FTA Report No. 0219

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Transit Bus Mirror Configuration Pilot Project

Final Report

PREPARED BY

New York City Transit Authority
Virginia Tech Transportation Institute

U.S. Department of Transportation
Federal Transit Administration

JUNE 2022

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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14. ABSTRACT
The New York City Transit Authority performed this safety, research, and development/demonstration project supported by the Virginia Tech Transportation Institute, New Flyer of America, Safe Fleet Mirrors, and Recaro North America. This research sought to meet the Federal Transit Administration's goal to advance the development of standards and safer designs to reduce the number of collisions and fatalities and mitigate the severity of transit-bus-related injuries. This was accomplished by collecting and analyzing data on transit bus mirror configurations and incidents, researching bus operator visibility, developing a mirror design guide, and demonstrating an optimized transit bus mirror in pilot test and field evaluations.

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Transit, bus, mirror, visibility, safety, development, demonstration

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Abstract

The New York City Transit Authority performed this safety, research, and development/demonstration project supported by the Virginia Tech Transportation Institute, New Flyer of America, Safe Fleet Mirrors, and Recaro North America. This research sought to meet the Federal Transit Administration's goal to advance the development of standards and safer designs to reduce the number of collisions and fatalities and mitigate the severity of transit-bus-related injuries. This was accomplished by collecting and analyzing data on transit bus mirror configurations and incidents, researching bus operator visibility, developing a mirror design guide, and demonstrating an optimized transit bus mirror in pilot test and field evaluations.

Executive Summary

Mirrors provide indirect visibility to bus operators so they can safely maneuver a transit bus through their daily routes. However, visibility can be limited depending on the size of the glass, the type of glass (i.e., flat or convex), size of the mirror housing, placement of the mirror housing, and other contributing factors such as glare and bus operator size. Further, the size of the mirror can create obstructions to direct visibility, impacting the safe operation of transit buses.

This project was designed with the goal of advancing the development of materials, technologies, and safer designs to reduce the number of collisions and fatalities and mitigate the severity of transit-bus-related injuries while also supporting the development of transit bus safety standards, protocols, and best practices related to mirrors. Standardization of mirrors is not typically found across transit agencies in the U.S. Sizes, mounting placement (e.g., high vs. low), and addition of convex mirrors all vary widely from agency to agency. Understanding these differences is critical in developing a set of mirror guidelines that can help all transit agencies reduce the number of incidents as well as in showing an optimized street-side mirror in a field demonstration.

New York City Transit (NYCT) is the largest transit agency in North America, providing a dense, urban environment for field of study with complex interactions between pedestrians, bicyclists, and e-scooters as well as both moving and parked vehicles. The research team gathered feedback via focus groups consisting of (1) bus operators, (2) trainers, and (3) management. Most bus operators felt a wider view provided by a convex mirror is necessary for the safe operation of transit buses. NYCT street-side mirrors are mounted in a low position, and NYCT has moved away from the use of convex mirrors on that side of the bus to reduce the visibility obstruction. A key takeaway from trainers and management was that in the dense urban environment, it is more important to reduce the size of the mirror housing to improve direct visibility than to provide a view that is two lanes wide in that mirror. Trainers indicated that they teach their bus operators to bob and weave to adjust view while operating the bus. These design and training challenges were recognized by the research team, and the research team sought to provide NYCT and the transit industry with optimal design guidance taking these challenges into consideration.

Based on focus group feedback, engineering data from scanning and modeling of four transit bus models (i.e., New Flyer, Proterra, Nova, and Orion), North American anthropometric data covering 2.5 percentile female to 97.5 percentile male, and analysis of 2019 NYCT bus incidents, an optimized prototype mirror was modeled, and the mirror development partner built pre-production models to use in the pilot testing.

Key Findings

Pilot testing involved having bus operators evaluate an optimized prototype mirror in static and dynamics settings. During the static evaluation the prototype mirror being evaluated was constructed with a single semi-curved glass within a mirror housing that was designed for motorized and heated operation. For the pilot testing, the mirror was mounted in both low–mount and high–mount positions. Bus operators noted how many of the visibility markers they could see and provided open-ended comments. The bus operators also provided the same type of feedback on their current flat mirror. Overall, the semi-curved prototype mirror was rated significantly higher than the current flat mirror in field-of-view provided, while there were no significant differences found in image quality, indicating the semi-curved prototype mirror provided an image that was just as good as their current flat mirror. The semi-curved prototype mirror was rated significantly better field of view; however, originally this mirror option was not pursued by NYCT for testing. Concurrently, NYCT provided the research team with a full year of 2019 incident data for evaluation. Researchers focused on left-side preventable (i.e., bus operator at fault) incidents. NYCT buses predominantly have flat mirrors only on the street-side, but there are a smaller number of older buses that still have the flat/convex mirror combination. To account for the different number of transit buses with and without a convex mirror, the analyses were based on rates per one million vehicle miles traveled. The findings revealed that the 40–foot transit buses with a flat/convex mirror combination had significantly fewer street-side incidents than flat mirror only buses; however, the opposite was true when it came to 60–foot articulated buses. The flat mirror only buses had significantly fewer street-side incidents than the flat/convex mirror combination buses. Upon further analyses, most street-side incidents with the flat/convex mirror combination were found to have occurred at the left front of the bus, potentially indicating direct visibility obstruction was the issue.

Another iteration of the optimized mirror (i.e., split-mirror) was developed and dynamically pilot tested, along with the original optimized mirror, in the Bronx, NYC. Based on the analyses and bus operator feedback from the dynamic pilot testing, the original optimized semi-curved prototype mirror was selected for implementation in the field demonstration.

The field demonstration consisted of 30 transit buses equipped with the optimized semi-curved mirror and evenly divided across the bus depots—10 each in the Bronx, Brooklyn, and Queens. The optimized mirrors were in operation for up to six months to allow for extended bus operator exposure and feedback. Overall, the results showed that bus operators rated the field-of-view provided by the optimized semi-curved mirror to be significantly better than the current flat mirror, while indicating they felt there was no difference in image quality or visibility obstruction. However, there were some notable differences between the depots. The depot in Queens generally had lower bus operator ratings and more negative feedback about the optimized semi-curved mirror than both Brooklyn and the Bronx. The depot in the Bronx had the highest bus operator ratings for all criteria.

Next Steps

These findings support consideration of the optimized semi-curved mirror to minimize visibility obstructions and maximize field–of–view. The need to minimize visibility obstructions may vary by transit agency based on the traffic and roadway environment. The objectives of the study were met for low floor transit buses. Transit bus agencies, standards organizations, and government entities should consider FMVSS No. 111 regulations for heavy vehicle mirrors based on these findings. These organizations should also consider these findings while developing and implementing mirror–camera systems that hold great promise to increase field of view, reduce visibility obstructions, and improve visibility even in low-light and bad weather conditions. Additional design guidance was also produced for coach–style buses based on modeling of two inter-city buses; however, the results of that analysis are documented separately.

Section 1 Introduction

Overview

In 2019, there were 995,033 buses registered in the United States that resulted in 72,231 crashes, combining fatal, injury, and property damage only. These crashes, which include all bus types, led to 258 fatalities and 25,000 injuries. When breaking down these crashes by type of bus involved, transit bus (i.e., bus and articulated bus) and motorcoach (i.e., over-the-road bus) buses accounted for 93 fatal crashes resulting in 101 fatalities. These two bus types alone account for nearly 40% of all fatalities in bus crashes. More importantly, though, only 10 of the 101 fatalities (9.9%) were the bus driver or occupants of the bus; the remaining 91 fatalities were not occupants. Across all bus types, 73 fatalities of pedestrians, bicyclists, and riders of personal conveyance (e.g., scooters) occurred due to collision with a bus [1]. The National Transit Database reports for 2018 that public pedestrians and occupants of other vehicles accounted for 84% of all fatalities (70 of 83), the majority of which (96%) occurred on fixed-route bus modes. Furthermore, in 2018 there were 17 pedestrian fatalities and 3 bicyclist fatalities [2]. According to data provided by New York City Transit (NYCT), from January 1, 2021, through November 30, 2021, there were 32 incidents between pedestrians, bicyclists, other personal conveyances, and NYCT transit buses.

The NYCT Department of Buses (DOB) postulates that one factor in these crashes is the bus operator compartment's layout. More specifically, the size, placement, and configuration of the mirrors combined with the seat position in relation to the transit bus A-pillar can limit the bus operator's visual field. Minor changes to the bus operator compartment and, perhaps more importantly, to the size and placement of the mirrors, have the potential to lessen the likelihood for transit bus-pedestrian/bicyclist/scooter conflicts.

This report presents the findings of a project sponsored by the Federal Transit Administration (FTA) and led by the NYCT DOB. Overall, the project took 51 months to complete, including a 6-month stoppage due to COVID-19. The research described below was completed through the funding and guidance of FTA by cooperation between the NYCT DOB and the Virginia Tech Transportation Institute (VTTI) and aided by its partners New Flyer of America, Safe Fleet Mirrors, and RECARO North America. Guidance was provided by the project evaluator from the Center for Urban Transportation Research (CUTR) at the University of South Florida.

Project Scope

This safety research and demonstration effort was performed from October 2017 through December 2021 and addresses the following FTA goals:

- Advance the development of materials, technologies, and safer designs to reduce the number of collisions and fatalities and mitigate the severity of transit-bus-related injuries.
- Support the development of transit bus safety standards, protocols, and best practices.

Currently, mirror size and placement are not standardized across transit agencies in the U.S., and there are variances by bus model and manufacturer as well as agency specification. Two common mirror mounting options (high and low mounts) are shown in Figure 1-1.

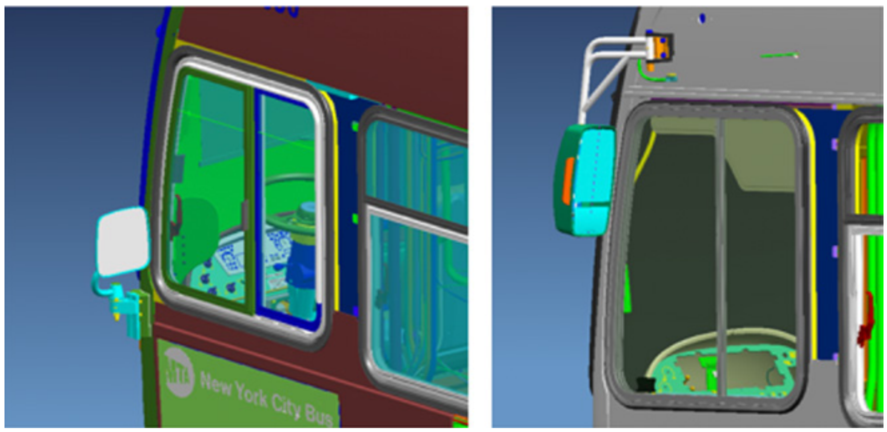


Figure 1-1 *Two common mounting options on transit buses*

Although the National Highway Traffic Safety Administration (NHTSA) provides standards for minimum mirror surface area, these can be met by various mirror configurations with individual features that do not necessarily aid or enhance operator visibility. Current regulations related to bus mirror configurations on transit buses are minimal compared to those for other vehicles. A uniform set of guidelines would ensure that public transportation bus operators have optimal views, both direct and indirect, of potential hazards around the vehicle. These guidelines are needed for mirrors on both sides of low-floor transit and motorcoach buses. To reduce the frequency and severity of crashes with pedestrians, it is critical to improve visibility in the zone obstructed by the street-side A-pillar and mirror. The street side is the most problematic side due to (1) the object viewing distance from the buses to pedestrians moving along the opposite side of the street and (2) the close proximity of the bus operator's eyes to the A-pillar structure and mirror. The design and demonstration of an optimized mirror solution set for street-side mirrors on low-floor transit buses could help reduce the number of fatal and injurious crashes and enhance the effectiveness of transit vehicle visibility systems. Investigations into the visibility performance of motorcoach buses will also support this goal.

This project sought to improve pedestrian, bicyclist/scooter, and vehicle occupant safety by enhancing the knowledge and effectiveness of visibility systems on a range of bus configurations that are used for public transportation. The research team performed the following activities to support this objective:

- Collect information from literature, recommended practices, development partners, and the partnering bus agency and its bus operators.
- Measure bus components that together produce the bus operator workstation and visibility envelope on a sample of four low-floor transit and two motorcoach buses.
- Apply a sample of recent anthropometry measures of the North American population to computer-assisted drawing (CAD) models of the buses and configurations to produce direct and indirect (mirror) visibility performance software models and design guidelines for transit and motorcoach.
- Develop an optimized street-side mirror assembly that may reduce direct visibility obstructions while maximizing mirror visibility for configurations of transit buses.
- Investigate transit incidents that may be impacted by mirror visibility, specifically on the street-side of 40-ft and 60-ft articulated low-floor transit buses.
- Demonstrate an optimized street-side mirror design on 40-ft and 60-ft articulated transit buses while collecting bus operator subjective ratings and measures of system effectiveness and incidents.

Figure 1-2 provides a process chart describing the steps undertaken for this research and development effort.

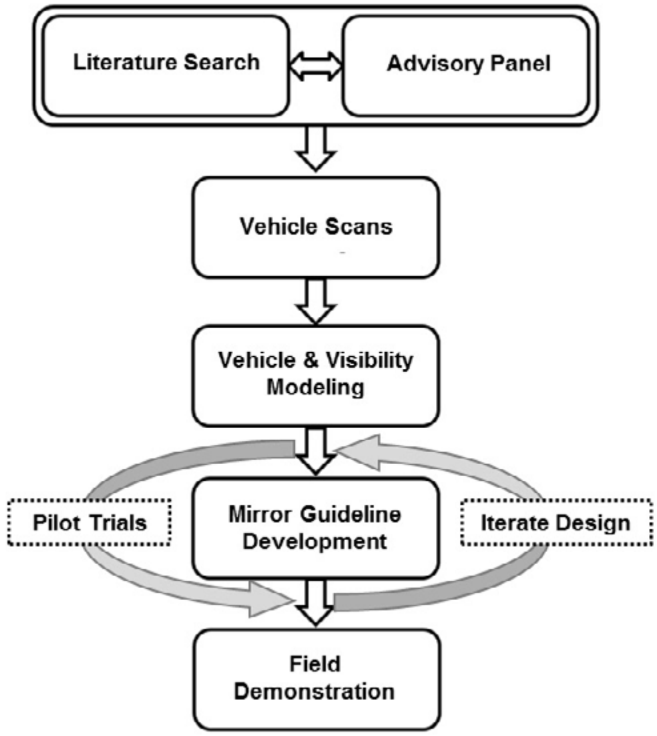


Figure 1-2 *Safety research and development process*

Section 2

Information Gathering

The research team explored sources that would provide background, guidance, and context on the factors that impact safe and efficient operation of public transportation buses in the environment where optimized visibility design would be applied in the field demonstration. These sources covered topics on engineering bus design, behavioral driver preference, agency operator training, and incident/crash/maintenance data. The collection and application of this information are organized according to the sources, which include the technical literature, focus groups, vehicle measurements, driver anthropometry (body size), and bus incidents.

Literature Review

The research team conducted a critical literature review of both domestic and international guidelines, standards, and requirements, including Federal Motor Vehicle Safety Standard (FMVSS) 111, United Nations Economic Commission for Europe (ECE) 46-02, State and City department of transportation mirror specifications, and mirror adjustment protocols and best practices that relate to commercial/transit buses [3]. The research team also assessed general direct visibility processes, including those from SAE Recommended Practices, Technology Maintenance Council of the American Trucking Associations Recommended Practices, European Bus System of the Future, ISO Requirements for Line Service Buses, and the American Public Transportation Association's *Standard Bus Procurement Guidelines*, called the "Whitebook." Transit bus and motorcoach original equipment manufacturers (OEMs) along with seat and mirror suppliers were contacted to provide specifications as they pertain to bus operator compartment layouts.

As a result of the literature review, the research team identified, classified, and reviewed a total of 74 documents. A majority of these documents were published from 2000 to the present day; however, one document was published in 1962, another was published in 1974, and a handful were published in the 1980s and 1990s. A master table was created with all literature sources, including basic information, assigned priority rating (low, medium, or high) in relation to this research effort, and a short summary of the document. See Appendix A for the full literature review table.

Focus Groups

The focus groups included various experts working in the field of transit bus operations. To obtain a broad range of opinions from participants, three separate focus groups were administered: (1) management and trainers, (2) transit bus operators, and (3) motorcoach bus operators. Input provided by these experts was a critical component of the project and gave the research team necessary guidance when evaluating both direct and indirect mirror visibility and mirror visibility obstructions and ultimately supported the creation of mirror performance guidelines. Two focus groups were conducted around a transit bus (management, trainers, transit operators) or a motorcoach bus (express operators) to encourage free-flowing discussion and allow the participants to physically sit in the seat or walk around and point out specifics they felt were important. A range of topics was discussed, including mirror type, size, and placement, along with visibility issues and obstructions, training methods, and maintenance. A summary of each focus group's findings and demographics is provided in the following sections.

Participants

There were 18 participants in the focus groups. The first focus group was conducted on April 19, 2018, at the Zerega Maintenance and Training Facility in the Bronx. A total of four management personnel and training supervisors participated. The second and third focus groups were both conducted on April 30, 2019, at the Mother Clara Hale Depot in Manhattan. A total of five transit bus operators and nine motorcoach bus operators participated.

An initial greeting to explain the purpose of the focus groups was followed by all participants reviewing and signing an informed consent that described the purpose of the focus group, the procedures, and voluntary participants' rights. The form also assured participants that the focus groups were confidential and that their identities would not be used in any reports, discussions, or briefings. All data were de-identified and reported as a whole for each focus group. Following the consent process, all focus group participants completed a demographics questionnaire that captured age, years of experience, employment history, and the different types of buses the participants had driven. Upon completion of the focus group discussions, all participants completed a post-discussion questionnaire.

Management and Training Supervisor Focus Group

This focus group consisted of two managers and two training supervisors, with a mean age of 53.5 years and 30.3 mean years of overall experience in transit bus operations. The group had an average of 27.5 years of experience at NYCT. Additionally, three of the four participants were bus operators prior to moving into management and training; these three participants had an average of 9 years of experience as bus operators.

Table 2-1 provides the discussion topics and key points of this focus group.

