator workstation compartment. The concept was estimated to provide high mitigation of air quality risk, assuming positive pressure can be created on the bus operator workstation side.

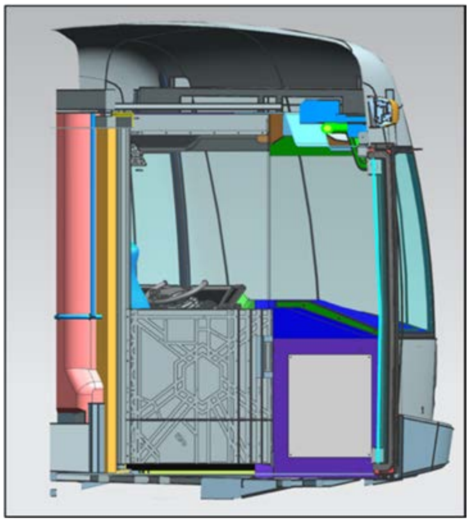

Figure 36. Side view of Concept C bus operator barrier latched at bus operator workstation demonstrating sealed closure with stationary barrier and no air exchange. Used with permission from ITLC and STYL&TECH.

Temperature

Concept C was estimated to eliminate cold temperature risk. The risk due to hot temperatures and humidity may not be mitigated and may be increased by the separate compartment due to the need for a separate bus operator workstation HVAC system and additional defrost/defogging vents near the additional barrier door and barrier stationary glazing surfaces.

ADA

Concept C was estimated not to pass clearance for passengers with disabilities based on the minimal dimensions for the ADA clearance in the passenger front entryway. The existing bus architecture used by the "Bus of the Future" team was not designed for ADA passenger front door entry. However, Concept C passes clearance for passengers with disabilities based on the dimensions for the ADA clearance box in the mid/rear door entry, as seen in Figure 37. Assuming the bus can dock for mid-entry and the bus would be equipped with a mid-entry ramp, this approach could accommodate devices that exceed the minimum ADA clearance box today.

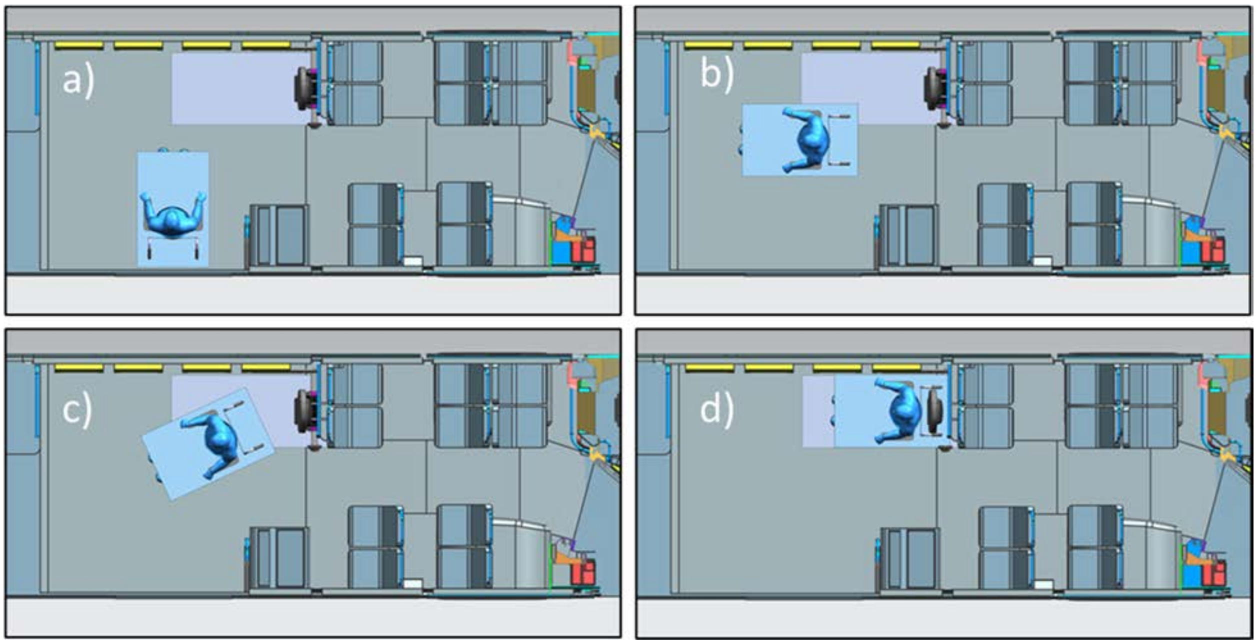

Figure 37. Top view of minimum ADA wheelchair clearance demonstrated on Concept C at mid/rear door entry at multiple entry stages. Used with permission from ITLC and STYL&TECH.

Usability

As demonstrated in Figure 38, Concept C was estimated to be implemented with automatic operation based on the state of the passenger front entryway door using a powered pneumatic armature and electro-magnetic latches (see Figure 39) at both positions for boarding and driving. For this concept, a manual bus operator switch is another option for the barrier door. A power override by the bus operator under normal operation would allow the bus operator to perform passenger service. The concept includes a physical hinge release for non-powered emergency egress.

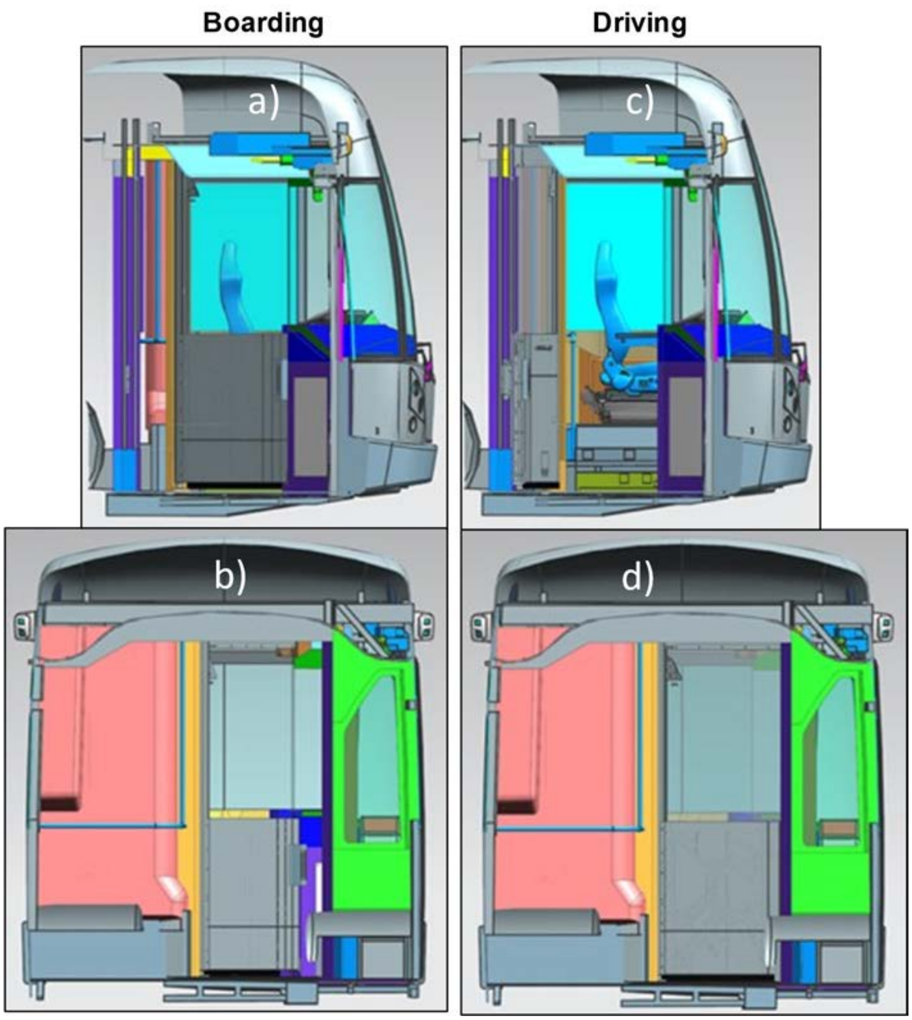

Figure 38. Demonstration of two positions for Concept C at boarding position in a) side view and b) rear view; and at driving position in c) side view and d) rear view. Used with permission from ITLC and STYL&TECH.

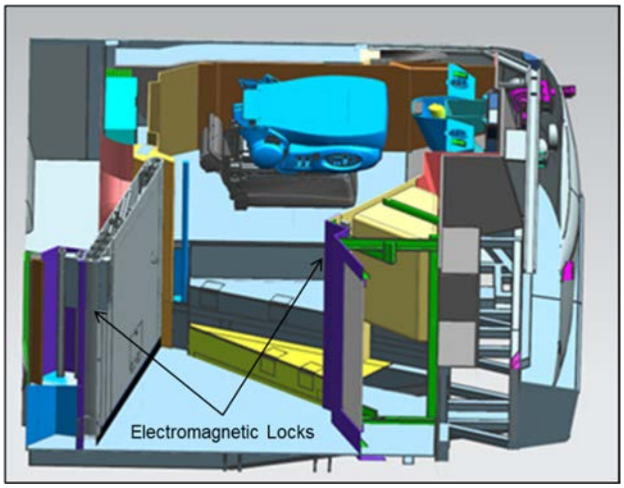

Figure 39. Demonstration of the pneumatically powered door mechanism and electromagnetic lock at optional driving position. Used with permission from ITLC and STYL&TECH.