Table 2-1 *Management and Training Supervisor Discussion Topics and Key Points*

Discussion Category	Key Points
Operator Training	Bus operators should be constantly scanning all of their mirrors, leaning into the mirrors to change their viewing angle and checking their surroundings.
	Bus operators should look ahead to identify pedestrians before they are obstructed.
	Utilize forward planning; look for advanced hints.
	Read the traffic signals so you don't have abrupt stops.
	Make turns at 3–5 mph. Set up 4 ft off the curb or parked cars.
	Always protect the outside of the bus during turns.
	Make sure that the seat is adjusted, and you are comfortable before adjusting mirrors.
	Generally, a bus that is stopping every other block can only reach 10–15 mph.
Curb-side Issues	Contact between curb-side mirrors and pedestrians is an important design concern.
	The curb-side convex mirror is primarily for seeing pedestrians.
	The curb must be visible in the curb-side mirrors for turning.
Street-side Issues	NYCT buses do not have convex mirrors on the street side.
	The street-side flat mirror bottom edge should be aimed at the rear tire, which means the bus operator should lean down to see behind them.
	The street-side flat mirror should view a thin strip of the bus along the vertical edge.
	Operators should use the viewing gap between the A-pillar and the street-side mirror to see pedestrians or objects hidden by either component.
Other Issues	The agency should use a set of guidelines to train everyone consistently.
	The large center interior mirror provides operators more street view on the right side of the bus.
	When the mirror is mounted lower, the driver vision obstruction zone on the ground from the mirror moves closer to the bus.
	Mirror arms need a break-away feature to avoid permanent damage or frequent modification due to impact during washing.

In addition to the summarized key points, direct quotes were captured from the audio transcriptions. A few of the direct quotes are as follows:

- "One thing we encourage is not to use the spot mirror as your main mirror, never [use it as] a substitute. That is why we went away from it on the left-hand side; [drivers] were focusing on that which is not a true image so that is why we went away from that side for the most part; if it was a requirement, it should be on the mirror or below the mirror and respectively you should adjust it."
- "What is being explained is particular to where we are at right now with our mirrors. We had a period of time where someone said bigger mirrors are better mirrors, so we had very tall mirrors with convex on this side. It's called a tall mirror but actually hangs down lower on this side [curb side]. We compressed all of that…because potential customers were getting hit at stops with low hanging mirrors. That's why we went with that and

this side [street side] I think the taller mirror was also more of a blockage right [another participant interjected ‘bigger obstruction’] along with the A-pillar.”

- “On the left side mirror also, we encourage looking between the mirror frame and the body so you can [see] if someone goes behind the pillar; we encourage head movement around those [so there’s a] better chance of seeing someone. So, if you have the A-pillar and mirror frame next to each other you are getting a wider amount of obstructed vision. So, we have that gap in between; not trying to put the mirror out too far either and increase getting hit from opposite traffic and so forth.”

Transit Bus Operator Focus Group

This group consisted of five bus operators with a mean age of 50.2 years and 16.8 mean years of overall experience as bus operator; this focus group had an average of 15.8 years of that experience at NYCT. All were employed as full-time bus operators. One participant had previously driven motorcoaches, and two participants had previously driven tractor-trailers. Table 2-2 provides the discussion topics and key points for this focus group.

Table 2-2 *Transit Operator Discussion Topics and Key Points*

Discussion Category	Key Points
Operator Training	They train us to scan back and forth and all mirrors every 10 seconds.
	The recommended mirror adjustment positions to teach bus operators to rock back and forth or they may miss something.
	The flat mirror is focused on back tires and sides; the convex mirror is focused on seeing passengers along the side of the bus. The mirrors and mirror arms need to be standardized.
Curb-side Issues	Muscle memory and instinct are involved in checking mirrors but there are differences between bus models.
	RTS [model] buses do not have curb-side convex mirrors.
Street-side Issues	No street-side convex mirrors.
	A street-side convex mirror would be beneficial to see the bus without the fear of timing the view wrong.
Other Issues	Sometimes the smaller street-side flat mirrors are used on the curb side.
	Mount mirrors as high as possible on both sides while maintaining necessary views.
	Replacement mirror parts do not always match the function of the original part.
	The mirror housing should be minimal to avoid obstructions

Similar to the management and training supervisors focus group, direct quotes were captured from the audio transcriptions; a few of the direct quotes are as follows:

- “Convex mirrors are good because you can see the whole bus, [and] any of the cars coming next to you. Without that, you have to lean more and sometimes you miss it.”
- “If you look at the private buses—and this is the thing that always ****** me off—is we should have the best equipment. You know, we are one of the biggest transit systems and I look at the others and they are so much superior.… The mirrors are up high, straight across, so you don’t have the issue of banging them [another operator interjected hitting somebody] and they are on the top while ours [are] down here on the driver’s side where theirs [are] up there. They got a little hook, and it eliminates those. I’ve had two accidents where somebody clipped this mirror [re: driver’s side low mount], so up there just makes more sense.”
- “That’s what he was saying before—they just throw any mirror up there [another operator interjects ‘whatever fits’]. The driver’s side mirror, sometimes they throw it up here [referring to curbside] and you lose half your field of view.”

Motorcoach Bus Operator Focus Group

This group consisted of nine bus operators with an average age of 54.3 years and an average of 27.3 years of overall experience as bus operators. All participants in this focus group reported being employed by NYCT for their entire careers. Similar to the transit operators, all operators reported being employed full time. Additionally, five of these bus operators indicated driving transit buses early in their career before switching to motorcoach buses. Table 2-3 provides the discussion topics and key points for this focus group.

Table 2-3 *Motorcoach Bus Operator Discussion Topics and Key Points*

Discussion Category	Key Points
Operator Training	No standardization of mirrors between models and depots.
	Scan the mirrors every 3 seconds. Make turns at 3–5 mph.
	Lean forward into the mirror, leaning and rocking.
	Adjust mirrors properly before you start driving.
Curb-side Issues	Rearward and downward visibility is limited on curbside
	Provide three mirrors on the curb side, two convex and one flat.
Street-side Issues	Adjust flat mirrors so you can see the very rear tire.
	Motorcoach buses typically have convex mirrors on both sides.
	The blind spot on the street side along the A-pillar is bad.
Other Issues	Condensation and fogging of mirrors is an issue in tunnels.
	The large center interior mirror provides a two-lane street view on the curb-side, but not for seeing pedestrians.
	Keep original mirrors.

Direct quotes were captured from the audio transcriptions for this focus group; a few of the direct quotes are as follows:

- "You gotta be rocking and rolling [referring to body movement]. That's why you gotta lean up [referring to limiting street-side obscured area]."
- "A third mirror, yes [when asked to confirm that they were asking for a second convex mirror on the curb side, for a total of three mirrors overall, multiple participants responded with yes]."
- "The blind spot on the left side, along the column itself [referring to the A-pillar], that's a bad blind spot, but if you make the turn slow you shouldn't have a problem."

Post Focus Group Questionnaire Results

All focus group participants completed a post focus group questionnaire to gather input on the use of different mirror configurations, their preference of mirror configurations, and proper street-side mirror adjustment. The results are presented in the figures below.

Across all three focus groups, only one participant (transit focus group) had previously driven a bus with high-mount mirrors installed on both the bus's street side and curb side. Conversely, all participants except for one (motorcoach focus group) had driven buses where both the street side and curb side utilized low-mount mirrors.

Focus group participants were also asked about their perception and how they felt about high-mount mirrors if they were mounted on the curb side and street side of the bus. Figure 2-1 and Figure 2-2 provide participant responses and comparisons among each of the three focus groups. A majority from each group selected the option stating they like or want curb-side high-mount mirrors. A majority of both bus operator groups selected the option stating they also like or want street-side high-mount mirrors, but managers preferred curb-side low-mount or were undecided.

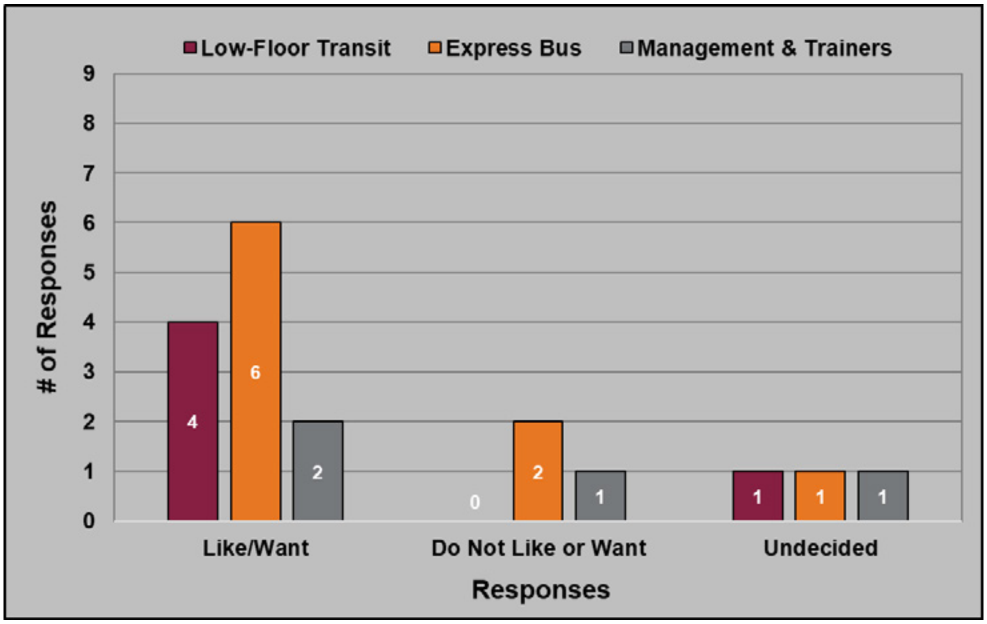


Figure 2-1 *Focus group opinions about curb-side high-mount mirrors*

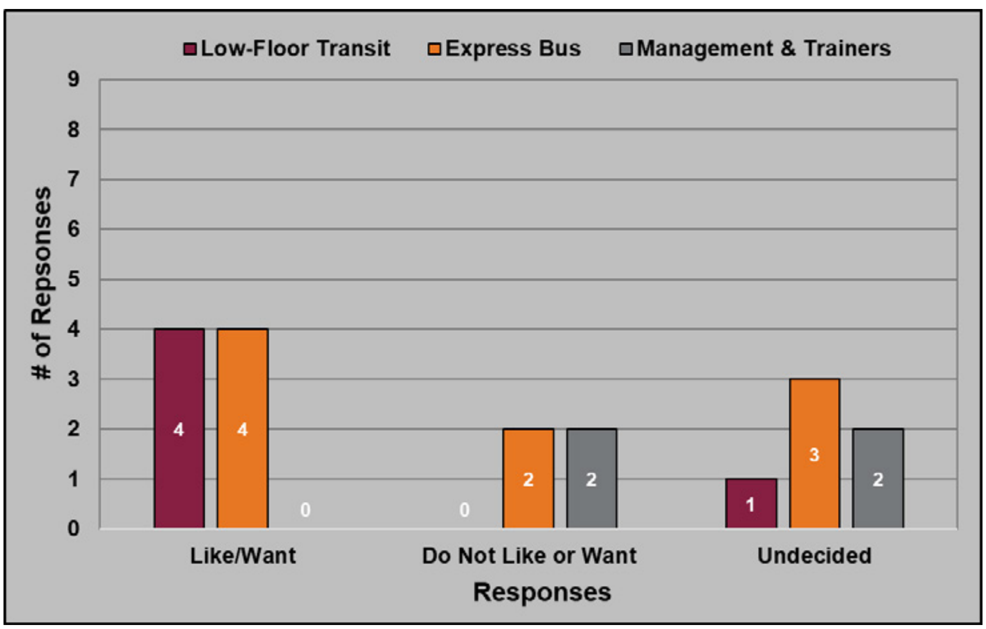


Figure 2-2 *Focus group opinions about street-side high-mount mirrors*

When assessing focus group responses about preference for having convex mirrors in general, 83% (15 of 18) of participants were in favor of the use of convex mirrors; however, when digging deeper into these results, preferences varied on their use between the curb side and street side. Figure 2-3 provides participant responses and comparisons between focus groups. The figure demonstrates that 44% (8 of 18) of participants did not prefer to have a convex mirror on the street side.

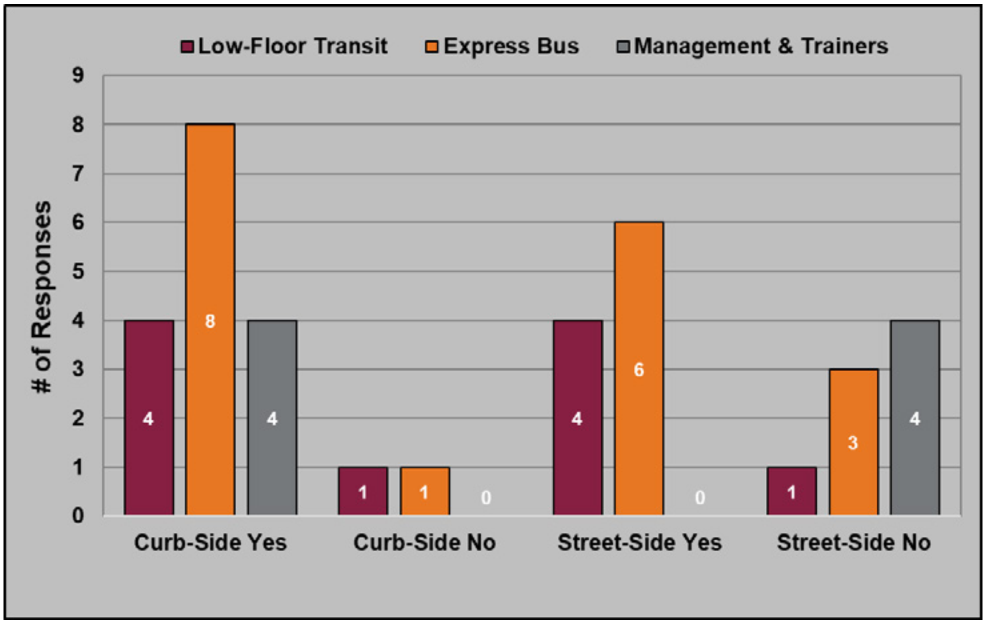


Figure 2-3 *Focus group opinions on use preference and location of convex mirrors*

Vehicle Measurement

This activity supplied important benchmarking data that provided common seating and eye-point references along with interior and exterior vehicle and component surfaces that were imported into CAD software for detailed modeling. NYCT's DOB scheduled a total of six buses for the research team to scan to obtain seating and eye-point references. All scanning and data collection were conducted at the Zerega Maintenance and Training Facility in the Bronx from April 15 to 30, 2018. Data were collected on a total of four different transit buses (Figure 2-4 and Figure 2-5) and two different motorcoach buses (MCI and Prevost) Figure 2-6.

Figure 2-4 *Orion (l) and New Flyer (r) transit buses*

Figure 2-5 *Nova (l) and Proterra (r) transit buses*

Figure 2-6 *Prevost (l) and MCI (r) motorcoach buses*

The main vehicle scanning process was completed with a FARO arm with an attached probe (Figure 2-7). Additional interior dash and A-pillar scanning was conducted utilizing a 3D laser scanner (Figure 2-8). All research team members were trained and proficient in the use of these measurement devices.

Figure 2-7 *FARO arm coordinate measuring device*

Figure 2-8 *Laser scanning photometric and probe reference stickers attached to bus street-side A-pillar and dash*

Common seating and eye-point references were captured in each of the buses using an SAE J826 H-point Machine that was certified and calibrated prior to use (Figure 2-9) [4].

Figure 2-9 *SAE H-point machine*

Scanning activities included both interior and exterior surfaces of each bus. Interior scanning included the entire bus operator's compartment, comprising the operator security door, instrument panel and dash, steering wheel, both A-pillars, windscreen, side windows, interior mirrors, and the fare box. The steering wheel was scanned four times for each bus to capture the full range of tilt and height. Exterior scanning included entry/exit doors in both open and closed positions, windscreen, wiper path, exterior mirror faces and all mounting brackets/arms, and the ground plane. The ground plane was scanned twice for each bus, once with the bus in the kneeling position and once at ride height. It should also be noted that the exterior mirror faces were scanned with the glass in a nominal position as adjusted by an NYCT DOB trainer as well as at the maximum limits for both left and right and up and down. Figure 2-10 and Figure 2-11 demonstrate examples of the interior and exterior bus scans. The remaining scans are provided in Appendix B. The thin lines represent probe scan data, and the solid surfaces represent the 3D laser scan data, excluding the ground planes.

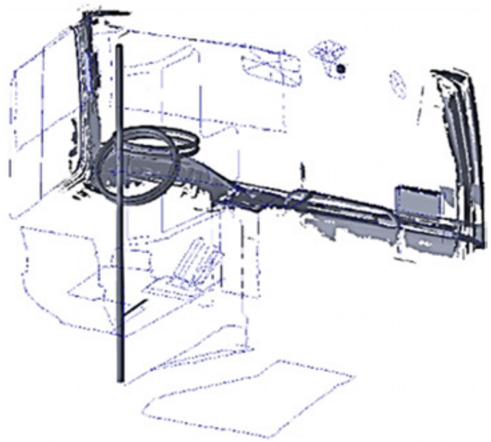


Figure 2-10 *Bus interior scan of New Flyer bus*

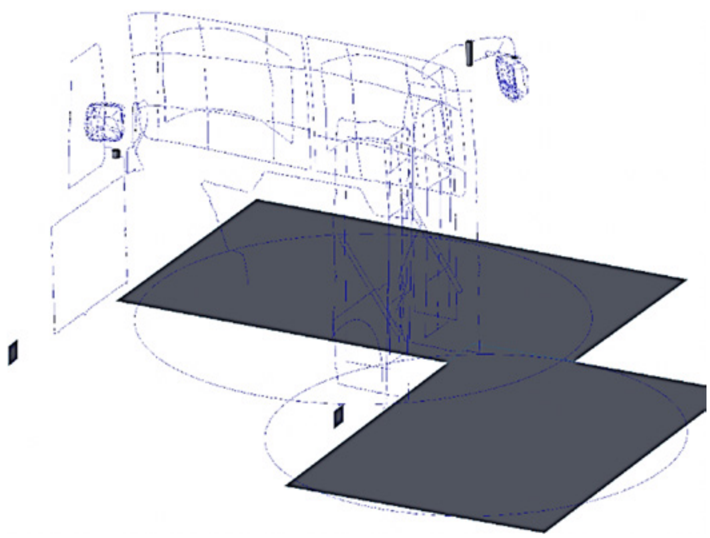


Figure 2-11 *Bus exterior scan of New Flyer bus*

Bus Operator Anthropometry

Prior to the visibility modeling, Human Solutions North America (HSNA) provided population measurements of 8,400 body scans of North American adults between ages 18 and 75 (see Table 2-4). HSNA conducted these anthropometric measurements across North America for its Size North America project.