Visibility

As demonstrated in Figure 40, Concept C was estimated to provide high mitigation of obstruction/glare risk for visibility of the curb-side exterior mirror due to the orientation of the stationary barrier, which does not interfere with the bus operator's view. Another alternative that may provide high mitigation of risk for obstruction/glare over exterior mirrors is the use of cameras and displays to replace rearview mirrors. Regarding the risk for obstruction/glare over the passenger front entry door, Concept C was estimated to provide high mitigation since the barrier door could automatically latch open during driving or the glass can be lowered in the barrier door, as seen in Figure 41.

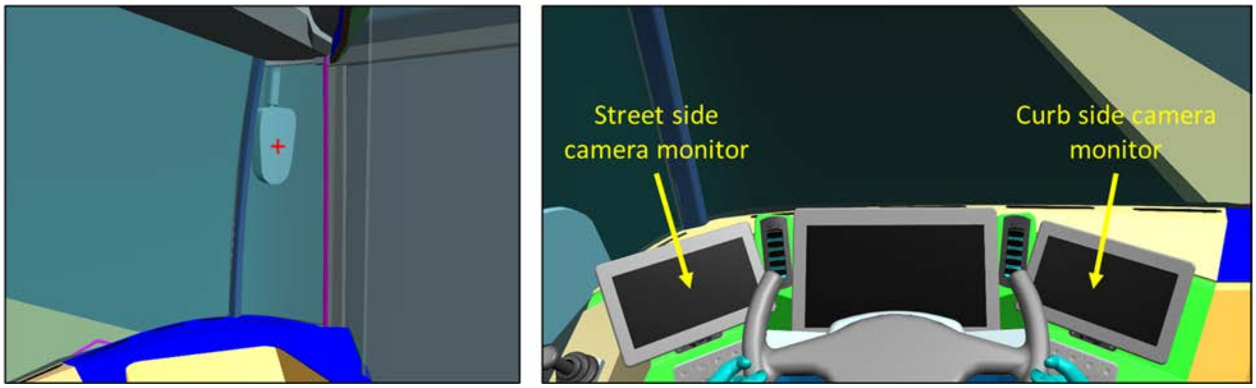

Figure 40. Bus operator perspective view with Concept C while looking at the optional curbside rearview mirror (left) and the alternative bus operator workstation rearview camera displays (right). Used with permission from ITLC and STYL&TECH.

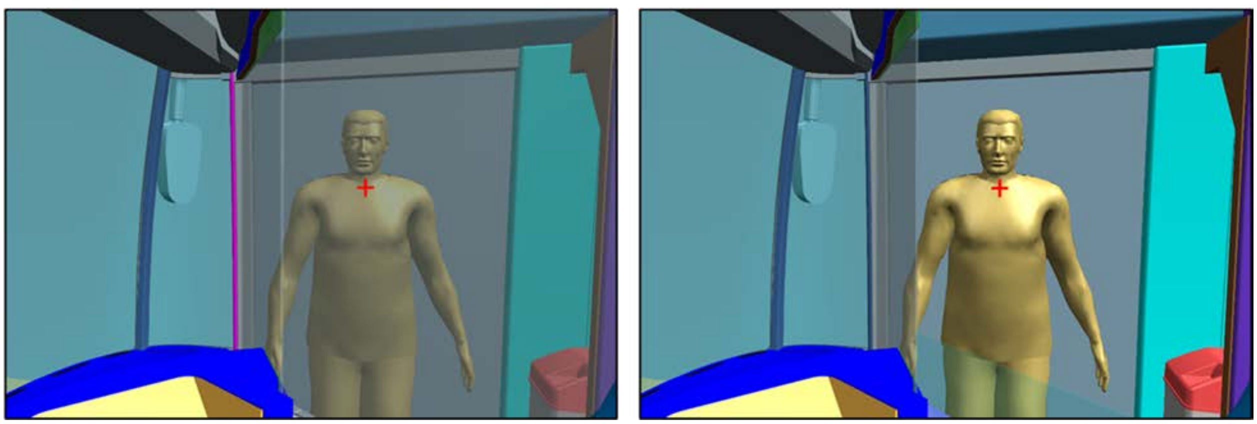

Figure 41. Bus operator perspective view with Concept C at boarding position while looking at the passenger front entry door with barrier glazing up (left) and with barrier glazing down (right). Used with permission from ITLC and STYL&TECH.

Stakeholder Feedback and Considerations

The bus operator barrier designs and requirements were shared with representatives on the TCRP Panel and others in industry that have a stake in the design of bus operator barriers in the roles of operations, HVAC manufacturing, glazing supply, and bus manufacturing. Comments and feedback have been generalized and listed below.

Concept B Operations Feedback

- Consider more support for the upper portion of the bus operator barrier to provide structure for latching, durability, and to prevent vibration.

Concept C Operations Feedback

- The mechanical interface between the barrier and stationary transparent structure at the windshield end is not clear.
- Where is the fare box?
- Did this configuration consider visibility with the driver's seat in a full forward and aft positions?
- With a fully separate air/temperature supply, the designers should consider condensation on the bus operator barrier glass.
- Front door use may be limited to bus operators in future applications. Some passengers report a preference for boarding and disembarking at the rear doorway.

Concept B HVAC Manufacturer Feedback

- The main HVAC could be used with extra ducting to get at least 100 cfm to the driver for comfort with this design, allowing for air return and circulation.
- Testing may be required but additional cooling for the driver could be accomplished with an in-duct damper.

Concept C HVAC Manufacturer Feedback

- A sealed cockpit will need a method to depressurize the enclosure to let new conditioned air in, meaning there will need to be some sort of return pathway.
- There may be an opportunity or need for a separate HVAC. This could be a stand-alone electric system or could be tied into the main HVAC.
- There may be a need to consider independent cooling and dehumidification for comfort; consider the effects of a well-sealed compartment with large amounts of glass.
- Consider that battery electric may require a glycol system for heat.
- Regarding air quality, consider the negative effects of some alternative air purifying solutions on passengers and interior components. Consider MERV-rated filters but be cautious about additional pressure on motors and remember regular maintenance.

General, Glazing Supplier Feedback

- Reflection on panels can be a major concern for implementing barriers on large, fixed route buses.
- Solutions for anti-glare are limited or non-existent for polycarbonate barrier materials and therefore some larger agencies will use glass that offers some amount of anti-reflection but comes at a significant weight and expense.
- For operators of mid-size or smaller buses, using glass in barriers may not be recommended since the driver is sitting lower and the door may extend above their head.
- Following the FMVSS No. 205 standard is important for barrier strength and safety.
- When considering bullet resistance, this feature requires laminated glazing, which would add significant weight to the door panel and would need to be part of a total redesign of the operator doors. Bullet resistance may also be impractical on small to mid-size buses.

General, Bus Manufacturer Feedback

- Implementers of bus operator barriers should check compliance with ADA throughout the design process from concept development to simulation to integration and installation to make sure that the bus operator barrier does not interfere with hand holds for ambulatory impaired passengers and sufficient clearance is provided for passengers with mobility devices (e.g., wheelchairs).
- Inferior designs such as shower curtains or transparent vinyl sheets do not support the industry's needs and are not relevant to bus operator barrier designs.
- Regulatory implications are important to consider when implementing bus operator barriers.
- The type of materials used in bus operator barriers should be carefully considered before making design decisions.

Concept A Bus Manufacturer Feedback

- Bus operator barrier designs that are developed for first purchase buses can also be incorporated into existing buses as aftermarket.

Concept B Bus Manufacturer Feedback

- Clearances to handholds must be maintained at all positions of the bus operator barrier door.
- All positions and modes of the bus operator barrier door must be carefully considered in light of best engineering practices to identify possible part and component failures, effects, likelihood, and design mitigation (i.e., Design Failure Mode and Effects Analysis).
- It is recommended to consider designing this concept barrier and door on separate planes to ensure clearance for ADA wheelchairs and handholds.

Concept C Bus Manufacturer Feedback

- This concept would require major vehicle redesign.
- The separate bus operator workstation compartment may require a stand-alone smaller HVAC unit over the bus operator.
- The replacement of mirrors with cameras has not been performed at any scale or been tested in the broader North American transit bus industry.
- The clearance at the front entryway may be insufficient for ramp and wheelchair access. If the front entryway is used for any passengers, handholds should be provided for passengers.
- Transitioning to mid/rear door entry for passengers with disabilities may increase the interaction required with the bus operator instead of reducing it. The task of docking and loading required for ADA necessitates further study with stakeholders prior to the transit bus industry moving to a mid/rear door entry concept.
- The application of electronic fares at mid/rear door entry would be required for this concept.
- Emergency egress capability for bus operators in the event of a crash is an important feature.

CHAPTER 4

Conclusions

The research team sought to respond to the growing list of challenges to bus operators that can be mitigated with thoughtfully designed and carefully implemented bus operator barriers in low-floor transit buses. The team surveyed the transit bus industry, collected reference materials on the designs of barriers and designs of heavy low-floor transit buses, produced a summary of design criteria, and produced and defined three bus operator barrier concepts that may mitigate the risks to transit bus operator safety and health.