Table 2-4 *Population Breakdown by Ethnicity for Visibility Modeling*

Ethnicity	Females (n)	Males (n)
Asian	422	259
American Native	0	0
Pacific Islander	0	0
Non-Hispanic White	2,216	1,686
Hispanic	1,020	531
Other Mixed	279	155
Black	1,275	606
Overall	5,212	3,237

The research team used RAMSIS Human Modeling Software to create eight manikin specifications that were then used in the visibility modeling for each of the buses (see Figure 2-12 and Figure 2-13). The following manikin specifications were created and applied:

- 97.5th-percentile male with largest sitting height (long torso)
- 97.5th-percentile male with shortest sitting height (long legs)
- 50th-percentile male, average
- 2.5th-percentile female with largest sitting height (long torso)
- 2.5th-percentile female with shortest sitting height (long legs)
- 50th-percentile female, average
- 2.5th-percentile Hispanic female with largest sitting height (long torso)
- 2.5th-percentile Hispanic female with shortest sitting height (long legs)

The eight manikins were placed in a seated position for application to the visibility performance modeling.

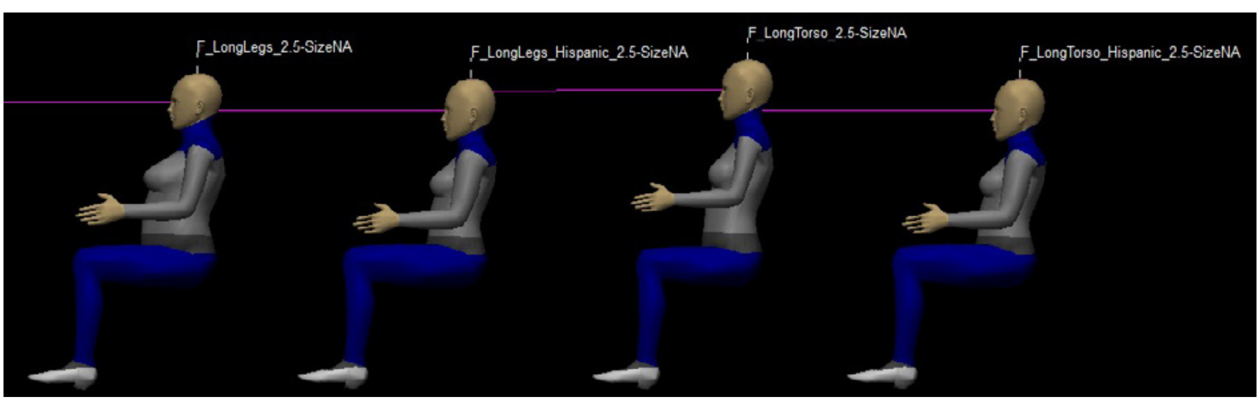


Figure 2-12 *Side view of four female manikins*

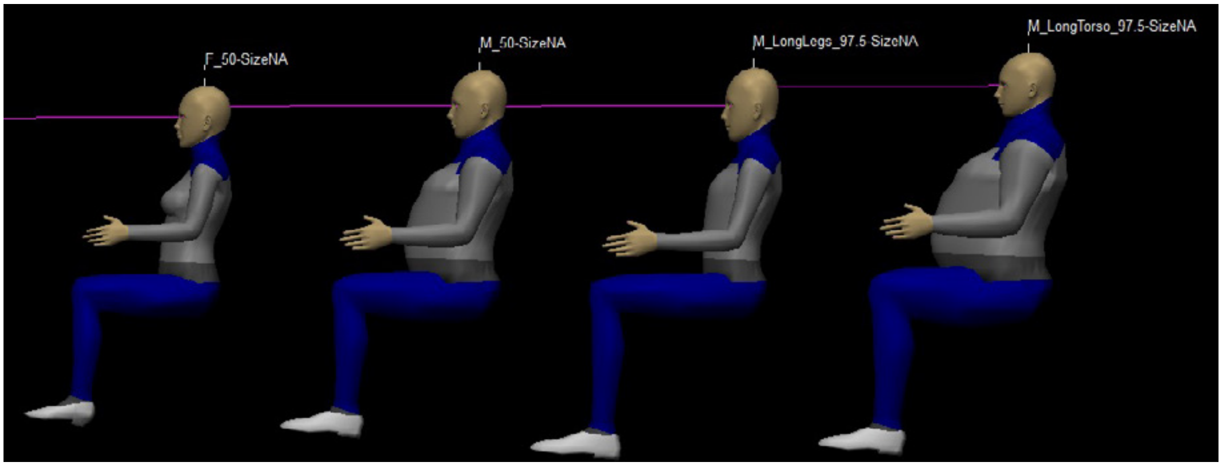


Figure 2-13 *Side view of one female and three male manikins*

Street Modeling

To complement the vehicle modeling and apply the visibility performance modeling in a real-world setting, a New York City roadway environment was selected for mock-up and rendering—the intersection of E 149th Street and Grand Concourse in the Bronx. This is a four-way intersection with multiple travel lanes in all directions that includes a transit bus dedicated left-turn lane when traveling southbound. See Figure 2-14 and 2-15 for the 3D CAD model created for this intersection. The intersection is both complex and busy throughout the day, so it provided the research team a realistic test environment to simulate visibility performance for bus operators, while also providing guidance for the placement of pedestrians and vehicle traffic.

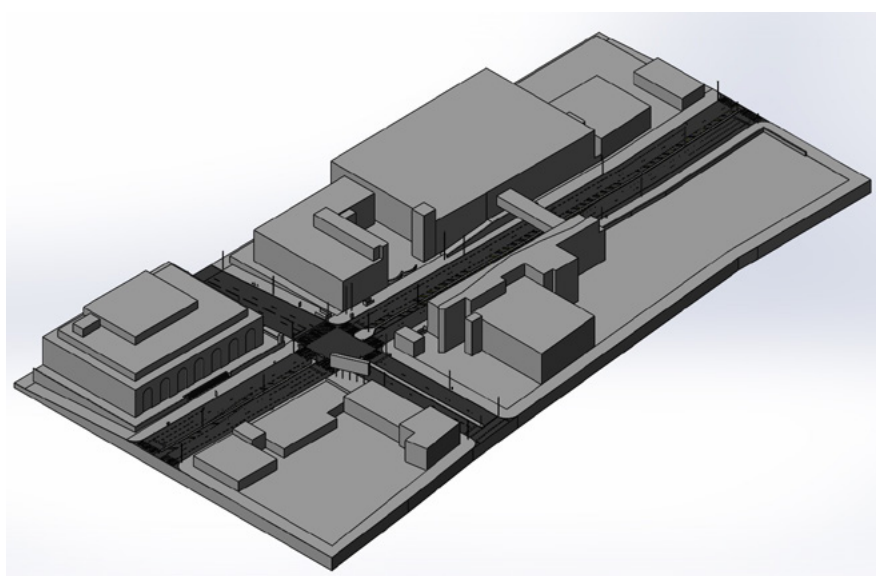


Figure 2-14 *Isometric view of 3D model of E 149th Street and Grand Concourse*

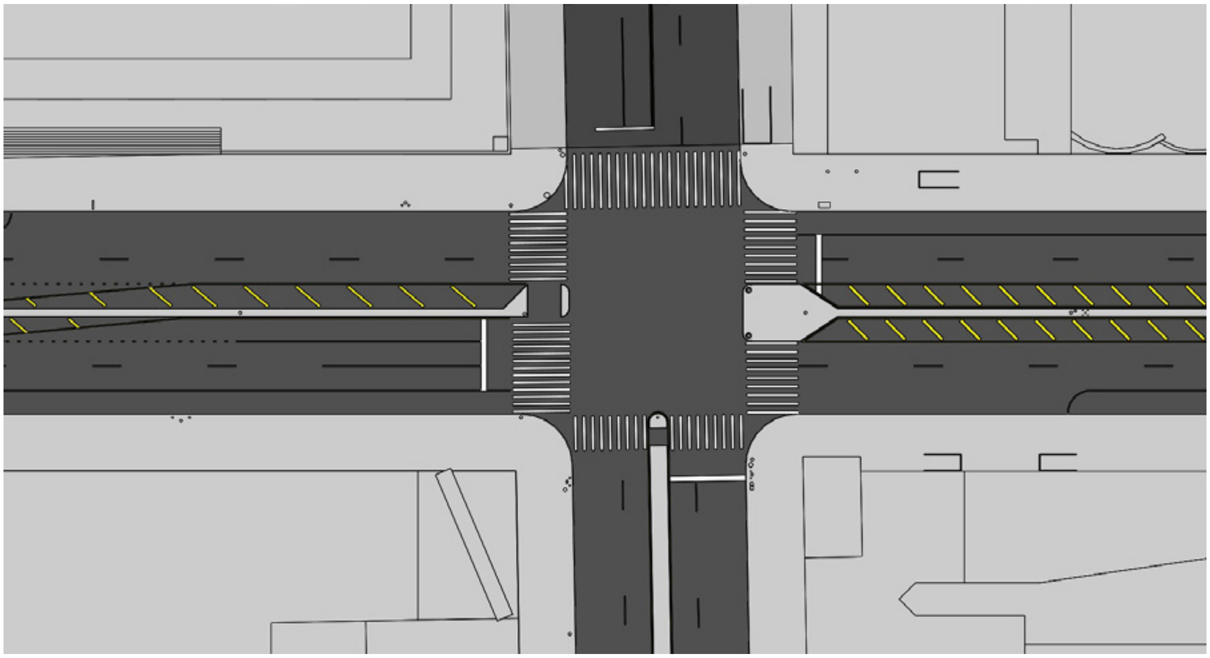


Figure 2-15 *Top view of E 149th Street and Grand Concourse*

NYCT Bus 2019 incidents

Other important aspects to evaluate when designing an optimal street-side mirror for transit buses are the number and type of incidents. NYCT provided the research team all incident data for 2019 involving New Flyer and Nova buses. All New Flyer buses have only a flat mirror on the street side; the Nova buses, depending on model year, may have only a flat mirror or a horizontal split mirror with both flat and convex mirrors. Table 2-5 provides a breakdown of the number of New Flyer and Nova buses in 2019 along with total mileage and number of left-side incidents and preventable left-side incidents.

Table 2-5 *Breakdown of New Flyer and Nova Buses for 2019 Incidents*

Bus Make/Model	2019 Buses (n)	Mileage (mi)	All Left-side Incidents (n)	Preventable Left-side Incidents (n)
New Flyer 40-ft – No Convex	1,486	38,628,159	1,017	190
New Flyer 60-ft – No Convex	626	13,463,230	407	53
Nova 40-ft – No Convex	251	4,616,866	106	24
Nova 60-ft – No Convex	16	228,498	10	2
Nova 40-ft – Convex	717	16,068,795	477	57
Nova 60-ft – Convex	563	12,563,557	750	94

Figure 2-16 shows the total number of left-side incidents by mirror type and bus configuration normalized per million vehicle miles traveled (MVMT); both preventable and non-preventable incidents are illustrated. The rate of left-side incidents per MVMT is greater for both 40-ft and 60-ft buses with convex mirrors than without convex mirrors.

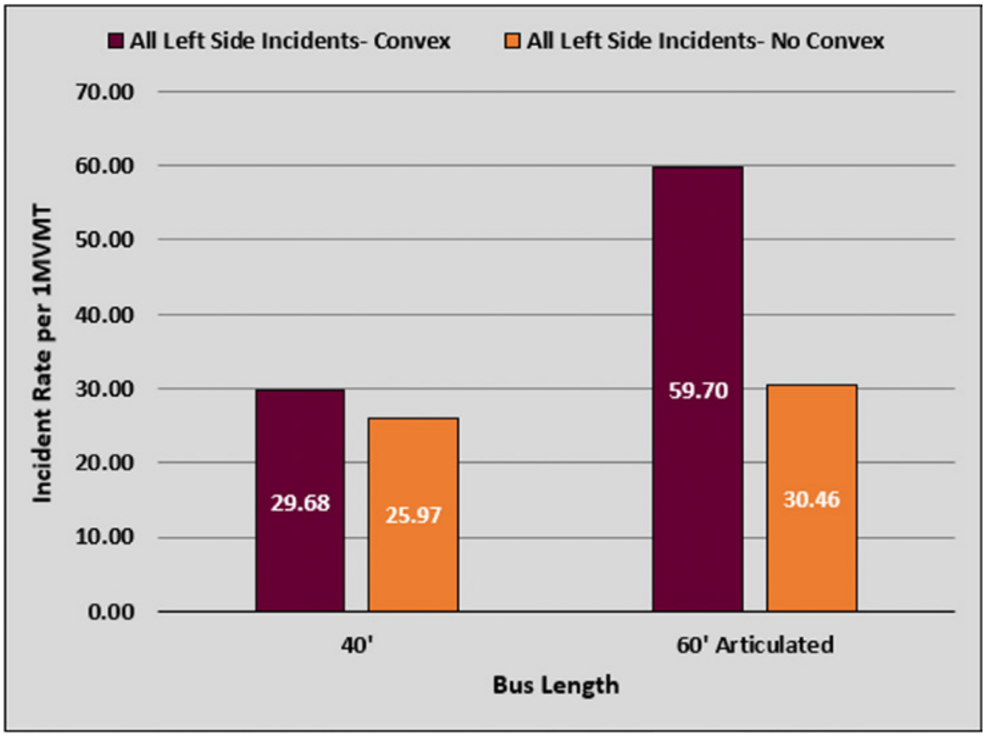


Figure 2-16 *Rate of all left-side incidents per 1 MVMT by mirror type and bus configuration*

Figure 2-17 shows the number of left-side incidents deemed preventable by mirror type and bus configuration normalized per MVMT for comparison to Figure 16. The rate of preventable left-side incidents per MVMT is greater for the 60-ft articulated buses with convex mirrors than without; however, the 40-ft buses with convex mirrors had fewer preventable incidents. A thorough review of the 2019 incidents involving these buses allowed the research team to categorize the left-side incidents in preparation for analyses. Incidents were organized into four categories: All Left-Side Incidents, Bus Moving—Left-Side Incidents, Bus-to-Vehicle—Left-Side Incidents (Omits Mirror-Only Strikes), and Left-Moving Incidents (i.e., bus was moving from right to left). Further, each of these four incident categories was subdivided between 40-ft transit buses and 60-ft articulated transit buses for a total of eight incident classifications. Only incidents deemed preventable by the NYCT investigator were included in the final analyses. Crash rates were calculated per one million MVMT, and rate ratios were calculated to determine if significant differences were observed. Table 2-6 provides the results of the crash rate calculations.

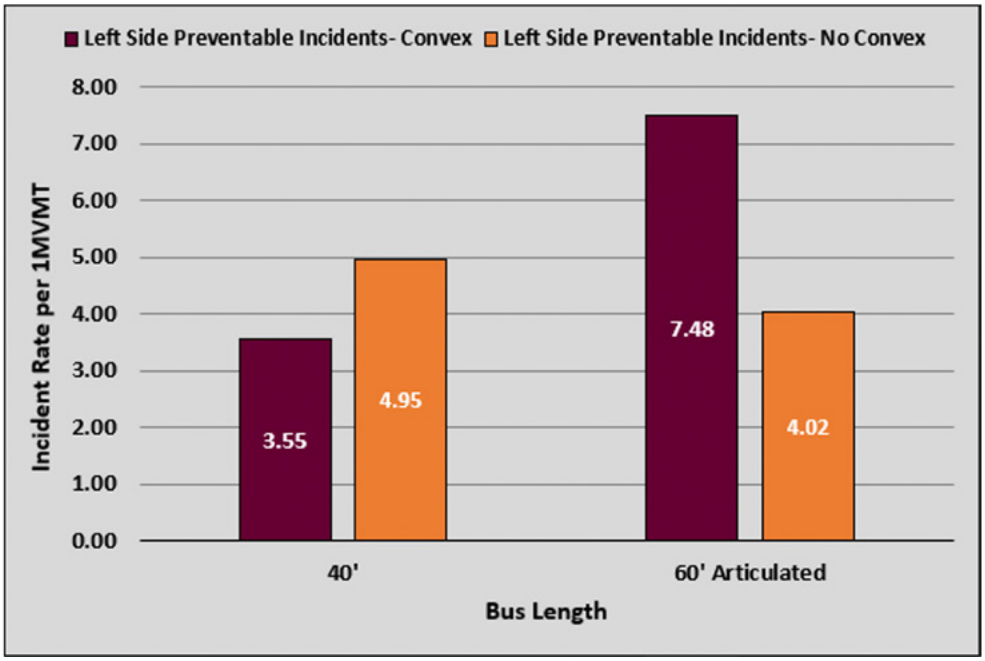


Figure 2-17 *Rate of left-side preventable incidents per 1 MVMT by mirror type and bus configuration*

Table 2-6 *Crash Rates per 1 MVMT by Incident Classification and Bus Length*

Incident Classification	Bus Length	Crash Rate per 1 MVMT Convex	Crash Rate per 1 MVMT No Convex	Rate Ratio	p-value
All Incidents	40-ft	3.55	4.95	1.40	0.0255*
All Incidents	60-ft	7.48	4.02	0.54	0.0002*
Bus Moving	40-ft	3.49	4.88	1.40	0.0252*
Bus Moving	60-ft	7.25	3.87	0.53	0.0003*
Bus-to-Vehicle	40-ft	3.11	4.56	1.46	0.0161*
Bus-to-Vehicle	60-ft	6.77	3.80	0.56	0.001*
Left Moving	40-ft	1.56	2.73	1.75	0.0107*
Left Moving	60-ft	2.07	1.46	0.71	0.2415

** Indicates significance*

Significant differences were observed in seven of the eight incident classifications. In all four incident classifications with the 40-ft transit bus, the results indicate that the Nova buses with the convex mirror had significantly fewer left-side incidents, thus indicating a protective effect with the convex mirror. The opposite effect was observed in the 60-ft articulated transit buses.

In three of the four incident classifications with the 60-ft articulated buses, those with only the flat mirror had significantly fewer left side incidents; the left-moving (i.e., moving from right to left) incidents did not find any significant differences between mirror type. The 60-ft articulated transit bus results led the research team to further investigate why the convex-mirror-equipped Nova buses resulted in more preventable left-side incidents.

The point of impact for these incidents was analyzed and crash rates were again calculated per 1 MVMT. Significant differences were observed between the flat-mirror-only buses and those equipped with both a flat mirror and convex mirror. Interestingly, the left front is the primary area of concern regarding left-side incidents on the 60-ft articulated transit buses. Those equipped with a convex mirror had significantly more left front incidents than flat mirror only buses. No significant differences were observed for the left middle and left rear points of impact. Table 2-7 provides the results of this analysis.