A survey of 77 transit agency personnel, with an average of 9.7 years of experience from across more than 26 transit agencies and additional organizations, illustrated the needs for bus operator barriers and the challenges with some existing designs. A majority of the respondents stated that their transit agency was currently using a barrier, but only a third of those stated that the barriers were in use prior to the COVID-19 pandemic. The primary reason for use prior to the pandemic was to prevent physical assault. Among the respondents who stated their agency started using bus operator barriers after the pandemic, all indicated that their transit agency was planning to continue barrier use. Most of the respondents, 46 out of 50, who answered the question about agency barrier use policy stated that their transit agency actively required bus operators to use the barriers during revenue-generating operations. Among the three respondents who stated their agency was not using barriers, the reasons given were lack of assaults, concern for emergency evacuation of the operator, and the need for more information about the quality and effectiveness of barriers. Respondents also provided cost estimates for initial purchase and maintenance.

Thirty respondents answered questions about the success of implementation. The challenges most frequently listed by respondents were glare, operator dislike, operator access, and incorrect use. Approximately half of the respondents suggested that no training was provided on the use of bus operator barriers. A majority of respondents (81%) thought the bus operator barriers were an overall success.

The collection of criteria that directly or indirectly impact the designs of bus operator barriers is provided in Appendix A. Judgments were made by the research team about how each of these criteria apply to the three concept bus operator barrier designs provided in this report. The purpose of the detailed criteria and classification of overall risk mitigations for each concept are not provided as a guarantee of performance, but the purpose is rather to educate readers as to how the attributes of three different bus operator barrier concepts can impact the overall success of implementation.

This report provided barrier concepts that can balance the needs of bus operators for security, usability, and visibility. However, the final production designs should involve the critical step of intentional outreach at each agency early in the process to solicit the needs of the users—in this case, bus operators. It is recommended that design teams discuss the integration of features such as automatic bus operator barrier door positions, overrides for passenger service, and emergency egress release mechanisms with bus manufacturers. The balance of important requirements and standards affected by bus operator barriers per each individual bus configuration also suggests that bus manufacturers should be consulted during the design process of after-market and integrated bus operator barriers. Lightweight transparent materials are available that can meet the strength requirements of FMVSS No. 205, but their application might be best fit for bus operator barriers with doors that automatically move during driving to reduce the impacts of glare on those surfaces. This might be a benefit for door designs with high rates of open and close cycles, where weight can increase cost and affect the durability of the automation mechanisms.

Glare is a recognized challenge for bus operator barriers. Glare is also a challenge to all glazing surfaces in vehicles where internal and external lighting can veil objects of interest or present false images on the glazing surfaces. Anti-glare coatings are available and can provide some aid, but the orientation and size of barrier glazing surfaces can be difficult to predict and should be attempted in pre-production prototypes in bus pilots. It is recommended that agencies consider and contact their bus HVAC suppliers to discuss impacts on air flow and defogging of additional barrier surfaces that might be positioned between the bus operator and other bus components to ensure consistent performance with defogging of street-side or curb-side exterior glazing. It is also recommended that design teams consider the effects on the overall bus systems' performance and warranty for any components that directly or indirectly interface with new bus operator barrier assemblies.

A rough bill of materials was developed for the two concept bus operator barriers that were developed for retrofit or integration in first purchase. These bills of materials can be found in Appendix B. Note that these part lists do not include estimated costs for development labor or assembly and installation labor. Additionally, the costs of design integration with the bus should be carefully considered.

The VTTI team produced information and guidance for North American public transportation agencies, standards committees, and government and non-government policy-making organizations on designing, procuring, and installing bus operator barriers to prioritize the health and safety of essential operators and the public they serve.

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APPENDIX A

Design Criteria Matrix

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Operator Workstation	Workplace width [Seat]	N/A	N/A	N/A	≥ 800 mm centered around operator centerline	The bus operator compartment should allow for clearance of the operator's shoulders and elbows (min. 800 mm cross-bus).	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Operator Workstation	Workplace width [Seat]	A, B, C	Clearance	Yes	Yes, > 825mm	Yes, > 825mm	Yes, > 825mm

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Operator Workstation	Platform Height [Seat]	N/A	Allows a seated bus operator to see a target positioned 610 mm in front of the bumper and 1067 mm above the ground. The height of the platform shall also allow the bus operator's vertical upward view to be greater than or equal to 15°.	300 (±50) mm above the bus floor and be reachable by a single step. If the platform height is greater than 350 mm, steps with equal height shall be provided with a maximum height of 250 mm and a minimum height of 125 mm.	In low-floor buses, the driver's workplace should be arranged on a platform. It is recommended that this platform be at a height of 300 ±50 mm above the floor and be reached by a single step. If the platform height is greater than 350 mm, steps with equal height shall be provided with a maximum height of 250 mm and a minimum height of 125 mm.	Allow a seated bus operator to see a target positioned 610 mm in front of the bumper and 1067 mm above the ground. The height of the platform shall also allow the bus operator's vertical upward view to be greater than or equal to 15°.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Operator Workstation	Platform Height [Seat]	A, B, C	Secondary	No Interference	No Interference	Driver's environment has been developed to ensure the operator will be able to see a target positioned 610 mm in front of the bumper and 1067 mm above the ground.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Seat	Seat back angle adjustment range	±10°	Shall adjust in angle from a minimum of no more than 90° (upright) to at least 105° (reclined), with infinite adjustment in between.	10° – 25° (required) 0° – 30° (recommended)	+10° – +25° adjustable (required) 0° – 30° adjustable (recommended)	Shall adjust in angle from a minimum of no more than 0° (vertical) to at least 15° (reclined), with infinite adjustment in between. The preferred adjustment in angle ranges from 0° (vertical) to at least 30° (reclined).	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Seat	Seat back angle adjustment range	A, B, C	Secondary	No Interference	No Interference	Seat has dual side recline to 105°	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Seat	Seat fore/aft adjustment range (2)	185 mm	Shall travel horizontally a minimum of 229 mm. It shall adjust no closer to the heel point than 152 mm.	≥230 mm (required) ≥250 mm (recommended)	≥ 200 mm (required) ≥ 230 mm (recommended)	230 mm	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Seat	Seat fore/aft adjustment range (2)	A, B, C	Secondary	No Interference	No Interference	Seat has 238 mm fore/aft adjustment range.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Seat	Seat upward/ downward adjustment range	143 mm	N/A	120 mm	≥ 100 mm (required) ≥ 130 mm (recommended)	165 mm	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Seat	Seat upward/ downward adjustment range	A, B, C	Secondary	No Interference	No Interference	Active suspension seat has 31 mm upward/downward adjustment range in active mode and 81 mm in passive mode	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Seat	Seat Pan Cushion Length (3)	N/A	Shall be no less than 419 mm at its minimum length and no more than 521 mm at its maximum length.	390 – 500 mm (required)	400 – 450 mm (required) 390 – 500 mm adjustable (recommended)	Shall be no more than 419 mm at its shortest length and extended to no more than 500 mm with a cushion extension feature. It is preferred that the seat pan cushion extension feature have multiple detent positions from its fully stowed to fully extended positions.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Seat	Seat Pan Cushion Length (3)	A, B, C	Tertiary	No Interference	No Interference	Shall be no more than 419 mm at its shortest length and extended to no more than 500 mm with a cushion extension feature. It is preferred that the seat pan cushion extension feature have multiple detent positions from its fully stowed to fully extended positions.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Seat	Seat Pan Cushion Width	N/A	432 – 533 mm across the front edge of the seat cushion; 508 – 584 mm across the side bolsters.	≥480 mm (required)	≥450 mm (required) ≥480 mm (recommended)	432 – 533 mm across the front edge of the seat cushion; 508 – 584 mm across the side bolsters	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Seat	Seat Pan Cushion Width	A, B, C	Clearance	No Interference	No Interference	Seat has a 559 mm wide seat cushion	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Seat	Seat Pan Cushion Height (4)	N/A	Shall adjust in height from a minimum of 356 mm, with a minimum 152 mm vertical range of adjustment.	N/A	N/A	Shall adjust in height from a minimum of 356 mm, with a minimum 165 mm vertical range of adjustment.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Seat	Seat Pan Cushion Height (4)	A, B, C	Tertiary	No Interference	No Interference	Active suspension seat has a min of 361 mm and a max of 442 mm height position in passive mode and a min of 386 mm and a max of 417 mm in active mode	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Seat	Seat Back Width	N/A	No less than 483 mm	≥475 mm (required)	≥475 mm (required)	No less than 483 mm	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Seat	Seat Back Width	A, B, C	Clearance	No Interference	No Interference	Seat has a 559 mm wide back cushion	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Steering Wheel	Wheel diameter	457 mm	457 – 508 mm	450 (±25) mm (required) 450 mm (recommended)	≤ 500 mm (required) 450 (±25) mm (recommended)	457 (recommended) – 508 mm	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Steering Wheel	Wheel diameter	A, B, C	Clearance	No Interference	No Interference	The steering wheel has a 450 mm diameter. The steering wheel will be semi-circular or stadium-shaped to provide the operator with an unobstructed view of displays when the steering wheel is in the central position. The steering wheel should have controls on the horizontal spokes for commonly used functions. These controls should be operable with thumbs to allow the operator to grip the wheel while selections are shown on the central display screen.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Steering Wheel	Rim diameter	N/A	22 – 32 mm	N/A	N/A	22 – 32 mm	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Steering Wheel	Rim diameter	A, B, C	Clearance	No Interference	No Interference	The steering wheel has a 34 mm rim diameter, but can be selected between 22 to 32 mm.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Steering Wheel	Rim clearance	N/A	N/A	N/A	N/A	≥ 38 mm	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Steering Wheel	Rim clearance	A, B, C	Clearance	No Interference	No Interference	The steering wheel has clearance with surrounding components of more than 38 mm.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Pedals	Spacing	N/A	25 – 51 mm measured at the heel of the pedals	Accelerator pedal: longitudinal spacing with bodywork (min. 50 mm) lateral spacing with bodywork (min. 30 mm). Brake pedal: clearance between accelerator pedal (min. 50 mm) lateral spacing with bodywork (min. 30 mm).	Accelerator pedal: longitudinal spacing with bodywork (≥ 50 mm) lateral spacing with bodywork (≥ 30 mm) clearance between accelerator and brake (50-75 mm; recommended). Brake pedal: clearance between brake pedal and any component (≥ 30 mm)	Accelerator pedal: longitudinal spacing with bodywork (min. 50 mm); lateral spacing with bodywork (min. 30 mm)	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Pedals	Spacing	A, B, C	Tertiary	No Interference	No Interference	The accelerator and brake pedals have at least 50 mm longitudinal clearance with bodywork and between each other. Accelerator and brake pedals have at least 30 mm lateral clearance with bodywork.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Pedals	Footwell Depth	N/A	N/A	N/A	≥350 from AHP	Sufficient clearance within bus operator foot well shall be provided around the accelerator and brake pedals (min. 350 mm).	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Pedals	Footwell Depth	A, B, C	Clearance	No Interference	No Interference	The pedals will be adjustable hanging pedals.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Fare Box	Positioning	Minimize obstruction of Driver's view	Minimize impact on passenger access and interference with the bus operator's line of sight. Shall not restrict access to the bus operator area, shall not restrict operation of bus operator controls and shall not—either by itself or in combination with stanchions, transfer mounting, cutting, and punching equipment, or route destination signs—restrict the bus operator's field of view per SAE Recommended Practice J1050.	N/A	N/A	Position to minimize impact to passenger access and interference with the bus operator's line of sight. It shall not restrict access to the bus operator area, operation of bus operator controls, or the bus operator's field of view per SAE Recommended Practice J1050, either by itself or in combination with stanchions, transfer mounting, cutting, and punching equipment, or route destination signs.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Fare Box	Positioning	A, B, C	Secondary	No Interference	No Interference	The farebox will be positioned to minimize interference with the driver's line of sight. Fareboxes will be placed at the front passenger entry and the middle door (or rear door in the absence of a middle door) for passenger entry when the operator barrier is deployed in rear-entry mode. Fare collection technology will display passenger's fare payment status on operator's electronic display screen.	The farebox being placed at the entry will make it easier to seal the operator environment with the barrier door. Placing the farebox away from the driver makes the driver less susceptible to attack from user. Configuration C can be reached with a farebox in the usual place.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Fare Box	Height	Less than 914 mm above the floor	N/A	N/A	N/A	Position to minimize impact to passenger access and interference with the bus operator’s line of sight. It shall not restrict access to the bus operator area, operation of bus operator controls, or the bus operator’s field of view per SAE Recommended Practice J1050, either by itself or in combination with stanchions, transfer mounting, cutting, and punching equipment, or route destination signs.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Fare Box	Height	A, B, C	Tertiary	No Interference	No Interference	The farebox being placed at the entry, the height of it has no impact on the driver's field of view.	The farebox being placed at the entry, the height of it has no impact on the driver's field of view.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Door Control	Location	N/A	Shall be located in the operator's area within the hand reach envelope described in SAE Recommended Practice J287, "Driver Hand Control Reach." Shall provide tactile feedback to indicate commanded door position and resist inadvertent door actuation.	N/A	N/A	Represented by 3-D CAD Models	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Door Control	Location	A, B, C	Secondary	No Interference	No Interference	The door control will utilize rocker switches that give haptic feedback, placed very close at hand, potentially on the right-hand switch pod.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Floor	Height above ground	N/A	No more than 406 mm	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Floor	Height above ground	N/A	Tertiary	N/A	N/A	Bus floor height is 394 mm from the ground.	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Area	Glare, General	N/A	Minimize to the extent possible. Front End: All colored, painted, and plated parts forward of the driver's barrier shall be finished with a surface that reduces glare.	N/A	N/A	Minimize to the extent possible.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Area	Glare, General	A, C	Primary	Potential issue, material selection is crucial	Alleviated by closing to rear (open to driver) for driving	Barrier glazing can be lowered to reduce glaring. Glare from the barrier can be alleviated by closing to rear (open to driver). Fix glazing is parallel to the line of sight to minimize obstruction. It should reach to vehicle "B" Post to ensure a direct view to the windshield and side window.	Barrier glazing can be lowered to reduce glaring. Glare from the barrier can be alleviated by closing to rear (open to driver). Fix glazing is parallel to the line of sight to minimize obstruction. It should reach to vehicle "B" Post to ensure a direct view to the windshield and side window.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Area	Glare, Exterior	N/A	The windshield shall be designed and installed to minimize external glare as well as reflections from inside the bus.	(same as interior)	N/A	Minimize to the extent possible.	(Mil-STD-1472 G) Exterior Sources: Visors or other means shall be used to preclude performance degradation due to glare from external sources such as sunlight or headlights. (9)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Area	Glare, Exterior	A, C	Reference	Potential issue, material selection is crucial	Alleviated by closing to rear (open to driver) for driving	Glares will be minimized to the extent possible, including using anti-glare coatings. The positioning of the barrier will minimize glare.	Glares will be minimized to the extent possible, including using anti-glare coatings. The positioning of the barrier will minimize glare.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Area	Glare, Interior	N/A	Objects within and adjacent to this area shall be matte black or dark gray in color wherever possible to reduce the reflection of light onto the windshield. The use of polished metal and light-colored surfaces within and adjacent to the driver's area shall be avoided. Driver Area Barrier, Transit Coach: The barrier shall minimize glare and reflections in the windshield directly in front of the barrier from interior lighting during night operation. Interior Panels, Interior Lighting: The light source shall be located to minimize windshield glare.	Reflections due to light sources or other illuminated objects and reflections by sunlight should affect or impede as little as possible the view of the outside or the information devices and controls.	Reflections due to light sources or other illuminated objects, and reflections by sunlight, shall affect or impede as little as possible the view of the outside or the information devices and controls.	Minimize to the extent possible.	(Mil-STD-1472 G) Interior Sources: Interior surfaces shall be designed to reduce reflected glare into the bus operator's eyes or onto the windshield. (9)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Area	Glare, Interior	A, C	Primary	Non-transparent pieces can be painted matte black without issue	Alleviated by closing to rear (open to driver) for driving, non-transparent pieces can be painted matte black without issue	Minimize to the extent possible. Non-transparent pieces can be painted matte black	Barrier glazing can be lowered to reduce glaring. Glare from the barrier can be alleviated by closing to rear (open to driver). Fix glazing is parallel to the line of sight to minimize obstruction. It should reach to vehicle "B" Post to ensure a direct view to the windshield and side window.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Area	Glare, Displays	N/A	(same as interior)	(same as interior)	Reflections in windscreen originating from interior light sources shall be minimized to the extent possible.	Minimize to the extent possible.	(Mil-STD-1472 G) Interior displays: Interior displays shall be designed to reduce reflected glare into the bus operator's eyes or onto the windshield. (9)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Area	Glare, Displays	A, C	Secondary	Non-transparent pieces can be painted matte black without issue	Alleviated by closing to rear (open to driver) for driving, non-transparent pieces can be painted matte black without issue	The position of the screens is adjustable so that the operator can position them to minimize glare in relation to his position. Sun shield can be added to reduce glare.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Area	General Illumination	N/A	Shall illuminate the half of the steering wheel nearest the bus operator to a level of 5 to 10 foot-candles.	N/A	N/A	Illuminate the half of the steering wheel closest to the driver to a level of 5-to-10-foot candles.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Area	General Illumination	N/A	Tertiary	N/A	N/A	N/A	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Area	Noise	N/A	**Overall Requirements, Interior Noise:** The combination of inner and outer panels and any material used between them shall provide sufficient sound insulation so that a sound source with a level of 80 dBA measured at the outside skin of the bus shall have a sound level of 65 dBA or less at any point inside the bus… The driver area shall not experience a noise level of more than 75 dBA. Measurements of interior noise levels shall be taken in accordance with SAE J2805. **Interior Panels, Driver Area Barrier**: The panel should be properly attached to minimize noise and rattles.	Driving noise at 50 km/h must not exceed 70 dB(A) at the bus operator's ear height (measuring method in accordance with DIN ISO 5128). Noise level at low idle must not exceed 55 dB(A).	The driving noise, expressed as a L_{eq} (taken over two minutes) at 50 km/h, shall not exceed 70 dB(A) at the bus operator's ear height (measured in accordance with ISO 5128). Noise level, when the bus is stationery and engine is idle, shall be < 60 dB(A). The noise level of the ventilation fan in the lowest position shall not exceed 55 dB(A) at the driver's ear height. The noise level in the middle position (de-misting, directed to the windscreen) shall not exceed 65 dB(A), with the engine off. Noises with distinct and unpleasant tonal characteristics (clattering, grating, squeaking, etc.) shall be avoided.	70 dBA measured at the driver's head position while driving.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Area	Noise	A, B, C	Secondary	Barrier door is locked down during operation	Barrier door is locked down during operation	70 dBA measured at the driver's head position while driving.	The barrier door creating a sealed environment for the operator in both positions will reduce noise from the passenger area.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Ventilation, Climate	General	N/A	N/A	Basic system must consist of conventional air heating and ventilation, *optionally* plus radiant panel heating.	Acceptable to the majority of the bus operators working in the normal conditions prevailing in the region throughout the year.	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Ventilation, Climate	General	A, B, C	Secondary	Minimal interference, potential benefits as explored in bus COVID barrier study	Minimal interference, potential benefits as explored in bus COVID barrier study	The barrier door creating a sealed environment for the operator will create an isolated climate zone.	The barrier door creating a sealed environment for the operator will create an isolated climate zone.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Ventilation, Climate	Controls and Temperature Uniformity	N/A	The HVAC system excluding the driver's heater/defroster shall be centrally controlled with an advanced electronic/diagnostic control system with provisions for extracting/reading data. The system shall be compliant with J1939 Communication Protocol for receiving and broadcasting of data. Hot engine coolant water shall be delivered to the HVAC system driver's defroster/heater and other heater cores by means of an auxiliary coolant pump, sized for the required flow, which is brushless and seal-less having a minimum maintenance-free service life for both the brushless motor and the pump of at least 40,000 hours at full power.	**Heating Requirements:** The set temperatures must be attainable in a normal operating condition and at an outside temperature of −15°C. The air outlet temperature must be within the range of 18 to 25°C ± 2 K. The temperature gradient shall not be more than 2 K/m (preferably laminar distribution with the head area approx. 1 to 3 K cooler than the footwell). The required heating capacity must be attainable at an air velocity of < 0.2 m/s near the body area at max. blower speed and all air nozzles open. Special measures are to be provided to prevent ingress of cold air when the front door is open (e.g., optionally by high cabin door, separation above the cabin door, warm air curtain etc.). During the heating operation a surface temperature of > 14°C should be ensured (at side walls and floor).	Subject to agreement between the client and manufacturer. Recommended heating performance provided in Annex A (informative).	N/A	Per FMVSS No. 103, S4. Except as provided in paragraph (b) of this section [applicable to non-continental US bus manufacturing], each passenger car shall meet the requirements specified in S4.1, S4.2, and S4.3, and each multipurpose passenger vehicle, truck, and bus shall meet the requirements specified in S4.1. S4.1 Each vehicle shall have a windshield defrosting and defogging system.13 Criteria should be applied from SAE J381-JUN2020 Recommended Practice for defrosting performance of windshield target and defrosting performance of side window project mirror perimeter.[14]