Table 2-7 *Crash Rates per 1 MVMT by Point of Impact on 60-ft Articulated Transit Buses*

Incident Point of Impact	Crash Rate per 1 MVMT Convex	Crash Rate per 1 MVMT No Convex	Rate Ratio	*p*-value
Left Front	3.02	1.61	0.53	0.0182*
Left Middle	0.56	0.22	0.39	0.1762
Left Rear	3.10	1.97	0.64	0.0699

A descriptive analysis of bus actions during the incident helps to further refine the hypothesis on why the left front is the primary area of concern on 60-ft articulated buses. Table 2-8 reveals the number of incidents per bus action by mirror type.

Table 2-8 *Number of Left Front Incidents per Bus Action on 60-ft Articulated Transit Buses*

Mirror Type	Moving Straight	Left Turn	Right Turn	Pulling Into Bus Stop	Leaving Bus Stop	Stopping	Changing Lanes	Standing	Reverse
No Convex	17	1	0	2	0	1	1	0	0
Convex	23	0	2	0	8	1	3	1	0

The majority of left front incidents occurred while the bus was moving straight, regardless of mirror type; however, leaving the bus stop was the largest difference in frequency of left front incidents with the convex-mirror-equipped buses having more.

Overall, the convex mirror provides a protective effect on the 40-ft transit buses, whereas the opposite is true on the 60-ft articulated transit buses. However, review and analysis revealed that the primary area of concern is the left front and not the left rear, with the 40-ft transit buses with a convex mirror having significantly more incidents. The research team reasoned that the larger mirror head needed to house both the flat and convex mirrors results in a larger forward obstruction; hence, these buses were observed to have more incidents while moving straight and when leaving the bus stop. However, without video and telematics data, the research team can only hypothesize this result.

Section 3

Development

Bus Modeling

Once all scanning activities at NYCT DOB were completed, the raw scan data were transferred to VTTI's secure server. The raw scan data were then organized at a common coordinate space location. The vehicle centerlines were aligned so that the longitudinal axis of each bus was parallel with the x-axis, the lateral axis of each bus was aligned at the front bumper, and the vertical axis of each bus was aligned on ground plane—at driving not kneeling position. The 3D laser scan data were aligned using references that were common in the probe data and laser scan data. These references were ball bearings that were intentionally positioned on large surfaces during the scanning in preparation for this modeling step. The scan data were cleaned to remove any noise and ensure no duplicate measures that might affect the accuracy and precision during the creation of the vehicle models and subsequent visibility zones. Once preparation of the raw scan data was completed, the VTTI engineering team confirmed all vehicle models were in common frames of reference for benchmarking. RECARO (bus seat manufacturing partner) provided engineering drawings that specified reference points for their seats that supported the H-point measurements taken for each of the buses. Using the bus scanning data along with the provided engineering drawings, 3D models of the four transit buses and two motorcoach buses were rendered using SolidWorks CAD software. Figure 3-1 and Figure 3-2 show examples of the fully-rendered transit bus and motorcoach bus models positioned commonly at the bumpers and on the ground.

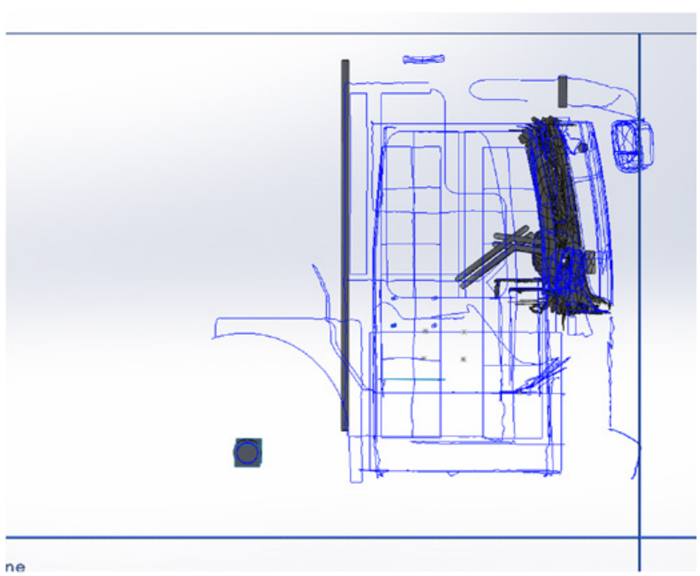


Figure 3-1 *Side view of fully-rendered New Flyer model*

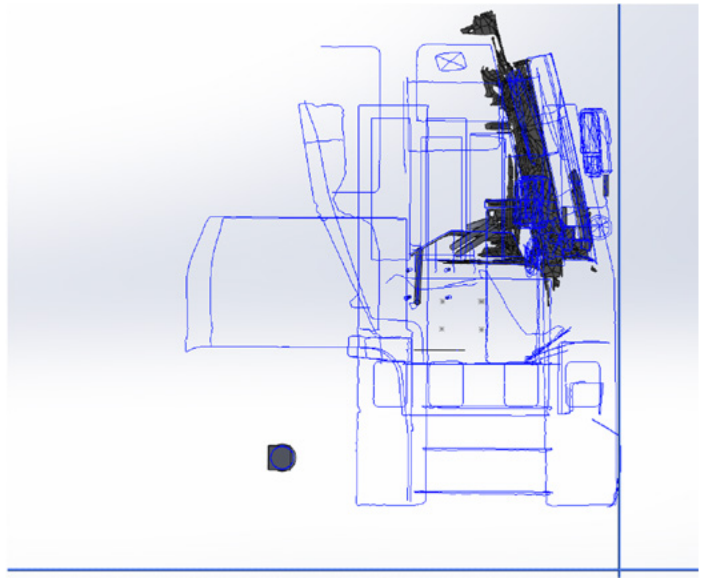


Figure 3-2 *Side view of fully-rendered MCI Motorcoach Bus model*

Visibility Performance Modeling

Following completion of the fully-rendered bus models, A-pillar obstruction angles were measured. These measurements were calculated in accordance with SAE J941–Appendix E and SAE J1050–Appendix C, procedures that take into account the 95th-percentile population for eye ellipses, 50/50 gender ratio, and seat at middle of vertical adjustment and ignore any attachments (e.g., communication devices, etc.) mounted on A-pillars [5, 6]. Figure 3-3 provides a reference of eyellipse position procedure per SAE J941 (Figure E1) [5]. Figure 3-4 provides a reference of pillar obstruction measurement per SAE J1050 (Figure C1) [6].

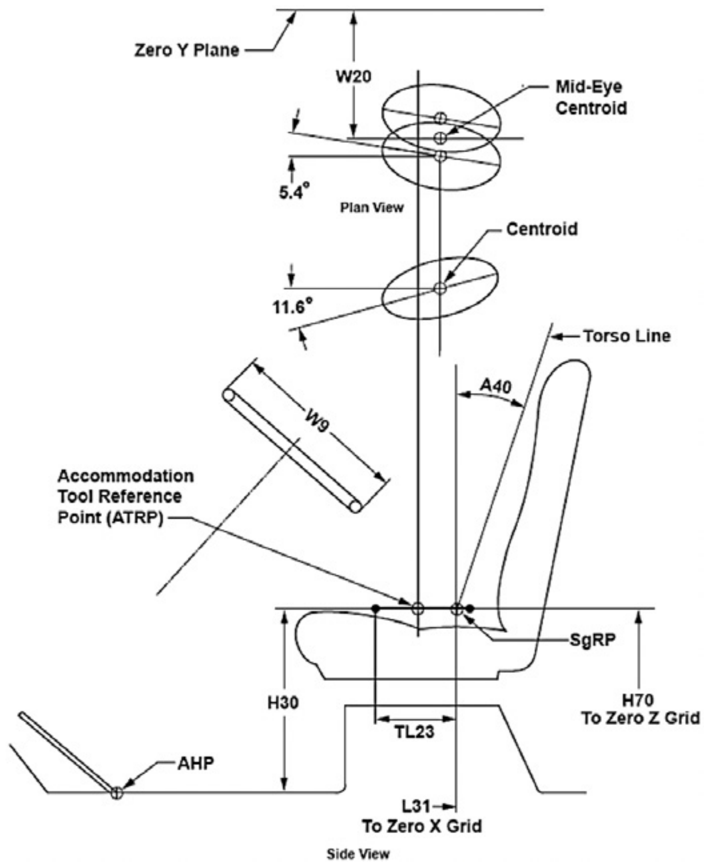


FIGURE E1 - EYELLIPSE LOCATION IN CLASS B VEHICLES

Figure 3-3 *SAE J941–Appendix E, Class B Vehicles Eyellipse location procedure [Figure E1]*

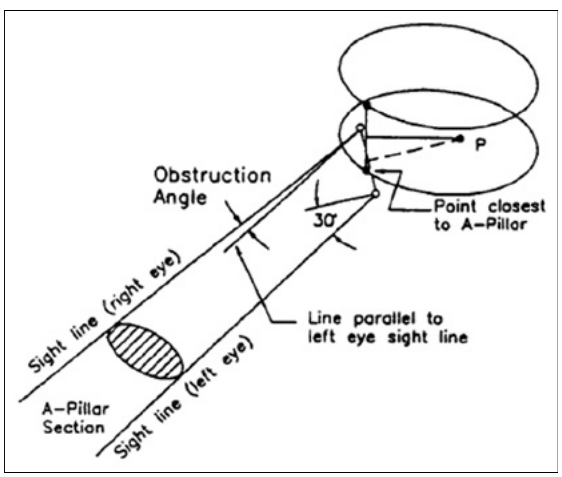


FIGURE C1 - METHOD FOR DETERMINING
A-PILLAR OBSTRUCTION ANGLE

Figure 3-4 *SAE J1050–Appendix C, measurement of A-pillar obstruction angle [Figure C1]*

A-pillar obstruction angles were developed for each bus model. An example of the result is demonstrated for one transit bus in Figure 3-5.

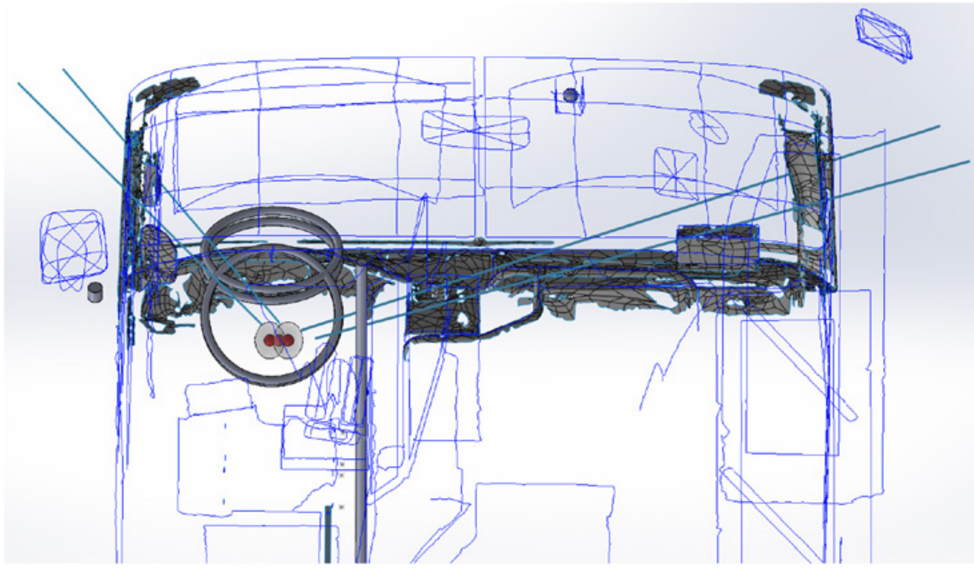


Figure 3-5 *Top view of New Flyer A-pillar obstruction angles*

Table 3-1 shows the obstruction angle measurements of the four transit buses. The buses have been anonymized in the table to limit distribution of performance metrics that may be considered sensitive.

Table 3-1 *A-pillar Obstruction Angles of Four Transit Buses*

A-pillar	Bus A	Bus B	Bus C	Bus D
Street-side Obstruction Angle	5.08°	7.02°	2.48°	4.84°
Curb-side Obstruction Angle	6.77°	3.35°	3.37°	2.31°

After calculating the A-pillar obstruction measurements, the research team then calculated the obstruction created by the street-side mirror head assembly. The same process assumptions (e.g., 95th-percentile eye ellipses, 50/50 gender ratio, etc.) were used as in the A-pillar measurements. The same eyellipse height as the A-pillar measurements was also used for the mirror head assembly measurements. It should be noted that obstruction angles measured for the mirror head assemblies were calculated at the mirror head's maximum obstruction width. An example of the result is demonstrated in Figure 3-6.

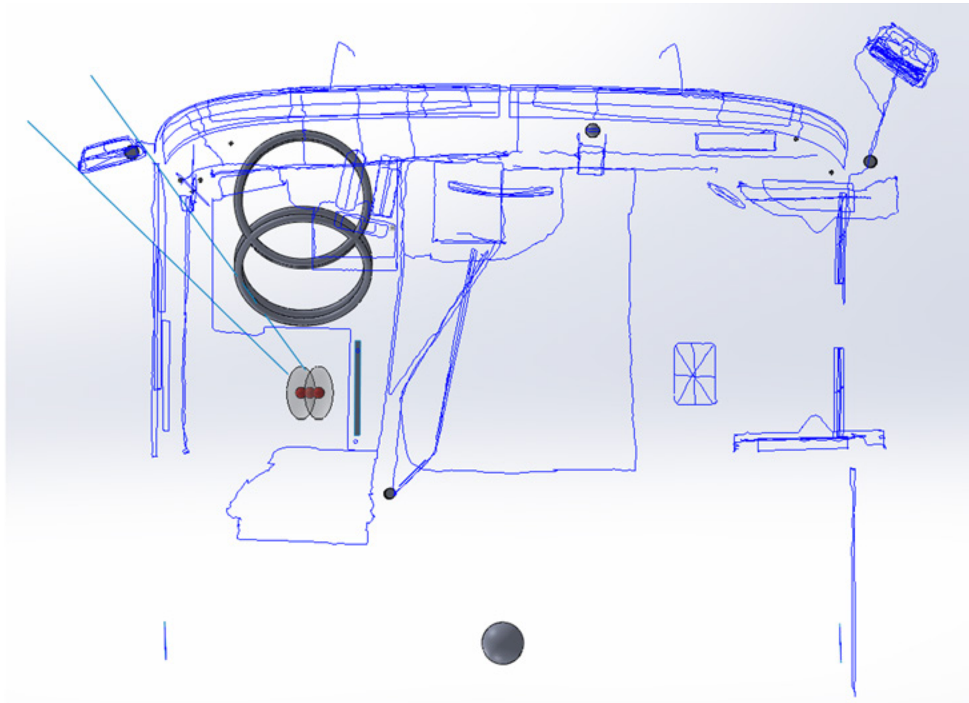


Figure 3-6 *Modified top view of New Flyer mirror head obstruction angle*

Table 3-2 provides the calculated mirror head assembly obstruction angles. The buses have been anonymized in the table to limit distribution of performance metrics that may be considered sensitive. The analysis of mirror head obstruction is a novel application. However, it allows the obstructions of mirror heads to be considered in the same point of reference as the obstructions of each bus's A-pillars.

Table 3-2 *Mirror Head Assembly Obstruction Angles*

Mirror Head	Bus A	Bus B	Bus C	Bus D
Street-side Mirror Head Obstruction	11.22°	12.17°	9.78°	9.17°

The bus operator manikins provided by HSNA were positioned into driving positions in each bus according to the range of seat and steering wheel adjustments as well as the pedals and limits of visibility. The visibility limitation was bounded by each bus's gauge panel and the American Public Transportation Association's (APTA's) visibility target at driver centerlines. Three manikins were selected for demonstration of the range of seated positions between all transit buses—2.5th-percentile stature Hispanic female with largest sitting height (long torso), 50th-percentile stature male, and 97.5th-percentile stature male with largest sitting height (long torso). The positioned manikins are demonstrated in Figure 3-7.

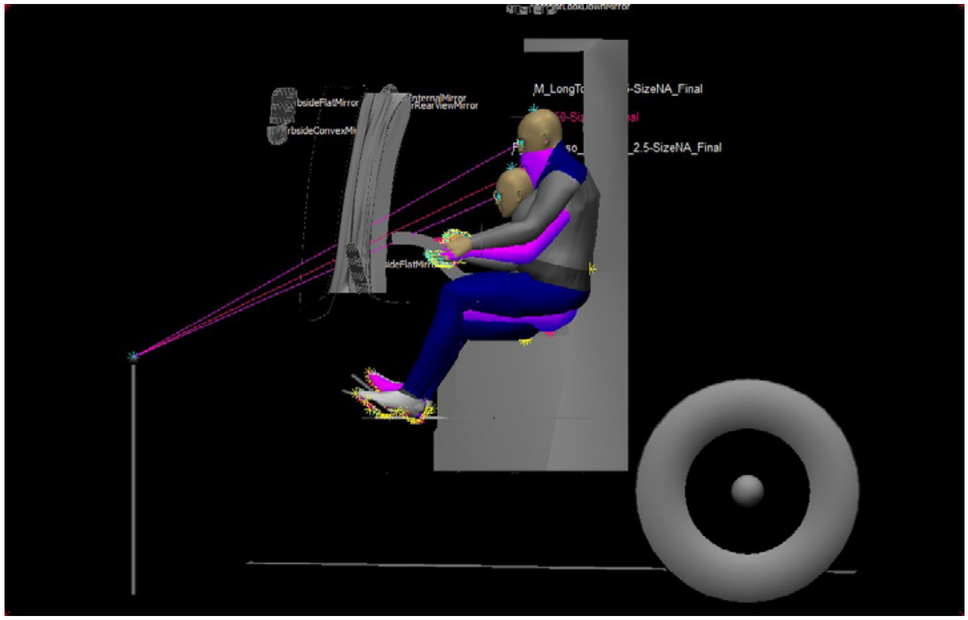


Figure 3-7 *Side view of three manikins positioned in New Flyer bus*

Based on the resulting positions of all eight manikins in the test sample, two were selected to represent the benchmarking and mirror design boundaries based on the coordinates of each individual manikin's eye point. The two manikins selected for benchmarking mirror visibility across all buses were the 2.5th-percentile Hispanic female long torso and the 97.5th-percentile male long torso. Representatives of the U.S. population below and above the typical 5th-percentile and 95th-percentile statures were chosen to ensure the benchmarking, design, and guidance outcomes of the project will accommodate as many prospective bus operators within the available population as possible.