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Ventilation, Climate	Controls and Temperature Uniformity	B, C	Secondary	Minimal interference, potential benefits as explored in bus COVID barrier study.Defogging and defrosting of barrier glazing surface should be provided at the same level of performance as driver side glass and passenger entry door glass if glazing is between the view of the bus operator and the curb-side mirror or side entry door glass.	Minimal interference, potential benefits as explored in bus COVID barrier studyDefogging and defrosting of barrier glazing surface should be provided at the same level of performance as driver side glass and passenger entry door glass.	Separate zones must offer the advantage that users' needs may differ from those of the operator. Especially in winter	Separate zones must offer the advantage that users' needs may differ from those of the operator. Especially in winterDefogging and defrosting of barrier glazing surface should be provided at the same level of performance as driver side glass and passenger entry door glass.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Ventilation, Climate	Controls and Temperature Uniformity (alternative)	N/A	Manually Adjustable Temperature Control Set Point: The climate control system shall have the provision to allow the driver to adjust the temperature control setpoint at a minimum of between 68 and 72 °F. From then on, all interior climate control system requirements shall be attained automatically, unless re-adjusted by the driver. The driver shall have full control over the defroster and driver's heater. The driver shall be able to adjust the temperature in the driver's area through air distribution and fans. The interior climate control system shall switch automatically to the ventilating mode if the refrigerant compressor or condenser fan fails.	**Overall Requirements:** Heating and ventilation in the driver's cab must be independently controllable from the passenger compartment.	**Basic Requirements:** The climate and ventilation in the driver's cab shall be controllable independently of that of the passenger compartment.	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Ventilation, Climate	Controls and Temperature Uniformity (alternative)	B, C	Tertiary	Should provide at least a slight advantage in maintaining operator area temperature separate to passenger area temperature	Should provide at least a slight advantage in maintaining operator area temperature separate to passenger area temperature	The separated climate zone will allow operator to have a better control of their environment to ensure comfort.	The separated climate zone will allow operator to have a better control of their environment to ensure comfort.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Ventilation (Air Flow)	Driver's Area	N/A	The bus interior climate control system shall deliver at least 100 cfm of air to the driver's area when operating in the ventilating and cooling modes. Adjustable nozzles shall permit variable distribution or shutdown of the airflow… [excerpt only]	**Overall Requirements:** Interference from the door area and the passenger compartment must be **reduced as much as possible (preferably overpressure in the driver's cab). Air velocity and temperatures should not be influenced by the vehicle speed.** **Ventilation Requirements:** Additional air nozzles or air jets in the direction of the driver to be provided (e.g., two outlet nozzles in the dashboard with adjustment for the rate of air flow and its direction). At maximum fan output an air velocity > 5 m/s must be attainable (measured directly at the air nozzle outlet).	**Ventilation:** The ventilation fan shall have a minimum of three speed settings. Additional adjustable air nozzles for direct air jets in the direction of the driver shall be provided. The airflow should be such that the nozzles can be closed if required.	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Ventilation (Air Flow)	Driver's Area	B, C	Secondary	Should provide at least a slight advantage in maintaining positive air pressure from operator area to passenger area	Should provide at least a slight advantage in maintaining positive air pressure from operator area to passenger area	The operator barrier will fully enclose the operator and help to create positive pressure isolation	The operator barrier will fully enclose the operator and help to create positive pressure isolation

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Ventilation (Air Flow)	Air Quality, Driver [Driver's Compartment Requirements]	N/A	A separate heating, ventilation and defroster system for the driver's area shall be provided and shall be controlled by the driver. The system shall meet the following requirements: Fan(s) shall be able to draw air from the bus body interior and/or exterior through a control device and pass it through the heater core to the defroster system and over the driver's feet. A minimum capacity of 100 cfm shall be provided. The driver shall have complete control of the heat and fresh airflow for the driver's area A ventilation system shall be provided to ensure driver comfort and shall be capable of providing fresh air in both the foot and head areas… [excerpt only]	**Air Quality Requirements:** The bus operator's cab must be ventilated with 75% outside air. For the filtration of the outside air, outside air filters must have a retention rate of at least 50% for particles ≥ 3 µm. There must also be a manually controlled air recirculation system. The fresh air supply must be drawn from a low pollution area (e.g., roof intake). For the filtration of the outside air, outside air filters must be used (particle filters) with the following criteria: retention rate of at least 50% for particles ≥ 3 µm, diagnosis solution for degree of filter fouling (optionally), optional or additional absorption filter.	**Air Quality:** Driver's workplace shall be capable of being ventilated from either external ambient air or re-circulated cabin air per ISO/TS 11155-1 and ISO/TS 11155-2. Recommended performance of a typical cabin air filter is provided in Annex B (informative).	Outside air should be provided to the operator workstation at a minimum rate of 0.57 m^3 (20 ft^3)/min. Air speed at the operator's head should be adjustable either continuously or with not less than three discrete increments from near 0 to 120 m (400 ft)/min. The operator workstation must be ventilated with 75% outside air and filtered with a retention rate of at least 50% for particles ≥ 3 µm.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Ventilation (Air Flow)	Air Quality, Driver [Driver's Compartment Requirements]	C	Secondary	Should provide at least a slight advantage in maintaining positive air pressure and separate temperature control from operator area to passenger area, potential benefits as explored in bus COVID barrier study	Should provide at least a slight advantage in maintaining positive air pressure and separate temperature control from operator area to passenger area, potential benefits as explored in bus COVID barrier study	The operator barrier will fully enclose the operator to create positive pressure isolation. Operator compartment will be ventilated with some outside air. Filtration of outside air should be MERV-13 or better.	The operator barrier will fully enclose the operator and help to create positive pressure isolation

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Ventilation (Air Flow)	Air Quality, Passenger Area (default)	N/A	No "Fresh Air" Requirements: To be used by agencies that have an operating profile where the door opening cycle results in effectively providing an adequate "fresh air" mixture.	N/A	N/A	N/A	

<table>
<tr><th colspan="2">Design Variables</th><th>C-25 Priority (A/B/C)</th><th>C-25 Criteria</th><th>Concept A Status</th><th>Concept B Status</th><th>BOF Design</th><th>Concept C Status</th></tr>
<tr><td>Ventilation (Air Flow)</td><td>Air Quality, Passenger Area (default)</td><td>N/A</td><td>Secondary</td><td>N/A</td><td>N/A</td><td>Should have vertical downstream ventilation for the passenger area to prevent virus and bacteria to propagate from one to others</td><td>N/A</td></tr>
</table>

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<tr><th colspan="2">Design Variables</th><th>Report 25 Guidelines</th><th>APTA SBP Guidelines</th><th>European Bus System of the Future</th><th>ISO 16121-1 through 4</th><th>Report 185 Guidelines</th><th>Other</th></tr>
<tr><td>Ventilation (Air Flow)</td><td>Air Quality, Passenger Area (alternatives)</td><td>N/A</td><td>(1) Requirement for 10 Percent “Fresh Air” Mixture: The air shall be composed of no less than 10 percent outside air.
(2) Air purification system.
(3) Ionization system.
(4) Ultraviolet system.</td><td>N/A</td><td>N/A</td><td>N/A</td><td></td></tr>
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<tr><td>Ventilation (Air Flow)</td><td>Air Quality, Passenger Area (alternatives)</td><td>C</td><td>Secondary</td><td>N/A</td><td>N/A</td><td>Should have vertical downstream ventilation for the passenger area to prevent virus and bacteria to propagate from one to others</td><td>N/A</td></tr>
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Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	General	N/A	A barrier or bulkhead between the driver and the street-side front passenger seat shall be provided.	N/A	**Appendix D, Basic Security for the Driver:** Door of the driver's place with no direct entry to the driver's cabin, in the back shielded towards the passenger area, provide a separation in the back side of the driver around to shoulder, theft protection space for driver's bag or valuables, door and door control for regulation of the passenger flow.	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	General	A, B, C	Primary	Yes	Yes	Barrier and barrier door provide a fully enclosed zone for the driver	Both barrier door positions provide a fully enclosed zone for the driver.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	Glare	N/A	The barrier shall minimize glare and reflections in the windshield directly in front of the barrier from interior lighting during night operation.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	Glare	A, B, C	Primary	Potential issue, material selection and finishing (e.g., painting non-transparent pieces matte black) is crucial	Alleviated by closing to rear (open to driver) for driving, non-transparent pieces can be painted matte black without issue	Barrier door glazing can be lowered to reduce glaring. Glare from the barrier can be alleviated by closing to rear (open to driver). Non-transparent pieces can be painted matte black without issue	Barrier door glazing can be lowered to reduce glaring. Glare from the barrier can be alleviated by closing to rear (open to driver).

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	Location, Part 1	N/A	Location and shape must permit full seat travel and reclining possibilities that can accommodate the shoulders of a 95th-percentile male.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	Location, Part 1	A, B, C	Clearance	No Interference	No Interference	Driver's environment has been developed to permit full seat travel and reclining possibilities.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	Location, Part 2	N/A	The partition shall have a side return and stanchion to prevent passengers from reaching the driver by standing behind the driver's seat. The lower area between the seat and panel must be accessible to the driver.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	Location, Part 2	A, B, C	Primary	No Interference	No Interference	Barrier and barrier door provide a fully enclosed zone for the driver to prevent passengers from reaching the driver.	Barrier door provides a fully enclosed zone for the driver to prevent passengers from reaching the driver.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	Strength	N/A	The partition must be strong enough in conjunction with the entire partition assembly for mounting of such equipment as flare kits, fire extinguishers (1.2kg), microcomputer, public address amplifier, etc.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	Strength	?	Reference	N/A	N/A	The partition is strong enough in conjunction with the entire partition assembly for mounting of such equipment as flare kits, fire extinguishers (1.2kg), microcomputer, public address amplifier, etc.	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	Noise	N/A	The panel should be properly attached to minimize noise and rattles.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	Noise	A, B, C	Primary	Yes	Yes	Electromagnetic lock for the barrier door eliminates rattle noise from standard mechanical lock.	Electromagnetic lock for the barrier door eliminates rattle noise from standard mechanical lock.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	Size (default)	N/A	Wheel-Well-to-Ceiling Configuration of Driver's Barrier: The driver's barrier shall extend from the top of the wheel well to the ceiling the level of the seated driver and shall fit close to the bus side windows and wall to prevent passengers from reaching the driver or the driver's personal effects.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	Size (default)	A, B, C	Primary	Yes	Yes	N/A	Both barrier positions provide a fully enclosed zone for the driver.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	Size (alternative)	N/A	Full-Height (Floor-to-Ceiling) Configuration of Driver's Barrier: The driver's barrier shall extend continually from the floor area to the ceiling and from the bus wall to the first stanchion immediately behind the driver to provide security to the driver and to limit passenger conversation.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	Size (alternative)	A, B, C	Primary	No Interference	No Interference	N/A	Both barrier positions provide a fully enclosed zone for the driver.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver Area Barrier	Size (alternative)	N/A	Driver enclosure or door.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver Area Barrier	Size (alternative)	A, B, C	Primary	Yes	Yes	Barrier and barrier door provide a fully enclosed zone for the driver.	Both barrier positions provide a fully enclosed zone for the driver.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Modesty Panels	General	N/A	Sturdy divider panels constructed of durable, unpainted, corrosion-resistant material complementing the interior shall be provided to act as both a physical and visual barrier for seated passengers.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Modesty Panels	General	N/A	Reference	N/A	N/A	N/A	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Modesty Panels	Strength	N/A	The modesty panel and its mounting shall withstand a static force of 250 lbs. applied to a 4 × 4 in. area in the center of the panel without permanent visible deformation.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Modesty Panels	Strength	N/A	Reference	N/A	N/A	N/A	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver’s Side Window	Operation	N/A	When in an open position, the window shall not rattle or close during braking.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver’s Side Window	Operation	N/A	Reference	N/A	N/A	Can be accommodated by proper equipment selection.	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Side Window	Visibility, Location and Size	N/A	The driver's view, perpendicular through operator's side window glazing, should extend a minimum of 33 in. (840 mm) to the rear of the heel point on the accelerator, and in any case must accommodate a 95th percentile male operator. The view through the glazing at the front of the assembly should begin not more than 26 in. (560 mm) above the operator's floor to ensure visibility of an under-mounted convex mirror. Driver's window construction shall maximize ability for full opening of the window.	**Appendix D, Lateral and Front Visibility:** Angle V, > 40 degrees required; ≥ 43 degrees recommended [reference seat H-Point in medium position [angle V is U angle < 10 degrees forward of a vertical plane that is parallel with the lateral axis of the vehicle]	N/A	The driver's view, perpendicular through operator's side window glazing, should extend a minimum of 1008 mm to the rear of the heel point on the accelerator and must accommodate a 95th percentile male operator. The view through the glazing at the front of the assembly should begin not more than 26 in (560 mm) above the operator's floor to ensure visibility of an under-mounted convex mirror.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Side Window	Visibility, Location and Size	A, B, C	Primary	No Interference	No Interference	The street-side window could be extended (beyond current design) rearward to accommodate a wide peripheral view with operator looking toward the left front.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Side Window	Visibility, Transmittance	N/A	Light transmittance shall be 75 percent on the glass area below 53 in. from the operator platform floor. On the top-fixed-over-bottom-slider configuration, the top fixed area above 53 in. may have a maximum 5 percent light transmittance.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Side Window	Visibility, Transmittance	A, B, C	Primary	No Interference	No Interference	Can be accommodated by proper equipment selection.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Side Window	Materials, Tint	N/A	The glazing material shall have a single-density tint.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Side Window	Materials, Tint	A, B, C	Primary	No Interference	No Interference	Can be accommodated by proper equipment selection.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Side Window	Materials, Strength (default)	N/A	The driver's side window glazing material shall have a ¼ in. nominal thickness **laminated safety glass** conforming to the requirements of ANSI Z26.1-1996 Test Grouping AS-2 and the recommended practices defined in SAE J673.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Side Window	Materials, Strength (default)	A, B, C	Primary	No Interference	No Interference	Can be accommodated by proper equipment selection.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Driver's Side Window	Materials, Strength (alternative)	N/A	The driver's side window glazing material shall have a ¼ in. nominal thickness **tempered safety glass** conforming to the requirements of ANSI Z26.1-1996 Test Grouping AS-2 and the recommended practices defined in SAE J673.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Driver's Side Window	Materials, Strength (alternative)	A, B, C	Primary	No Interference	No Interference	Can be accommodated by proper equipment selection.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Passenger Doors	Dimensions, General (default)	N/A	When open, the doors shall leave an opening no less than 75 in. in height. Front door clear width shall be a minimum of 31 ¾ in. with the doors fully opened… [excerpt only]	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Passenger Doors	Dimensions, General (default)	B, C	Reference	N/A	No Interference	A single leaf full glass door his use to minimize view obstruction to the side.	No Interference