RAMSIS software was used to analyze mirror indirect visibility for these two manikins. In RAMSIS, mirror models can be created using CAD geometry and the RAMSIS ergonomics package to generate mirror models based on mirror geometry, center of rotation, and angle of incidence/reflection. With these mirror models created, the bus operator manikins' eyes were set to look at the mirror center. The RAMSIS software creates mirror reflection zones based on each bus operator manikin's eye-points and the mirror geometry. Using these tools, the A-pillar and mirror forward visibility obstructions, as well as the mirror rearview ground zones, were developed for the four transit buses for comparison and to highlight performance factors that should be considered while optimizing the visibility zones for the New Flyer bus that was used in the demonstration phase. The software was also used to develop obstructions to the driver's forward and side visibility, which result from other parts of the bus body. The male and female manikins' eyes were set to look left behind the street-side A-pillar and through the street-side glass, straight forward between the two A-pillars, and right behind the curb-side A-pillar and through the passenger entry door glass. The obstructions created by the A-pillar, mirrors, dashboard, fare box, route box, bus body near the bus operator workstation, bus operator security door (if applicable), and passenger entry door obstruction, as well as the rearview mirror performance for female and male manikins among the four transit buses, are provided in Figures 3-8, 3-9, 3-10, and 3-11.

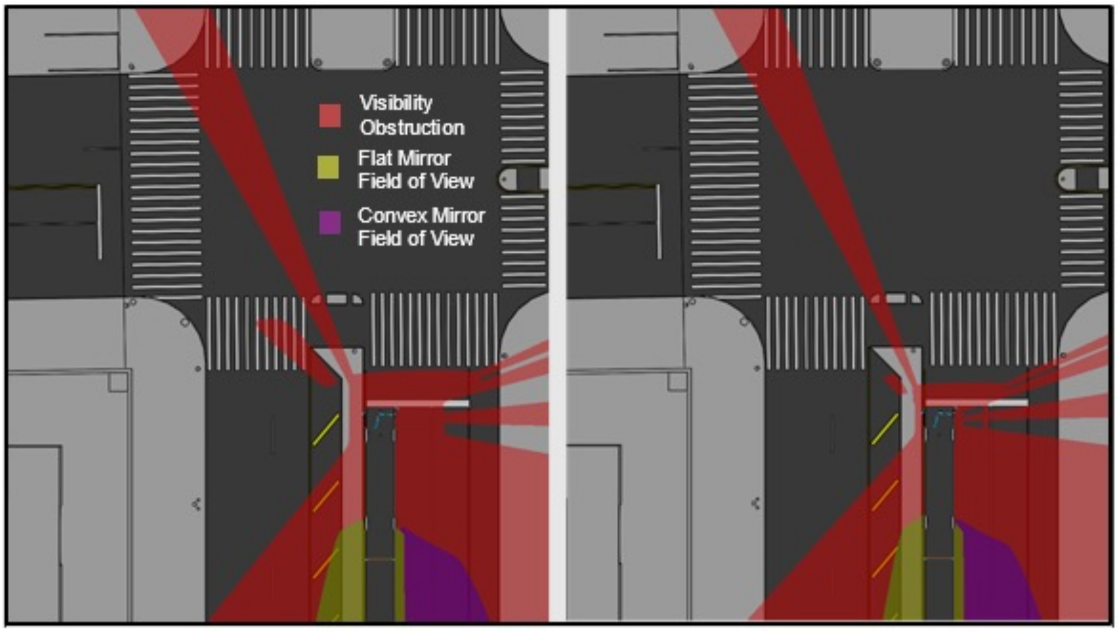


Figure 3-8 *Top view of short female (l) and tall male (r) direct visibility obstructions and rearview mirror visibility of Orion bus*

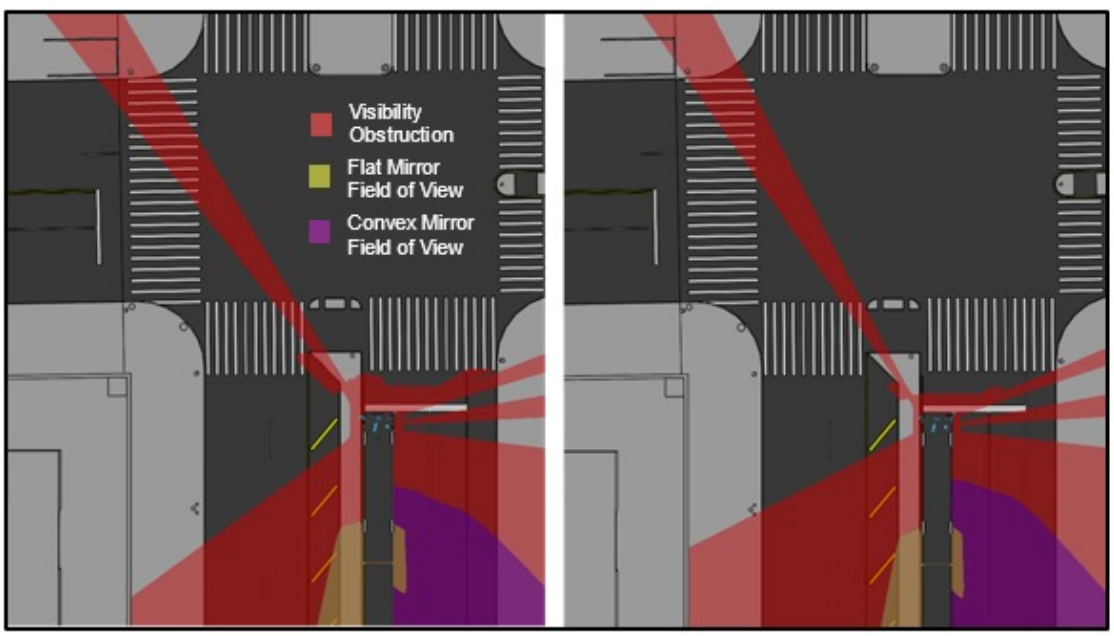


Figure 3-9 *Top view of short female (l) and tall male (r) direct visibility obstructions and rearview mirror visibility of New Flyer bus*

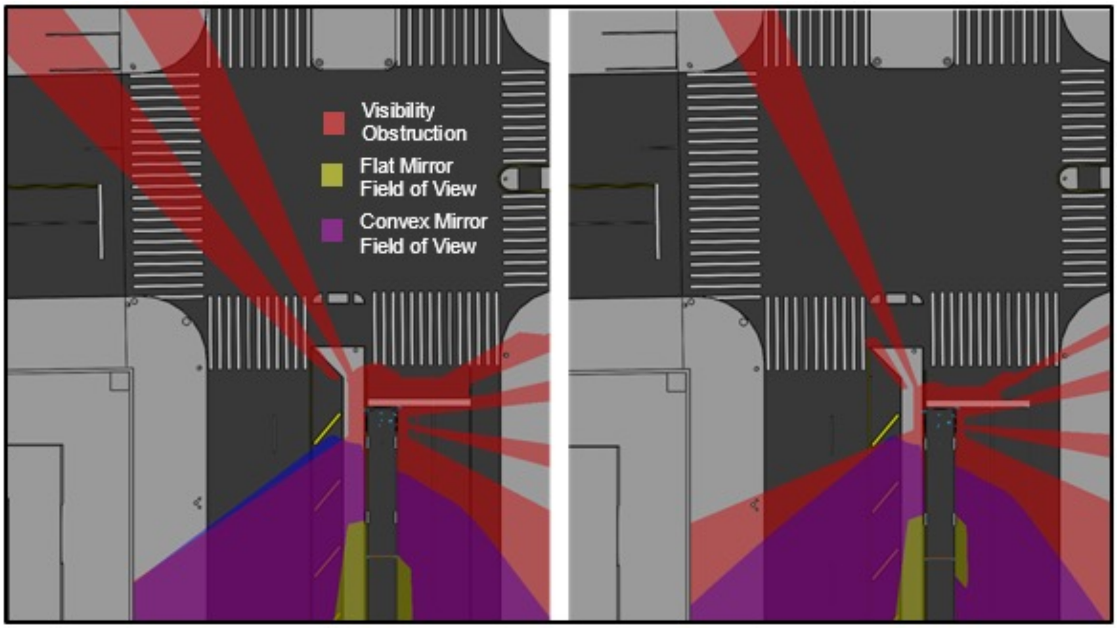


Figure 3-10 *Top view of short female (l) and tall male (r) direct visibility obstructions and rearview mirror visibility of Nova bus*

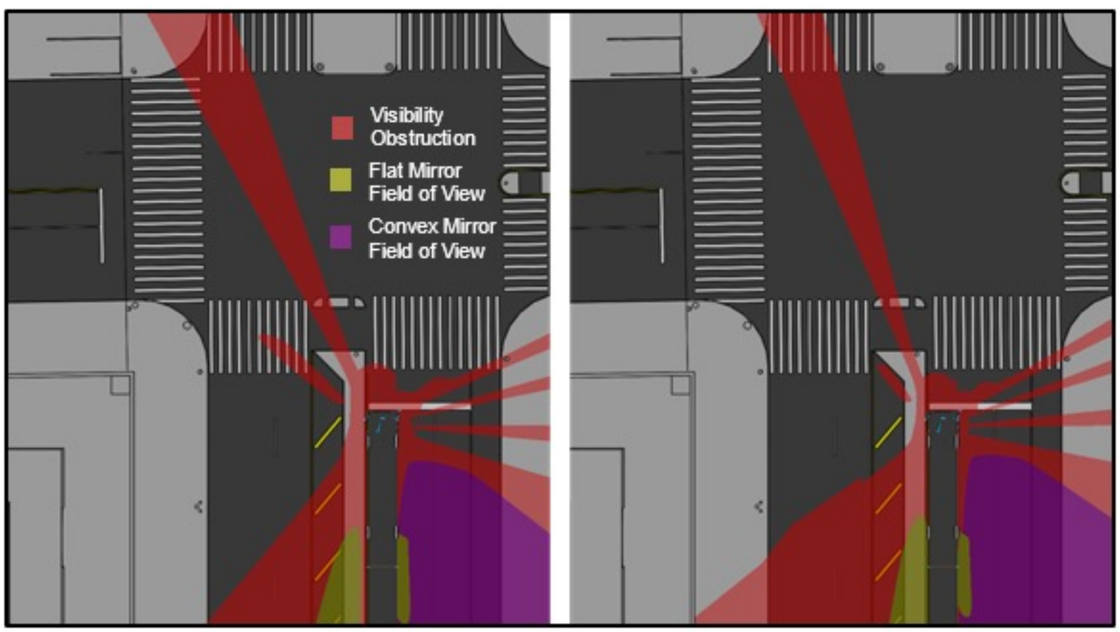


Figure 3-11 *Top view of short female (l) and tall male (r) direct visibility obstructions and rearview mirror visibility of Proterra bus*

Transit Bus Street-Side Mirror Design Optimization

VTTI used the information collected during the focus groups, vehicle data from the bus scans, mirror visibility modeling data and benchmarking results, and the results of the human simulation models developed with the manikins in the NYCT roadway environment to optimize mirror designs and visibility for the New Flyer buses planned for the demonstration in NYC. The optimization and design guides were completed simultaneously and updates to the design guide were made as the research team learned from the findings of the data collection and optimization activities.

The research team used the domestic and international visibility guidance standards (i.e., FMVSS 111, ECE 46-02) that provide references for mirror visibility performance and the aiming procedures collected from the focus groups to determine the optimized visibility performance for transit bus [3]. The goal of visibility optimization was to reduce or eliminate obstructions created by the mirror head on the street side, while maintaining or improving the rearview mirror performance. To accomplish this, the visibility obstructions that exist due to the bus body, including A-pillars, limitations of the street-side glass, and the curb-side entry doors, were considered. Additionally, if an obstruction could not be eliminated, then approaches to viewing objects in the roadway were attempted by separating the mirror head and A-pillar obstructions. Various mirror surfaces and positions were tried and the performance for both the short female and tall male were considered. Mirror surfaces and positions that could accomplish these optimization goals were considered.

One early attempt to accomplish the reduction of mirror obstructions led to a high-mount concept with flat glass and convex mirror combination above the street-side glass (Figure 3-12) high-mount mirror. However, the result for the tall male was not successful, as some sections of the opposing crosswalk with a simulated pedestrian were blocked from view by the high-mount mirror. A simulation of the comparison of the visible pedestrian in the crosswalk for the short female and the blocked pedestrian for the tall male is provided in Figure 3-13.

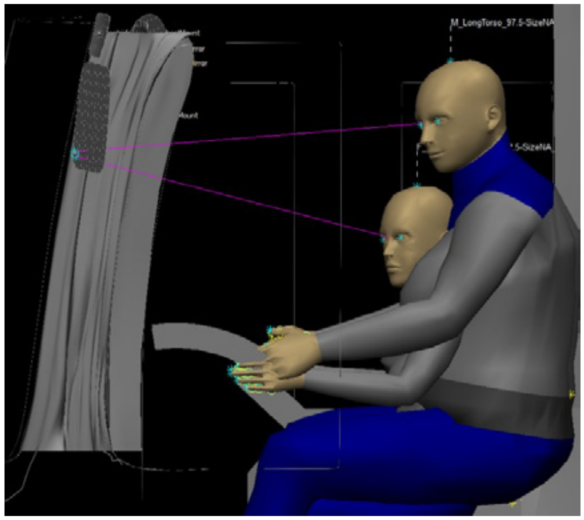


Figure 3-12 *Side view of short female and tall male looking at flat and convex mirror combination*

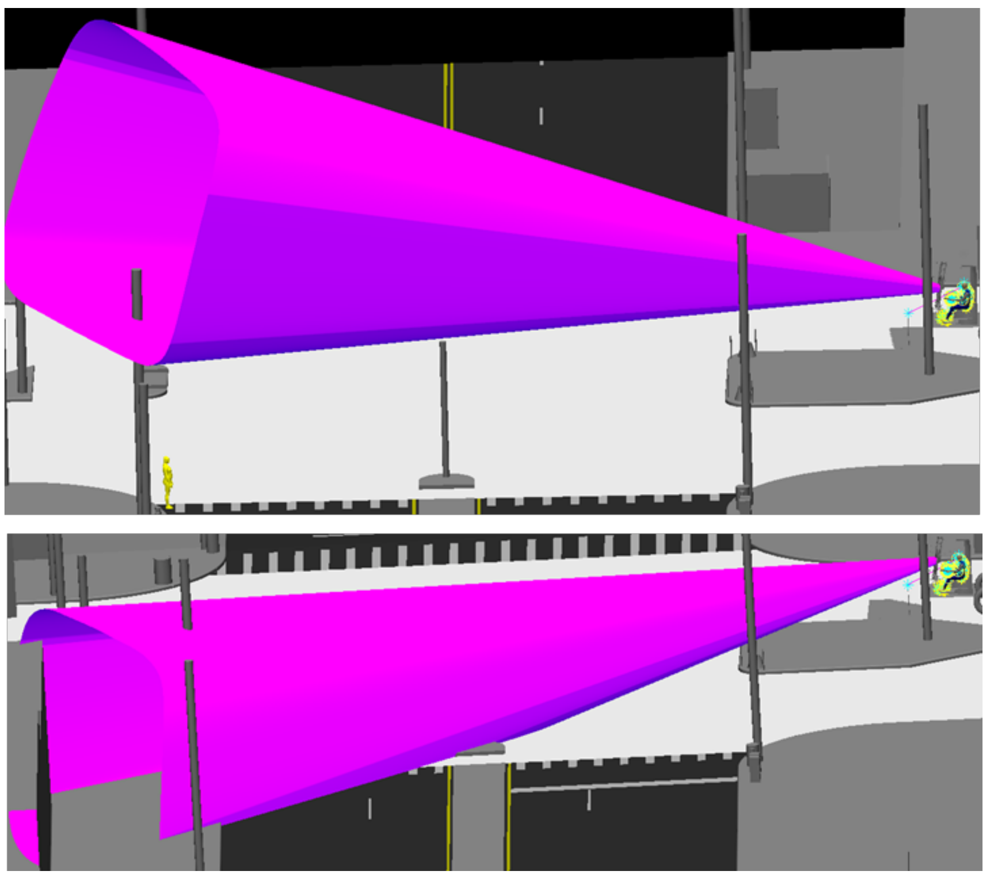


Figure 3-13 *Birds-eye view of short female looking up (top) and tall male looking down (bottom) obstruction cones of flat mirror head with convex combination prototype simulated on New York City street*

This finding led the research team to consider other alternatives, such as a semi-curved glass that had the advantage of maintaining the mirror head size of the flat glass mirror while excluding the additional obstruction of a convex mirror. Therefore, the mirror could be mounted high without obstructing the tall male's view of the crosswalk. This semi-curved ECE-style mirror surface increases the rearview to include two lanes adjacent to the bus. The result was the elimination of any forward visibility mirror head obstruction for both the short female and the tall male manikins (Figure 3-14) and an increased mirror rearview (Figure 3-15).

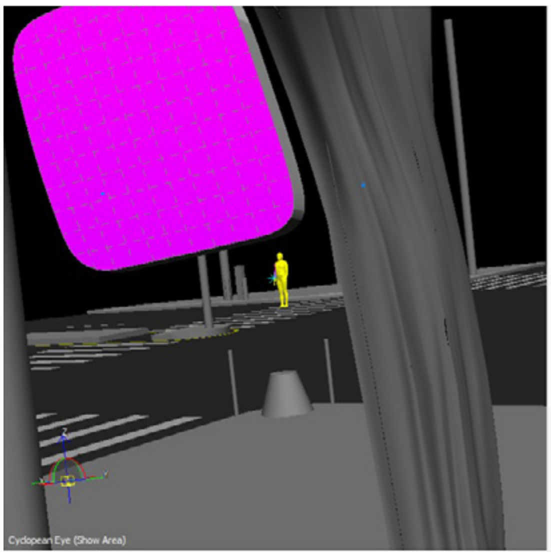


Figure 3-14 *Simulation of tall male bus-operator view under semi-curved, high-mount prototype mirror with clear view of pedestrian on crosswalk*

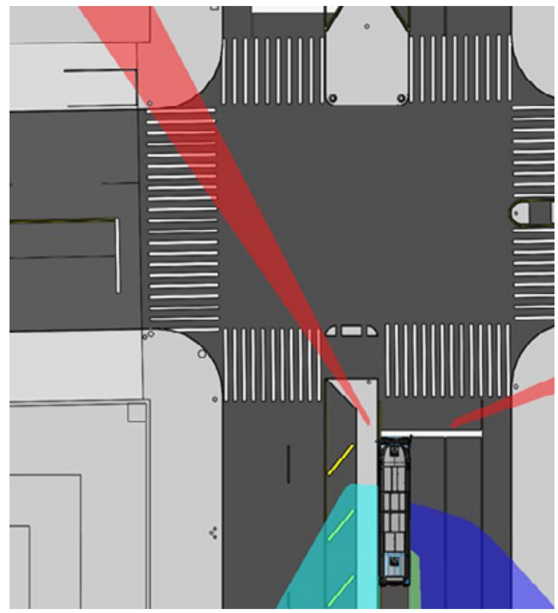


Figure 3-15 *Top view of tall male mirror rearview of two adjacent lanes with semi-curved, high-mount prototype mirror*

The performance of the semi-curved mirror was intended to fit the same function of an ECE 46-02, Class II mirror. The rearview performance of the mirror on the bus was simulated using the ground zone required in ECE 46-02. The result for the short female is shown in Figure 3-16. The concept mirror provides better viewing performance than required under ECE 46-02. The thin dark-gray zone labeled "Type II" illustrates the ground zone that should be visible in the mirror on the street side. The zone labeled "Type IV" is also provided for reference to illustrate the ground zone that according to ECE 46-02 should be visible for smaller radius convex mirrors.

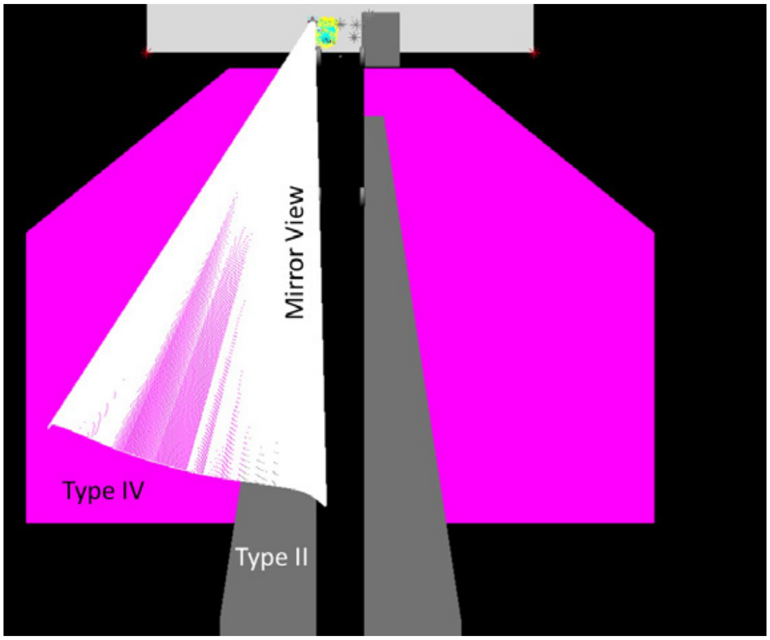


Figure 3-16 *Top view of short female mirror rearview of ECE 46-02 Class II ground zone with semi-curved, low-mount prototype mirror*

It was also important to identify how the semi-curved mirror might affect the quality and size of objects viewed in the mirror. To examine the object image quality and size, a 1 x 1 x 1 meter cube was developed and positioned on the ground and at the rear axle (Figure 3-17). Figure 3-18 demonstrates a simulation comparison between the size and shape of this cube when viewed by the short female in the flat mirror, the concept convex mirror, and the concept semi-curved low-mount mirror.

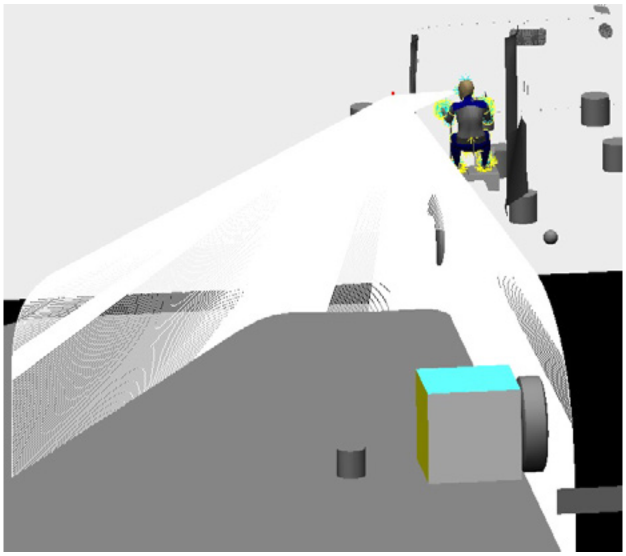


Figure 3-17 *Simulation view looking forward into short female mirror rearview zone with cube placed on ground at bus rear axle*

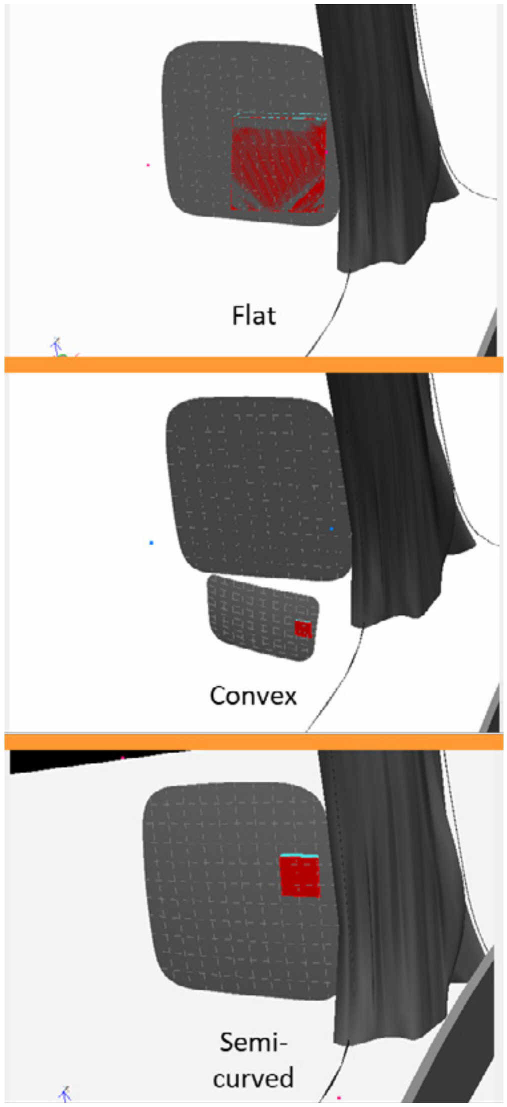


Figure 3-18 *Simulation of view from short female bus operator's eyes looking at cube in flat (top), convex (middle), and semi-curved low-mount (bottom) mirror surfaces*

Each attempted mirror solution used similar mirror aiming guidelines for the street-side mirror or combination of mirrors:

- Maintain a view of the horizon rearward of the bus.
- Maximize the view in the mirror along the length of the bus body to eliminate as much obstruction created by the bus body as possible up to and including the side turn indicator above the front axle.
- Maximize the image quality in the mirror.
- Maintain a view of the roadway adjacent to the side of the bus body.
- Maximize the view of the lane or lanes adjacent to the side of the bus body.

Based on the goals and mirror aiming guidelines, three prototype mirror designs were developed:

- Production flat mirror with convex mirror mounted below the flat glass but above the bottom window obstruction with A-pillar visibility gap
- Semi-curved mirror mounted high
- Semi-curved mirror mounted low with A-pillar visibility gap

The resulting direct visibility obstructions and rearview mirror visibility zones are demonstrated in CAD model images in Figure 3-19, 3-20, and 3-21. These mirrors were produced as prototype parts and applied in static prototype, driving prototype, and field demonstration driving evaluations on NYCT buses.

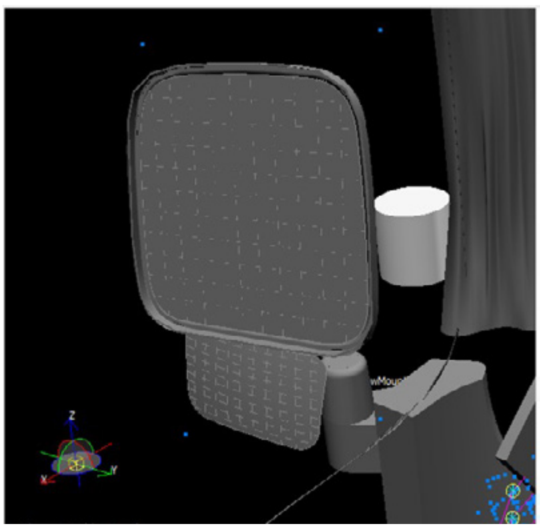


Figure 3-19 *Production flat with convex low-mount prototype mirrors moved rearward*

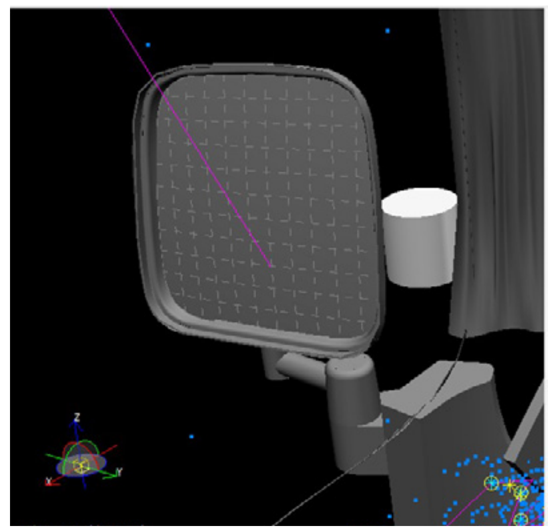


Figure 3-20 *Semi-curved, low-mount prototype mirror moved rearward*

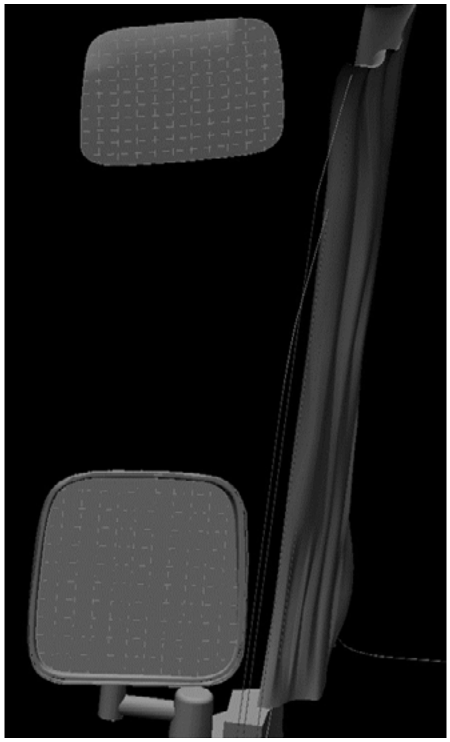


Figure 3-21 *Semi-curved, high-mount prototype mirror*

Transit Bus Mirror Visibility Design Guide

The transit bus mirror design guide provides guidance to transit bus manufacturers and suppliers for the design of transit mirrors and components that affect direct and indirect mirror visibility performance. A similar mirror design guide was developed for motorcoach buses.

The guidelines were developed to apply to vehicles sold in the U.S., although they may apply generally to other nations, with considerations for some modifications required due to regional differences in regulations, operator anthropometry, bus operator tasks, or bus operator preferences.

The intended users of the guidelines were vehicle engineers and designers and bus procurement staff, who must also comply with all applicable Federal, State, and local regulations. The guidelines state that users should consider Federal Americans with Disabilities Act (ADA) and State and local accessibility, safety, and security requirements. The guidelines also state that the bus must meet all applicable FMVSS and accommodate all applicable FTA regulations in effect at the date of manufacture. Finally, the guidelines state that in the event of conflict between the requirements of the document and any applicable legal requirement, the legal requirement must prevail, although technical requirements that exceed the legal requirements were not expected to conflict.

The document's structure aims to improve the comprehension of key design criteria with supporting rationale. At the beginning of each section, a summary is provided in a table for quick reference. More details about each guideline are provided later in the section with a standardized format that includes the following:

- Definition: Provides a description of each individual transit bus feature.
- Figure: Provides an illustration of each specific feature if available.
- Benchmark: Provides the range and suggested design objectives based on ergonomic principles and vehicle design literature.
- Design Guideline: Provides suggested design objectives based on ergonomic principles and vehicle design literature.
- Need for Design Guideline: Provides the reasoning for the design criteria and factors that must be considered during the design of transit bus mirrors.

The topics covered in the mirror and visibility performance-focused guidelines include:

- Introduction
- Elements Important to Consistent Driver Packaging:
  - Operator Workstation
  - Bus Operator's Seat
  - Steering Wheel
  - Foot Controls
- Mirror Design
  - Flat Mirror Reflective Surface
  - Semi-curved Mirror Radius of Curvature
  - Convex Mirror Radius of Curvature
  - Mirror Face Adjustment Range
  - Curb-side Mirror Height Above Ground
  - Street-side A-pillar to Mirror Head Gap
  - Mirror Head Fixture
  - Mirror Head and Mounting Arm Fold-away Feature
- Mirror Field of View
  - Rearward Field of View, Street-side Mirrors (40-ft bus)
  - Rearward Field of View, Curb-side Mirrors (40-ft bus)
  - Mirror Forward Obstruction, Street-side Mirrors, Low Mount
  - Mirror Forward Obstruction, Street-side Mirrors, High Mount
  - Mirror Blockage, Curb-side Mirrors

- Daylight Openings Design
  - Street-side Window View
  - Glare
  - Visors
  - Windshield A-pillar Visibility Obstruction Angle
- References

A sample from the design guideline is provided below on the topic of Rearward Field of View, Street-side Mirrors (40-ft bus). The figure provided below is inserted in the design guideline as "Figure 15."

- **Definition:** This refers to the rearward field of view of the bus operator along the street-side of the bus, nearest the bus operator. An example is provided below.

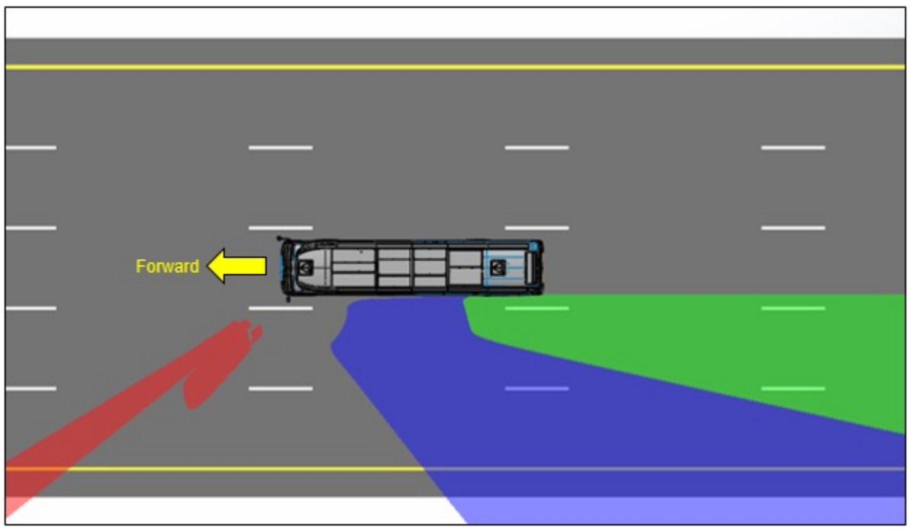


Figure 15. Top View. Rearview mirror street-side field of view at ground level for a small female. The smaller green zone is the example performance of a flat mirror. The larger blue zone is the example performance of a convex mirror. The red zones demonstrate the visibility obstructions of the A-pillar and the mirror head.

- **Benchmark:** Only one of the four transit buses was capable of meeting the guideline. It was equipped with a street-side convex mirror. Some flat mirror configurations on the buses do not provide a view of the entire adjacent lane until some distance rearward of the bus.
- **Design Guideline**
  - Forward operation, lateral: The street-side mirrors should provide the bus operator an indirect view of the ground from the side of the bus through all of the immediate adjacent lane at the rearward axle in a flat or semi-curved mirror. Additionally, the street-side mirrors should provide the bus operator an indirect view of the ground from the side of

the bus through all of the two adjacent lanes at the rear bumper of the bus in the reflective surface of a semi-curved or wide-angle mirror.
  - Forward operation, longitudinal: The street-side mirrors should provide the bus operator an indirect longitudinal view of the ground from the front axle of the bus rearward to the horizon with any individual or combination of flat, semi-curved, or wide-angle mirrors.
  - Note: Lane width is defined as at least 10-ft wide.
- **Need for Design Guideline**
  - The bus operator needs to be able to see the roadway, objects, or vehicles adjacent to the bus and street curbs or other infrastructure to maneuver along the bus routes safely and efficiently. The street-side zone immediately adjacent to the bus and near the bus operator's seating position is important, as the bus operator's vision may be obstructed by body panels that surround the side glass/window.

Section 4

Evaluations

Static Evaluation

A prototype mirror evaluation was determined to be an effective way of determining if the designs developed during the visibility optimization were viable for further development and eventual field demonstration on NYCT low-floor transit buses.

VTTI delivered to Safe Fleet the CAD models of the three different design prototypes for street-side mirrors on the New Flyer bus. VTTI developed steps to communicate, deliver, and verify the specifications of the prototype mirrors. These steps are listed in Table 4-1.

Table 4-1 *Prototype Mirror Communication and Verification Steps*

Step	Description
1	Definition and development of three prototype models
2	Comparison of prototype CAD models to visibility performance
3	Iteration and selection of prototypes
4	Bus operator evaluation location and bus operator outreach
5	Bus operator prototype evaluation protocol
6	Parts ship to NYCT; installation and verification
7	Bus operator evaluation in NYC June 3–7
8	Evaluation results

The mirror evaluation was planned to ensure that the mirror designs selected for use would not only provide necessary and practical improvements, but that they would also be accepted by bus operators. The evaluation participation criteria required that only bus operators with a valid Class A or B commercial driver's license and passenger endorsement who drive on a full-time basis for NYCT were qualified to participate in the bus mirror prototype evaluation. This evaluation gathered important real-world feedback from bus operators who drive in a heavily populated urban city environment. New York City is the largest city in the United States, with a population of approximately 8.55 million. With over 6,000 miles of roadways in the city, this evaluation by NYCT bus operators ensured that participating bus operators experienced complex urban traffic scenarios, including roadway design and intersection layouts, bridges, tunnels, heavy pedestrian traffic, and bicyclists.

Mirror Types

Three prototype mirrors were selected for use in the bus operator evaluation (see Figure 4-1)—a current production NYCT street-side low-mount flat mirror with an added convex 430-mm radius mirror, a semi-curved mirror with 1,260 mm radius mounted in a low position, and the same semi-curved mirror mounted in a high position. The intent of this evaluation was to assess possible mirrors to reduce and/or eliminate forward/side mirror visibility obstructions, increase mirror visibility near the street-side front axle, increase mirror visibility of the adjacent lane of the street-side near the rear axle, and optimize both direct and indirect mirror visibility for a full range of users.