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
ADA Wheelchair	General	N/A	**Interior Circulation:** Maneuvering room inside the bus shall accommodate easy travel for a passenger in a wheelchair from the loading device and from the designated securement area.	N/A	N/A	N/A	Vehicles [buses] shall be readily accessible to and usable by individuals with disabilities. (5) The driver seat platform shall not extend into the aisle beyond the wheel housing. (6)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
ADA Wheelchair	General	A, B	Primary	Extends into aisle but leaves sufficient passage.	Extends into aisle but leaves sufficient passage (33.3 in. minimum lateral clearance).	BOF Wheelchair access primarily rear door entry.	BOF Wheelchair access primarily rear door entry. Design can be modified to accommodate front entry wheelchair access.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
ADA Wheelchair	Clearance Width	N/A	No width dimension should be less than 34 in. Areas requiring 90° turns of wheelchairs should have a clearance arc dimension no less than 45 in., and in the parking area where 180° turns are expected, space should be clear in a full 60 in. diameter circle. A vertical clearance of 12 in. above the floor surface should be provided on the outside of turning areas for wheelchair footrests.	N/A	N/A	N/A	Minimum clear width of 30 in. (6)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
ADA Wheelchair	Clearance Width	A, B	Primary	Extends into aisle but leaves sufficient passage.	Extends into aisle but leaves sufficient passage (33.3 in. minimum lateral clearance; bus aisle is 34.6 in., so it is exceedingly difficult not to impede on 34 in. APTA requirement).	BOF Wheelchair access primarily rear door entry.	BOF Wheelchair access primarily rear door entry. Design can be modified to accommodate front entry wheelchair access.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
ADA Wheelchair	Clearance Length	N/A	N/A	N/A	N/A	N/A	Provide a clear path for mobility aids at minimum length of 48 in. (6)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
ADA Wheelchair	Clearance Length	A, B	Primary	No Interference	No Interference	BOF Wheelchair access primarily rear door entry.	BOF Wheelchair access primarily rear door entry. Design can be modified to accommodate front entry wheelchair access.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
ADA Wheelchair	Securement	N/A	N/A	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
ADA Wheelchair	Securement	N/A	Tertiary	N/A	N/A	Wheelchair securement will be front-facing and rear-facing with an option for automated self-securement.	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
General Safety	Fire Safety, Materials, Default	N/A	All materials used in the construction of the passenger compartment of the bus shall be in accordance with the Recommended Fire Safety Practices defined in FMVSS 302.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
General Safety	Fire Safety, Materials, Default	N/A	N/A	N/A	N/A	Material selection can satisfy	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
General Safety	Fire Safety, Materials, Alternative	N/A	All materials used in the construction of the passenger compartment of the bus shall be in accordance with the Recommended Fire Safety Practices defined in FTA Docket 90-A, dated October 20, 1993…	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
General Safety	Fire Safety, Materials, Alternative	N/A	N/A	N/A	N/A	Material selection can satisfy	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Side Windows	Materials, Default	N/A	**Safety Glass Glazing Panels:** Side windows glazing material shall have a minimum of 3/16 in. nominal thickness tempered safety glass. The material shall conform to the requirements of ANSI Z26.1-1996 Test Grouping 2 and the recommended practices defined in SAE J673.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Side Windows	Materials, Default	A, B, C	Primary	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Side Windows	Materials, Alternative	N/A	**Polycarbonate Glazing Panels:** Side window glazing material shall have a minimum 3/16 in. nominal thickness. The material shall conform with the requirements of ANSI Z26.1-1996, "Standard for Type AS-5 Safety Glazing Materials," except for Test Number 17, which shall subject the specimens to 100 cycles with less than 4 percent hazing and 500 cycles with less than 12 percent hazing. Windows shall be polycarbonate sheet with an abrasion-resistant coating on both sides of the window.	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Side Windows	Materials, Alternative	A, B, C	Primary	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier	General	N/A	N/A	N/A	N/A	N/A	The transparent material of the barrier located to the right of the driver is an interior partition composed of motor vehicle “glazing” that must comply with FMVSS No. 205, “Glazing materials.” Manufacturers or distributors that cut the glazing into components for use in motor vehicles or items of motor vehicle equipment must ensure the glazing meets the requirements of FMVSS No. 205. (10, 1)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier	General	A, B, C	Primary	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier	Panels	N/A	N/A	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier	Panels	C	Primary	N/A	N/A	Two panels with glass at top and metal at bottom matching the style of the barrier door will create the total enclosure of the operator. One secondary panel is just behind the front door and at right angles to the axis of the bus. The other secondary panel is in plane with the B pillar and the operator’s eyes. Both secondary panels must achieve a seal to maintain positive pressure isolation (this does not refer to measurable pressure).	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier	Materials, Strength	N/A	N/A	N/A	N/A	N/A	According to NHTSA, any transparent material to the right of a driver is an interior partition motor vehicle glazing that must comply with FMVSS No. 205, Glazing materials. FMVSS No. 205 requires by reference that the material complies with ANSI/SAE Z26.1-1996 fracture test. (1, 10)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier	Materials, Strength	A, B, C	Primary	Material selection can satisfy	Material selection can satisfy	The glazing will withstand 500 lbs. of force without breaking.	The glazing will withstand 500 lbs. of force without breaking.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier	Materials, Fire Safety	N/A	N/A	N/A	N/A	N/A	According to NHTSA the barrier should not impact vehicle compliance with flammability of interior materials required by FMVSS No. 302. (3, 10)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier	Materials, Fire Safety	A, B, C	Reference	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier	Materials, Transparency	N/A	N/A	N/A	N/A	N/A	According to NHTSA, any portion of barrier glazing that the driver sees through in order to view windows required for driving visibility is also required for driving visibility. (1, 10)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier	Materials, Transparency	A, B, C	Primary	Material selection can satisfy	Alleviated by closing to rear (open to driver) for driving, material selection can satisfy	Alleviated by closing to rear (open to driver) for driving. Fix glazing is parallel to the line of sight to minimize obstruction. It should reach to vehicle B-pillar to ensure a direct view to the windshield and side window. Material selection can satisfy	Alleviated by closing to rear (open to driver) for driving Fix glazing is parallel to the line of sight to minimize obstruction. It should reach to vehicle B-pillar to ensure a direct view to the windshield and side window. Material selection can satisfy

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier	Passenger Service, Fare	N/A	N/A	N/A	N/A	N/A	**C-25 New:** Passengers shall be able to access the farebox when the barrier is in the bus operator secured position.

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier	Passenger Service, Fare	A, B	Primary	No Interference, access is maintained	No Interference, access is maintained	Fareboxes are located at front and rear entry locations so that farebox is accessible when the bus is in front-entry and rear-entry modes.	Farebox is located next to entry doors, so there is no interference with the barrier door. In case of farebox in standard location, the access is maintained.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier, Door	Access	N/A	N/A	Clear and unrestricted access to the driver`s workplace shall be ensured, with a required passage width of at least 450mm (see ECE R107). A passage width of at least 500mm is recommended. The door lock should be well reachable. Appendix D: Driver's cabin door with safety window (anti-aggression construction) with integrated cashpoint, safety window with cutout to speak, and adaptation of the driver's cabin rear wall to minimize the clearance between cabin and cabin door.	**Driver's Workplace in General, Access to the Driver's Workplace:** Clear and unrestricted access to the bus operator's workplace shall be ensured, with a passage width of at least 500 mm.	**Platform Access:** If the driver's platform is 300 mm (± 50 mm) above the bus floor, a single step should be provided. If the platform height is greater than 350 mm, steps with equal vertical spacing shall be provided with a maximum and minimum vertical spacing of 250 mm and 125 mm, respectively.	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier, Door	Access	A, B, C	Primary	No Interference	No Interference, minimum access width is 797.3mm	BOF bus operator workstation will be separated from the passenger entry area with a floor to ceiling barrier that will require a large opening to walk into the workstation while climbing up at least one step near the barrier.	Minimum access width is 709 mm

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier, Door	Emergency Access	N/A	N/A	N/A	N/A	If a rectangular emergency access hatch is provided through the driver-side glass, the hatch must have a height of at least 650 mm and a width of at least 470 mm. [SAE J185]	The barrier should not prevent the driver from readily accessing emergency exits which comply with FMVSS No. 217. (10, 11)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier, Door	Emergency Access	A, B, C	Primary	No interference, door can easily be opened by driver.	No interference, door can be operated pneumatically or manually switched to free-swinging.	Driver can access emergency exit through the driver side glass. Barrier door can be operated mechanically or manually for emergency exit. Emergency access to the operator's compartment is achieved by activating the battery cutoff switch.	No interference, the door can be operated mechanically or manually switched to free swinging. Emergency access to the operator's compartment is achieved by activating the battery cutoff switch.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier, Door	Size, Height, and Width	N/A	N/A	**Appendix D, Figure 1 (see Figure 2):** L1 maximum distance = 400 mm (rearward of accelerator heel point); L2 minimum distance = 1600 mm (above passenger entry floor)	N/A	**CAD Model:** When the door provides access to the driver workstation platform through a large enclosure the recommended door width is 680 mm (26.8 in.), and the height should provide clearance of 1,800 mm (70.9 in.) above a nearby workstation platform step. [SAE J185]	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier, Door	Size, Height, and Width	B, C	Primary	Yes	Yes, minimum access width is 797.3mm	Access width is 709 mm and height is 1867 mm	Access width is 709 mm and height is 1867 mm

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier, Door	Operation	N/A	N/A	N/A	N/A	N/A	**C-25 New:** Configuration A barrier may be operated manually and automatically. Configuration B shall be operated automatically based on the state of the passenger entry door; and shall be capable of being released by the bus operator only for customer service or in the case of emergency. When released the Configuration B barrier shall be capable of latching at both bus operator workstation and standee line positions.