Figure 4-1 *Prototype mirrors—low mount with convex (l), semi-curved low mount (c), and semi-curved high mount (r)*

Static Evaluation Methods

The prototype mirror evaluation took place at the West Farms Depot in the Bronx and the Jackie Gleason Depot in Brooklyn. The research team spent two days at each bus depot. The NYCT DOB provided three New Flyer buses of similar configuration for use, each of which had a different prototype mirror installed. In total, 18 orange targets were placed around each of the three buses. Currently, FMVSS No. 111 does not include requirements or guidance relating to targets around commercial buses that must be visible to drivers, with the exception of school buses. Target placements for this prototype mirror evaluation were adapted in part from FMVSS No. 111 School Bus standards (Figure 4-2) while taking into consideration the description of the driving task and mirror aiming and performance expectations collected in the manager and bus operator focus groups. Figure 4-3 shows the setup and target placement at the West Farms Depot.

The participating bus operators were asked to rate the quality of the view provided by each mirror by rating the size and shape of a 1 x 1 x 1 meter cube positioned at the rear axle (Figure 4-4). This setup imitated the CAD simulation of performance visibility.

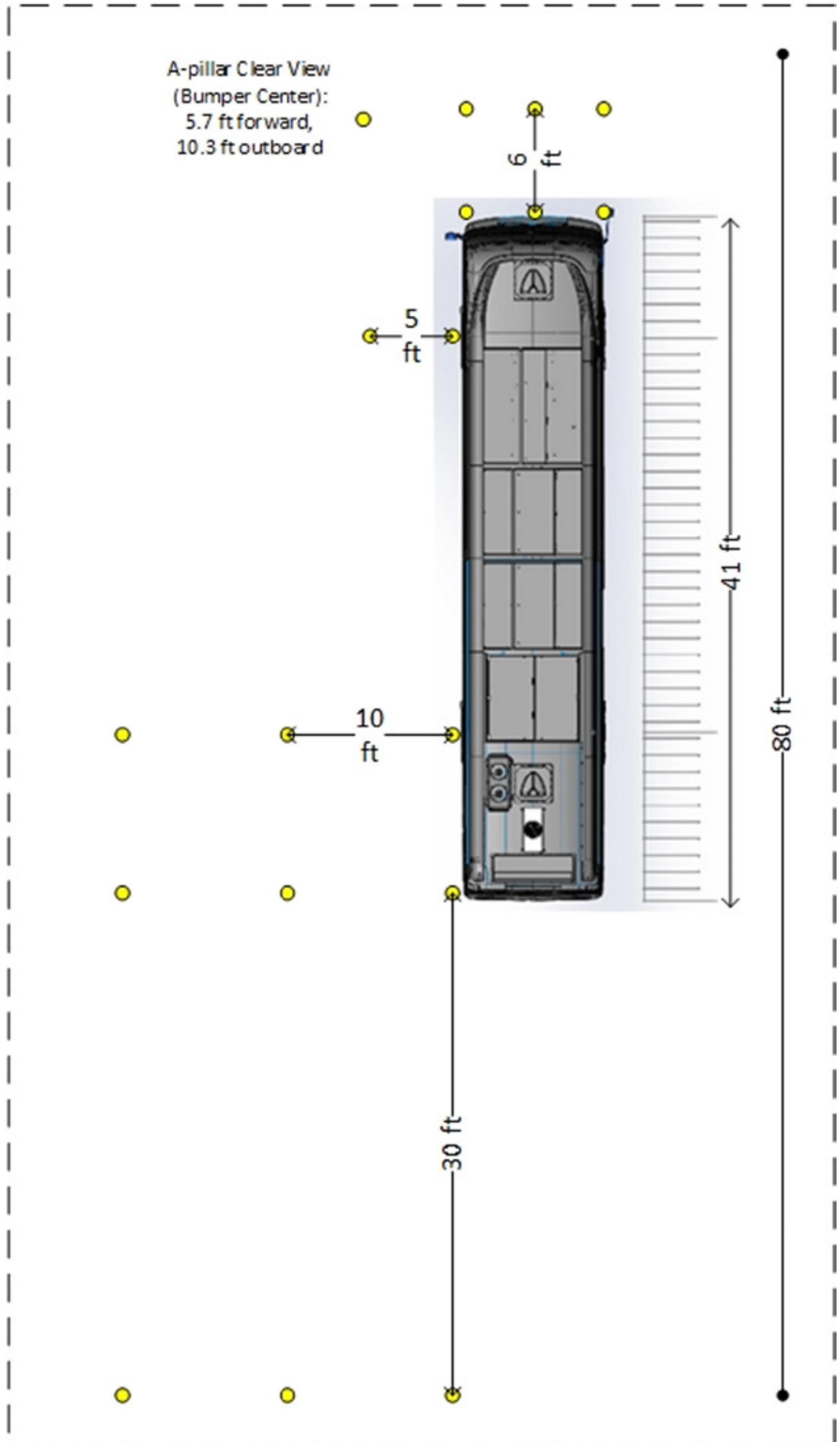


Figure 4-2 *Target placement for prototype mirror evaluation*

Figure 4-3 *Prototype mirror evaluation setup with targets*

Figure 4-4 *Prototype Mirror evaluation targets with image quality box*

All participants initially completed an informed consent explaining the purpose of the evaluation, the procedures, the complete confidentiality of the evaluation, and each individual's rights as a volunteer participant. Following the informed consent, participants filled out a demographics questionnaire and then proceeded to one of the three buses to begin the prototype mirror evaluation. A balanced order of mirror presentation between participants was used to account for any order bias. For the prototype mirror evaluation, participants were asked to adjust the seat and mirrors in the manner typical of their normal driving position. Once participants were comfortable, they provided subjective ratings of field of view, reflected object image quality, and visibility obstructions using a Likert-type scale, driver acceptance (yes or no), and mirror design preference (picked one of the three mirrors). See Appendix C for the full evaluation questionnaire.

Static Evaluation Results

In total, 26 bus operators (22 male, 4 female) participated in the prototype mirror evaluation. All bus operators were employed full-time with NYCT and had at least 5 years of experience as transit bus operators. The mean age of participants was 48.2 years, and the mean years of experience as a NYCT bus operator was 13.8 years.

Bus operator ratings using a Likert-type scale were evaluated using an analysis of variance statistical method. Significant differences were observed in the bus operator ratings of the street-side field of view provided by the mirrors—$F(3) = 9.372$, $p = 0.00$. Post hoc analysis using contrast coefficients found both the standard flat mirror and convex mirror were rated significantly worse in regard to the rear view when compared to either semi-curved mirror. Figure 4-5 provides the mean bus operator ratings of the street-side field of view by mirror type.

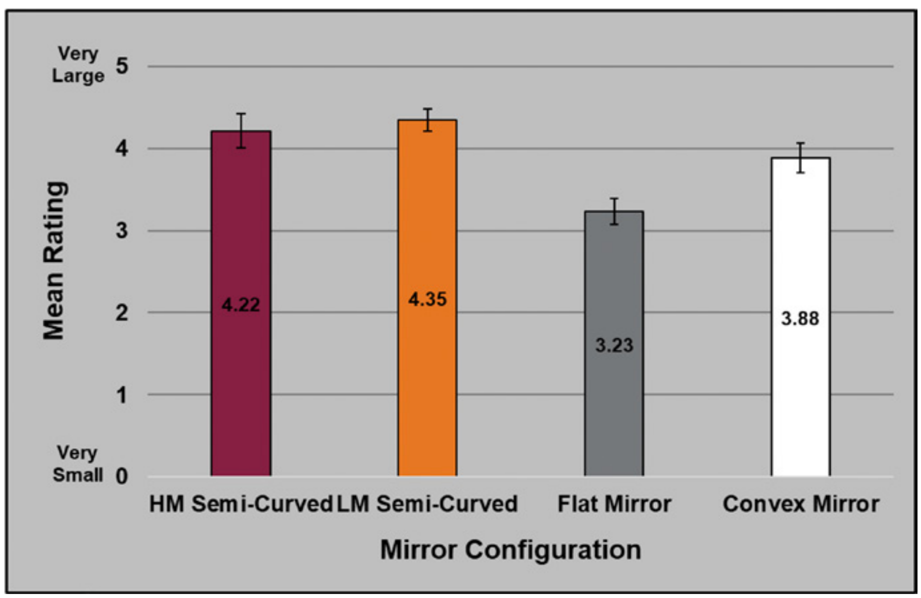


Figure 4-5 *Mean bus operator ratings of street-side field of view by mirror configuration*

Assessment of bus operator ratings for the quality of view again found significant differences between mirror types—$F(3) = 5.594$, $p = .001$. Post hoc analysis concluded that the convex mirror had significantly worse ratings when compared to the other three mirror types. Figure 4-6 provides the mean bus operator ratings of quality of view by mirror.

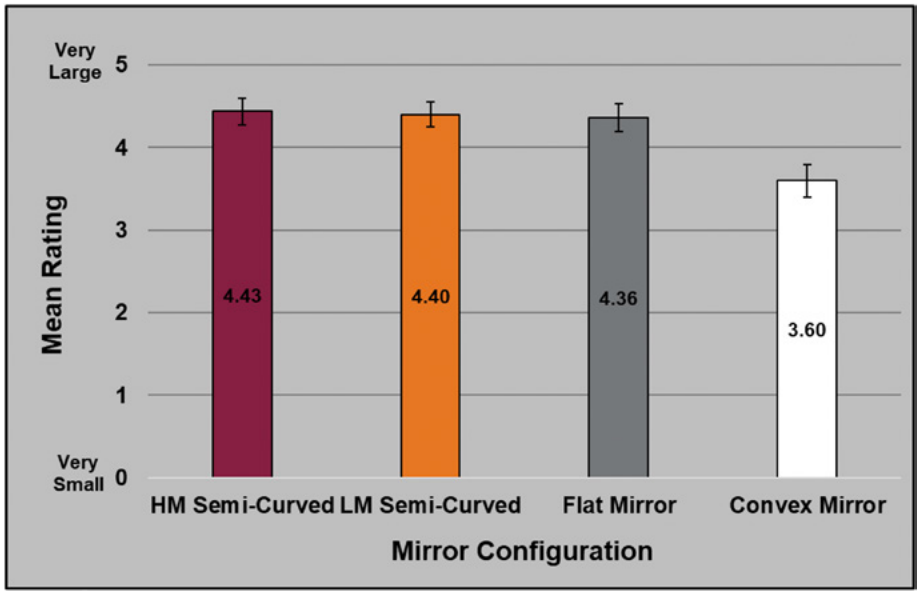


Figure 4-6 *Mean bus operator ratings of image quality by mirror configuration*

Similar to the previous two ratings, assessment of the forward view obstruction by the mirror found significant differences between mirror types—$F(3) = 6.370$, $p = .001$. The post hoc analysis found that the high-mount semi-curved mirror created significantly less forward obstruction than the other three mirrors. Figure 4-7 shows the mean bus operator ratings for forward obstruction created by each mirror type.

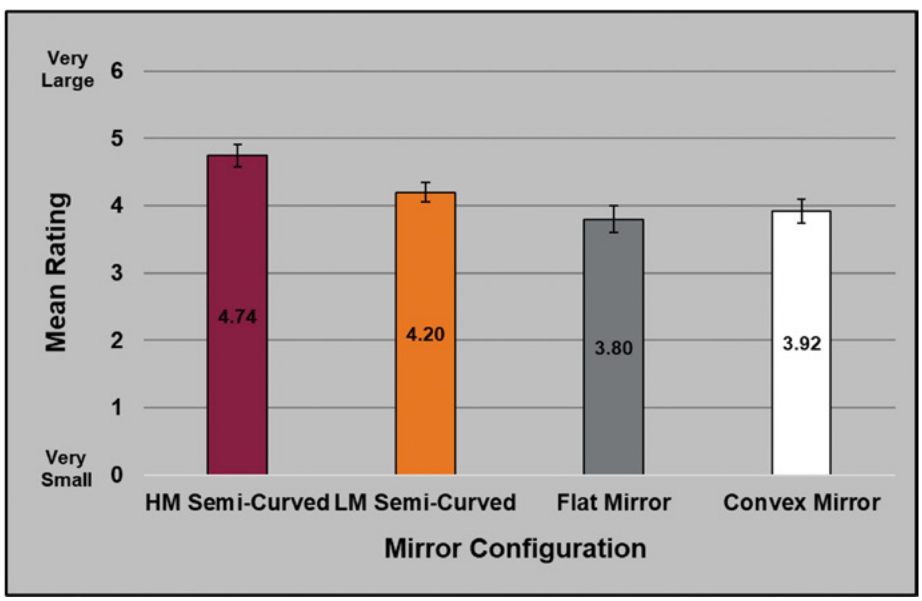


Figure 4-7 *Mean bus operator ratings of forward mirror obstruction by mirror configuration*

Additionally, bus operators were asked two questions relating to mirror preference—(1) the mirror type they would prefer when driving in high pedestrian traffic and (2) the mirror type they would prefer when driving in high vehicular traffic. The high-mount semi-curved mirror was most preferred for driving in high pedestrian traffic, while the low-mount semi-curved mirror was most preferred for driving in high vehicular traffic. Further, only one of the 26 bus operators stated they would not want to drive their route with the low-mount semi-curved mirror.

A summary of the results of the static mirror evaluation is provided in Table 4-2. The bus operators rated the prototype semi-curved (ECE-style) mirrors highest in field of view, view quality, and forward obstruction. Most bus operators picked the semi-curved mirrors for vehicle and pedestrian traffic. Only one bus operator stated that they would not want to use the low-mount semi-curved mirror on their daily route.

Table 4-2 *Bus Operator Prototype Mirror Evaluation Rating Summary*

Mirror Type	Avg. Rearward View Rating (Scale 1–5)	Avg. View Quality Rating (Scale 1–5)	Avg. Obstruction Rating (Scale 1–5)	Use Yes	Use No	Pick Vehicle Traffic	Pick Pedestrian Traffic
High-mount ECE	4.23	4.35	4.69	21	5	7	11
Standard Flat	3.23	4.35	3.73	20	6	7	8
Convex	3.88	3.54	3.85				
Low-mount ECE	4.35	4.38	4.15	25	1	12	7

Pilot Testing

After presenting the results of the bus operator prototype mirror evaluation to NYCT management and training department, further discussions ensued about additional prototype mirror options. Several factors were discussed between NYCT and VTTI about the prototype mirrors that were evaluated by the bus operators. Although the semi-curved high mount prototype mirror was rated significantly better in field of view than the current NYCT flat mirror and had the smallest forward obstruction of all mirrors, the training department felt it would require significant retraining of all bus operators to utilize this mirror. NYCT transit buses are equipped with low-mount mirrors. Switching to a high-mount mirror may result, at least in the short term, in an increase in the number of incidents due to bus operators being unfamiliar with the techniques required to use this mirror. Additionally, the low-mount semi-curved mirror also was rated significantly better in field of view than the current NYCT flat mirror. Furthermore, the bus operator ratings showed no significant differences between the semi-curved prototype mirror and the current NYCT flat mirror for image quality; however, NYCT management and the training department were concerned about not having the true image representation as provided by the flat mirror. Therefore, VTTI began designing another prototype option to be evaluated.

Pilot Test 1

VTTI, NYCT, and FTA engaged in discussions on potential prototype mirror alternatives. Ultimately, the research team decided to go with the vertical split-glass prototype mirror shown in Figure 4-8. The inner two-thirds of the mirror has the flat glass similar to the current NYCT flat mirror, while the outer one-third uses a convex mirror. The intent of this mirror is to keep the overall mirror head size as similar as possible to the current NYCT flat mirror to minimize the forward obstruction while adding the convex mirror for an increased field of view that the bus operators indicated is needed in both the focus groups and previous static bus operator mirror evaluations.

Figure 4-8 *Vertical split-glass prototype mirror*

Methods and Procedures

The pilot test 1 evaluation took place at the Zerega Central Maintenance and Training Facility in the Bronx. The research team spent one day at the facility to collect the data. The NYCT DOB provided one New Flyer bus for installation of the vertical split-glass prototype mirror. Whereas the original bus operator prototype mirror evaluation took place statically, this pilot test was conducted dynamically on a designated route in the Bronx.

The participating bus operators were asked to rate the field of view, image quality, and forward obstruction. Implied consent was clearly stated at the top of each pilot test questionnaire and explained the purpose of the evaluation, the procedures, the complete confidentiality of the evaluation, and each individual's rights as a volunteer participant.

Participants and Results

In total, 13 bus operators participated in pilot test 1 and completed the questionnaire. All were employed full time with NYCT as transit bus operators and were receiving their 19A recertification. Age and gender data were not collected for the pilot test.

Bus operators provided ratings using a Likert-type scale similar to the original bus operator prototype mirror evaluation. The overall mean ratings with standard error can be found in Figure 4-9. The lower the bus operator rating, the more negative their feedback. For field of view, a rating of "1" equals "Very Small" and a rating of "5" equals "Very Large." For image quality, a rating of "1" equals "Very Poor" and a rating of "5" equals "Very Good." Finally, a rating of "1" equals "Very Large" and a rating of "5" equals "None" related to the forward obstruction the mirror creates.

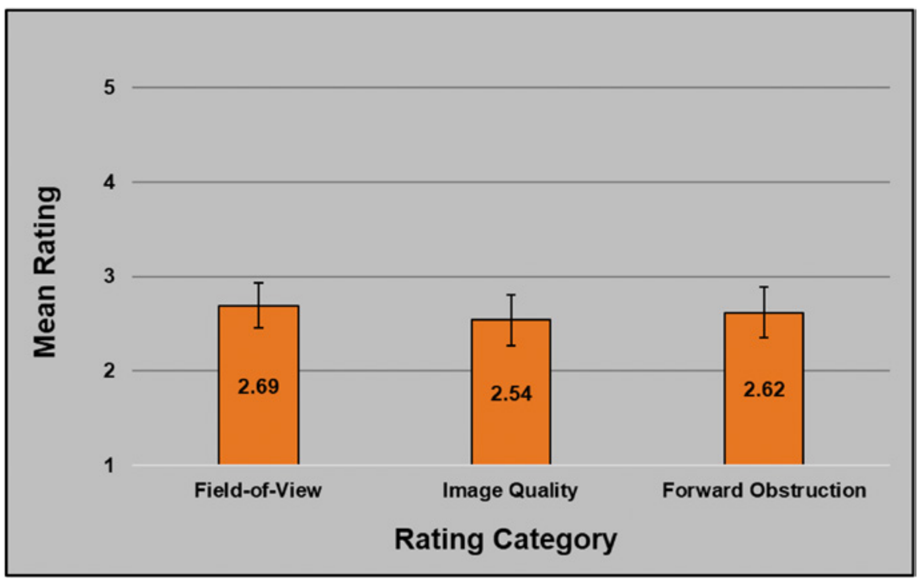


Figure 4-9 *Mean bus operator ratings of vertical split-glass mirror*

A chi squared goodness-of-fit test was conducted on each of the rating categories to determine if there were any statistical differences in the distribution of response ratings by the bus operators. No statistical differences in the distribution of bus operators' ratings were observed in field of view or image quality, indicating bus operator responses were evenly distributed across response choices; however, significant differences were observed for the forward obstruction, indicating bus operator responses were not evenly distributed across response choices. The majority of responses favored the negative ratings in the forward obstruction category. Table 13 provides the results of this analysis.