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier, Door	Operation	A, B, C	Primary	Operated manually in most cases we have seen	Main operation controlled by pneumatic cylinder - can be controlled either by driver or by an automated system, and the cylinder can be opened to atmosphere on both sides for free-swinging operation in case of emergency; Door is secured by electromagnet latch in driving position, can also be included for passenger access position.	The door would be manual or automated depending on preference. Main operation can be controlled by the driver or by an automated mechanical system, and the mechanical system can be deactivated for free-swinging operation in case of emergency; Door is secured by electromagnetic latch in both barrier door positions.	Main operation can be controlled by driver or by an automated mechanical system, and the mechanical system can be deactivated for free-swinging operation in case of emergency; Door is secured by electromagnetic latch in both barrier door positions.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier, Door	Modes	N/A	N/A	N/A	N/A	N/A	**C-25 New:** The range of modes include 1) parked-passenger entry, 2) parked-customer service, 3) driving, and 4) emergency access. Configuration A barrier shall be operated manually during all modes. Configuration B barrier shall operate automatically between parked-passenger entry and driving modes; and it shall operate manually in parked-customer service and emergency access modes.

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier, Door	Modes	A, B, C	Primary	Operated manually in most cases we've seen	Main operation controlled by pneumatic cylinder - can be controlled either by driver or by an automated system, and the cylinder can be opened to atmosphere on both sides for free-swinging operation in case of emergency or for passenger assist	BOF Configuration C modes include 1) front-passenger entry, 2) parked-customer service, 3) rear passenger entry driving, 4) emergency access, and 5) emergency rapid window closure. All modes can be controlled either by driver or by an automated system. The door will have glazing that opens vertically as in a standard car door using pneumatic power that can be employed to physically interrupt an assault (referred to as “emergency rapid closure”) and lowered at the discretion of the operator.	BOF Configuration C modes include 1) front passenger entry, 2) parked-customer service, 3) rear passenger, 4) emergency access, and 5) emergency rapid window closure. All modes can be controlled either by driver or by an automated system. The door will have glazing that opens vertically as in a standard car door using pneumatic power that can be employed to physically interrupt an assault (referred to as “emergency rapid closure”) and lowered at the discretion of the operator.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier, Door	Glazing	N/A	N/A	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier, Door	Glazing	unknown	unknown	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy	Material selection can satisfy

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Bus Operator Barrier, Door	Latching	N/A	N/A	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Bus Operator Barrier, Door	Latching	C	Primary	N/A	Door is secured by electromagnet latch in driving position, can also be included for passenger access position	The barrier will have a door for operator egress that latches in a standard position immediately to driver's right ("front-entry mode", referring to the ability of passengers to enter the bus through the front door), and latches to the wall in an alternative position horizontally across the bus to eliminate any optical effects ("rear-entry mode", referring to passengers having to enter to the bus through the middle or rear doors). The door will close with an electromagnetic latch with 600 lbs. of latching force to prevent rattling.	The barrier will have a door for operator egress that latches in a standard position immediately to driver's right ("front-entry mode", referring to the ability of passengers to enter the bus through the front door), and latches to the wall in an alternative position horizontally across the bus to eliminate any optical effects ("rear-entry mode", referring to passengers having to enter to the bus through the middle or rear doors). The door will close with an electromagnetic latch with 600 lbs. of latching force to prevent rattling.

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Mirror	Visibility, Streetside	N/A	N/A	N/A	N/A	N/A	

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Mirror	Visibility, Streetside	N/A	N/A	N/A	N/A	Mirrors will be replaced by a camera mirror system. The cameras will be mounted low, barely above 95th percentile male eye height to avoid lenses that distort distance. Avoid wide angle lenses to the extent possible. Camera mirror system will show everything that is not observable through direct vision. Wide angle distortion of distance is to be minimized by increasing direct vision through window design.	N/A

Design Variables		Report 25 Guidelines	APTA SBP Guidelines	European Bus System of the Future	ISO 16121-1 through 4	Report 185 Guidelines	Other
Mirror	Visibility, Curbside	N/A	The roadside rearview mirror shall be positioned so that the driver's line of sight is not obstructed.	All drivers must have a good view of the mirrors. Option: A construction (e.g., barrier) to refuse passengers the opportunity to stand at the front right of the bus which occludes the driver's view, shall be provided.	**Lateral Visibility:** If there is a service door located at the front corner of the vehicle, a cube measuring 100 x 100 x 100 mm, positioned adjacent to the door at a height of 800 mm above the ground, shall be visible either directly or indirectly.	N/A	Mirrors [or other objects] mounted on the interior of the bus should not block the curb-side exterior mirror reflective surfaces when in driving mode. (9) The barrier should not obstruct the driver's view of the mirrors and/or rearview image required for FMVSS No. 111 when in driving mode. (10, 12)

Design Variables		C-25 Priority (A/B/C)	C-25 Criteria	Concept A Status	Concept B Status	BOF Design	Concept C Status
Mirror	Visibility, Curbside	A, B, C	Primary	Ideally minimal impediment, to be analyzed further in task 4	Driving position holds barrier door out of any possible driver view obstruction	The low mounting of the camera allows seeing from the front wheel contact point to the horizon without the use of extreme wide angle, expanding apparent distance to objects and thereby distorts perception of speed. Camera housing aerodynamics must prevent creation of bound vortices which fling rain and debris forward obscuring vision.	Driver should have a direct view to the curbside mirror without having to look through other glazing at the windshield

Design Criteria References

1. Barrier Materials: FMVSS No. 205; Glazing materials.
2. Barrier Materials: ANSI/SAE Z26.1-1996
3. Barrier Materials: FMVSS No. 302; Flammability of interior materials.
4. Barrier Materials: SAE J673_202107; (R) Automotive Safety Glazing Materials
5. ADA Transportation Services: 49 CFR PART 37 – Transportation Services for Individuals with Disabilities (ADA) [https://www.ecfr.gov/current/title-49/subtitle-A/part-37], 37.7 Standards for accessible vehicles. (a).
6. Wheelchair clearance dimensions: 49 CFR Part 38 – Americans with Disabilities Act (ADA) Accessibility Specifications for Transportation Vehicles [https://www.ecfr.gov/current/title-49/subtitle-A/part-38/subpart-B], Subpart B - Buses, Vans and Systems, 38.29 - Interior circulation, handrails and stanchions. (e).
7. Wheelchair clearance dimensions: 49 CFR Part 38 - Americans with Disabilities Act (ADA) Accessibility Specifications for Transportation Vehicles [https://www.ecfr.gov/current/title-49/subtitle-A/part-38/subpart-B], Subpart B - Buses, Vans and Systems, 38.23 - Mobility aid accessibility. (b) Vehicle lift - (6) Platform surface.
8. Wheelchair clearance dimensions: 49 CFR Part 38 - Americans with Disabilities Act (ADA) Accessibility Specifications for Transportation Vehicles [https://www.ecfr.gov/current/title-49/subtitle-A/part-38/subpart-B], Subpart B - Buses, Vans and Systems, 38.23 - Mobility aid accessibility. (c) Vehicle ramp - (2) Ramp surface.
9. FTA Transit Bus Mirror Configuration Pilot Project (Report 0219), VTTI Mirror Design Guide

10. US DOT NHTSA Letter of clarification, Jonathan C. Morrison (Chief Counsel) June 4, 2020: "571-205-Driver Shield for Buses and Vans_final signed.pdf"
11. FMVSS No. 217; Bus emergency exits and window retention and release.
12. FMVSS No. 111; Rear visibility.
13. 49 CFR 571.103 FMVSS Standard No. 103; Windshield defrosting and defogging systems.
14. SAE J381-JUN2020, Windshield Defrosting Systems Test Procedure and Performance Requirements - Trucks, Buses, and Multipurpose Vehicles.

APPENDIX B

Bill of Materials

Concept A Bus Operator Barrier	
Upper Bent Tube	80
Lower Bent Tube	310
Center Tube	20
Extension Tube	10
Lower Screen	250
Small Window Frame	60
Large Window Frame	80
Small Window (Impact-resistant polycarbonate) - price drops dramatically with scale (10 pieces are $60 each)	115
Large Window (Impact-resistant polycarbonate) - price drops dramatically with scale (10 pieces are $130 each)	250
Hinge/Mount Assembly	120
Latch	80
Total	1375

Concept B Bus Operator Barrier	
Upper Bent Tube	500
Lower Bent Tube	130
Upright Tube	20
Center Tube	20
Lower Screen	80
Small Window Frame	20
Large Window Frame	50
Small Window (Impact-resistant polycarbonate) - price drops dramatically with scale (10 pieces are $68 each)	130
Large Window (Impact-resistant polycarbonate) - price drops dramatically with scale (10 pieces are $200 each)	380
Hinge/Mount Assembly	120
Electromagnetic lock	480
Electromagnetic lock - wiring and switches	50
Pneumatic Cylinder	70
Pneumatic Control	150
Pneumatic tube and fittings	50
Pneumatic Cylinder mounting	100
Total	2350