Table 4-3 *Chi Squared Goodness-of-Fit Test for Vertical Split-glass Mirror*

Field of View	X^2 (4, n = 13) = 8.92308	p = 0.063
Image Quality	X^2 (4, n = 13) = 5.84615	p = 0.211
Forward Obstruction	X^2 (4, n = 13) = 11.2308	p = 0.024

The bus operators also had the opportunity to provide open-ended comments about any positive or negative experiences with the mirror. Overall, the majority of bus operators experiencing the vertical split-glass mirror provided negative opinions of this mirror. (See Appendix E for all bus operator comments.) Taking into consideration the preponderance of negative opinions and the relatively low mean bus operator ratings for field of view, image quality, and forward obstruction, the research team deemed this prototype mirror option unsuitable for use in the field demonstration.

Pilot Test 2

Based on the results of pilot test 1, VTTI, NYCT, and FTA discussed other prototype mirror alternatives. It was decided that the low mount semi-curved prototype mirror used in the earlier evaluation was still likely the best choice moving forward. NYCT management and the Training Department agreed to proceed with a second pilot test using this mirror; however, it would be conducted dynamically similar to Pilot Test 1 rather than statically as in the initial evaluation. The same questionnaire used in Pilot Test 1 was also used for this pilot test.

Methods and Procedures

The Pilot Test 2 evaluation took place at the Zerega Central Maintenance and Training Facility in the Bronx. The research team spent two days at the facility to collect the data. The NYCT DOB provided one 40-ft New Flyer bus and one 60-ft New Flyer articulated bus for installation of the low-mount semi-curved prototype mirror. Whereas the original bus operator prototype mirror evaluation took place statically, this pilot test was conducted dynamically on a designated route in the Bronx.

Just as in Pilot Test 1, the participating bus operators used the same questionnaire and were asked to rate the field of view, image quality, and forward obstruction. Implied consent was clearly stated at the top of each pilot test questionnaire and explained the purpose of the evaluation, the procedures, the complete confidentiality of the evaluation, and each individual’s rights as a volunteer participant.

Participants and Results

In total, 21 bus operators participated in Pilot Test 2 and completed the questionnaire. Of these bus operators, 16 drove a 40-ft bus and the remaining 5 drove a 60-ft articulated bus. All bus operators were employed full-time with NYCT as transit bus operators and were receiving their 19A recertification. Age and gender data were not collected for the pilot test.

Bus operators provided ratings using a Likert-type scale similar to the previous pilot test. The overall mean ratings with standard error can be found in Figure 4-10. The rating scale is also the same, with lower ratings indicating more negative feedback.

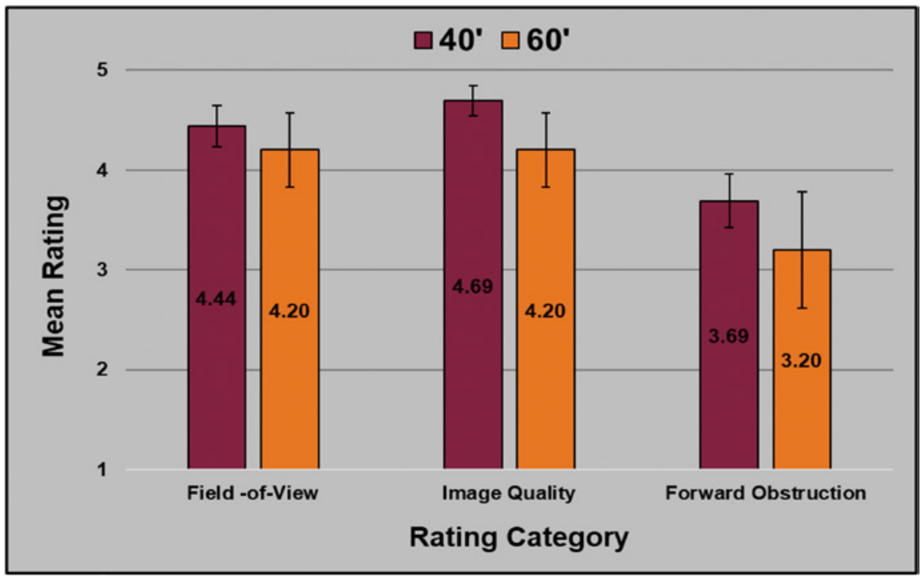


Figure 4-10 *Mean bus operator ratings of low-mount semi-curved mirror*

Similar to Pilot Test 1, a chi squared goodness-of-fit test was conducted on each of the rating categories to determine if there were any statistical differences in the distribution of response ratings by the bus operators. No statistical differences in the distribution of bus operators' ratings were observed in field of view or forward obstruction ratings, indicating bus operator responses were evenly distributed across response choices; however, significant differences were observed for the image quality rating, indicating bus operator responses were not evenly distributed across response choices. The majority of responses favored the positive ratings in the image quality category. Table 4-4 provides the results of this analysis.

Table 4-4 *Chi Squared Goodness-of-Fit Test for Semi-curved Mirror*

Field of View	X^2 (3, n = 21) = 5.42857	p = 0.066
Image Quality	X^2 (3, n = 21) = 11.1429	p = 0.004
Forward Obstruction	X^2 (4, n = 21) = 1.28571	p = 0.733

The bus operators in this pilot test also had the opportunity to provide open-ended comments about any positive or negative experiences with the mirror. Overall, the majority of bus operators experiencing the semi-curved mirror provided positive opinions of this mirror. See Appendix F for all bus operator comments. Taking into consideration that the majority of bus operator feedback was positive, the research team deemed this mirror the best suited for use in the field demonstration.

Static and Dynamic Pilot Testing Summary

At the conclusion of the second pilot test, a more in-depth analysis combining the static evaluation data along with the data from both dynamic pilot tests was conducted by the research team and presented to the NYCT management and training department for consideration to move forward with the field demonstration.

Results

Figures 4-11, 4-12, and 4-13 provide the comparisons of bus operator ratings across all three mirror configurations for field of view, image quality, and forward obstruction. Note that the 60-ft articulated bus operator ratings are shown separately, as only the semi-curved mirror was evaluated on that bus length. Those ratings were not included in the analyses.

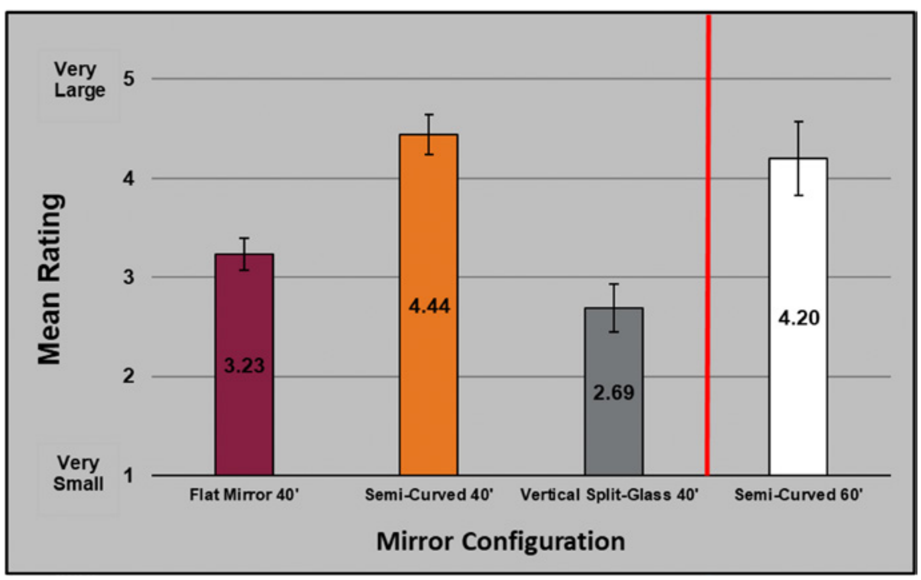


Figure 4-11 *Mean bus operator ratings for field of view across mirror configurations*

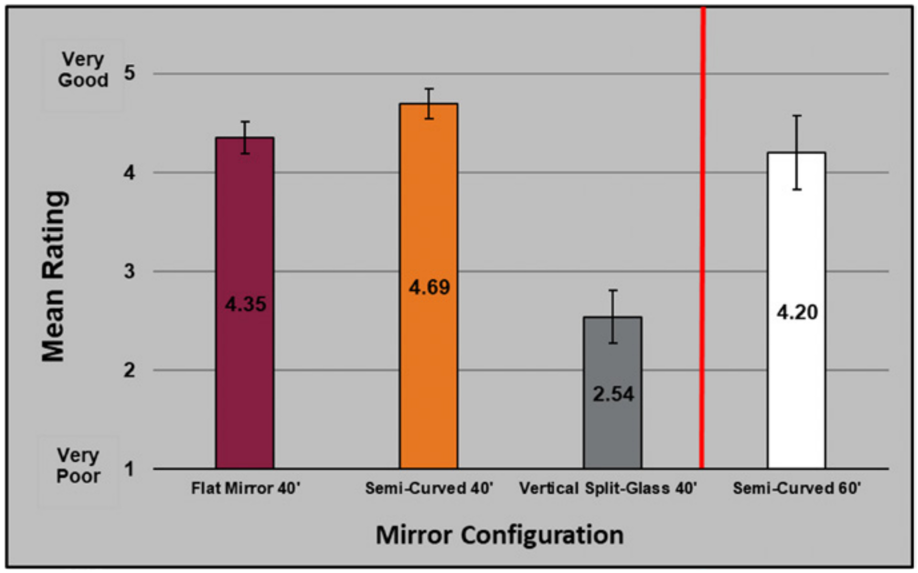


Figure 4-12 *Mean bus operator ratings for image quality across mirror configurations*

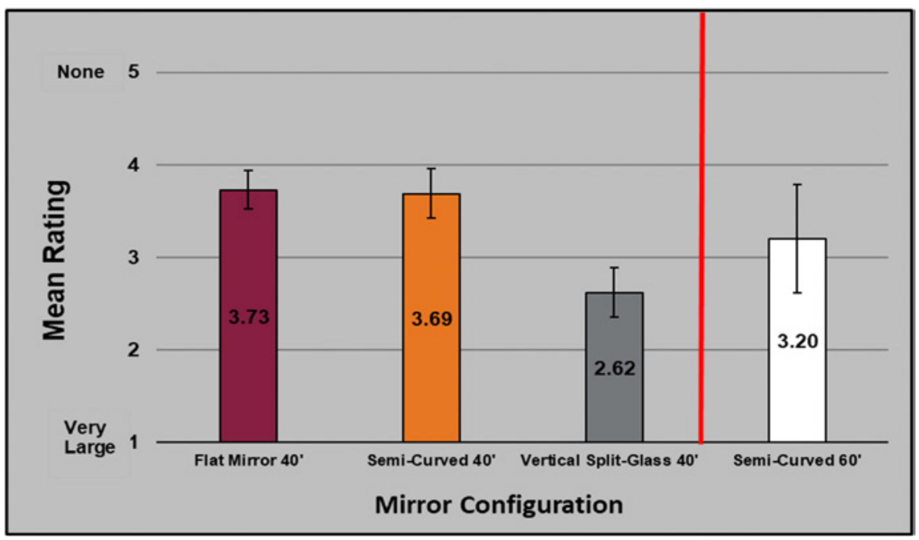


Figure 4-13 *Mean bus operator ratings for forward obstruction across mirror configurations*

The Kruskal-Wallis statistical analysis was used on each of the primary rating categories when evaluating these data. Significant differences were observed in the bus operator ratings of the field of view provided by the mirrors—$H(2) = 19.09$, $p = 0.000$. Post hoc analysis using the Mann-Whitney-Wilcoxen method revealed that the semi-curved mirror was rated significantly better in field of view than both the vertical split-glass mirror and the current NYCT flat mirror. No significant differences in bus operator ratings were observed between the vertical split-glass mirror and current NYCT flat mirror.

Table 4-5 *Post Hoc Analysis of Mean Bus Operator Ratings for Field of View*

Mirror Configuration Comparison	Result
NYCT Flat Mirror vs. Semi-curved Mirror	W = 421.00; p = 0.000*
NYCT Flat Mirror vs. Vertical Split-glass Mirror	W = 573.00; p = 0.118
Vertical Split-glass Mirror vs. Semi-curved Mirror	W = 326.00; p = 0.000*

** Indicates significance*

Analysis of the bus operator ratings for image quality also found significant differences between mirror types—$H(2) = 22.80$; $p = 0.000$. The post hoc analysis revealed the semi-curved mirror and current NYCT flat mirror were rated as having significantly better image quality than the vertical split-glass mirror. No differences in image quality were observed between the semi-curved mirror and current NYCT flat mirror. Table 4-6 provides the post hoc analysis results.

Table 4-6 *Post Hoc Analysis of Mean Bus Operator Ratings for Image Quality*

Mirror Configuration Comparison	Result
NYCT Flat Mirror vs. Semi-curved Mirror	W = 512.50; p = 0.233
NYCT Flat Mirror vs. Vertical Split-glass Mirror	W = 658.50; p = 0.000*
Vertical Split-glass Mirror vs. Semi-curved Mirror	W = 336.50; p = 0.000*

** Indicates significance*

The final analyses evaluated how the bus operators rated the forward obstruction caused by the mirror head. Analysis again found significant differences between mirror types—$H(2) = 8.85$; $p = 0.012$. Similar to the image quality, the post hoc analysis revealed that the semi-curved mirror and current NYCT flat mirror were rated as creating less forward obstruction than the vertical split-glass mirror. No differences were observed between the semi-curved mirror and current NYCT flat mirror. Table 4-7 provides the post hoc analysis results

Table 4-7 *Post Hoc Analysis of Mean Bus Operator Ratings for Forward Obstruction*

Mirror Configuration Comparison	Result
NYCT Flat Mirror vs. Semi-curved Mirror	W = 565.00; p = 0.887
NYCT Flat Mirror vs. Vertical Split-glass Mirror	W = 614.50; p = 0.005*
Vertical Split-glass Mirror vs. Semi-curved Mirror	W = 295.50; p = 0.016*

** Indicates significance*

Key Findings

The key findings were presented to the NYCT management and training department on March 4, 2021. Overall, the semi-curved mirror was rated by the bus operators as significantly better than the vertical split-glass mirror in all three rating categories (Field of View, Image Quality, Forward Obstruction). The semi-curved mirror was also rated significantly better in field of view than the current NYCT flat mirror. There were no significant differences found between those two mirror types for image quality and forward obstruction; however, this is an important non-significant finding. A flat mirror provides the truest image representation reflected in the glass; but these results reveal that bus operators felt the image reflected in the semi-curved mirror was similar to the current NYCT flat mirror. Figure 4-14 provides a collapsed view of bus operator ratings across mirror type and rating category.

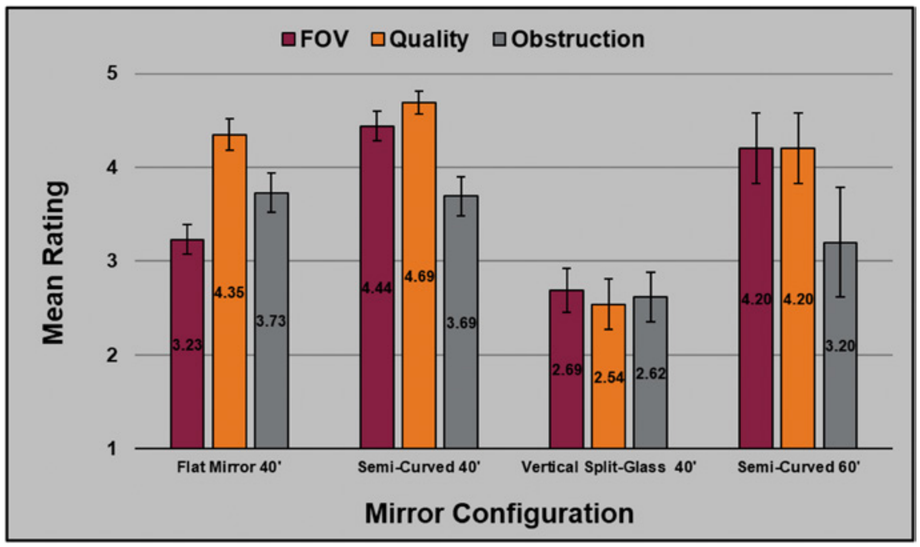


Figure 4-14 *Mean bus operator ratings across mirror type and rating category*

It was clear from these findings that the semi-curved mirror was as good as and even better in some instances than the current NYCT flat mirror. NYCT management and the Training Department, after reviewing and discussing these results with the research team, gave the greenlight to proceed with the field demonstration utilizing the semi-curved mirror.

Field Demonstration

Field demonstration planning began immediately following the greenlight from NYCT to proceed with the field demonstration. The research team contacted the mirror vendor, Safe Fleet, to begin the process of parts procurement and production for 36 semi-curved mirrors that would be built as production-ready units from the factory.

Methods and Procedures

The field demonstration was conducted at three depots, each located in a different borough in New York City—(1) West Farms Depot (Bronx), (2) Jackie

Gleason Depot (Brooklyn), and (3) Casey Stengel Depot (Queens). This allowed the research team to capture diverse bus operator ratings and feedback from a variety of locations and roadway types and configurations as well as different traffic, pedestrian, bicyclist, and scooter conditions. In total, 10 buses (five 40-ft and five 60-ft articulated) were installed with semi-curved mirrors at each of the three depots. Two additional semi-curved mirrors were held in reserve at each depot in the event a mirror had to be replaced due to damage from an incident. Additionally, 10 buses (five 40-ft and five 60-ft articulated) with the current NYCT flat mirror were assigned at each depot as the control group. Data collection for the field demonstration lasted for six months.

Bus operators that were assigned to a bus in either the control group or demonstration group (i.e., semi-curved mirrors) were to complete a short survey following the completion of their shift. The survey consisted of eight questions and captured bus operator ratings on field of view, image quality, and forward obstruction, bus operator preference on mirror adjustment and use on a permanent basis, and open-ended feedback of any positive or negative experiences with the type of mirror they had just driven with. The bus operators were asked to complete a survey at least once each week that they drove a control group or demonstration bus, but they could do so more often if desired. Implied consent was listed at the top of each survey and explained the purpose of the project, that all surveys were confidential, and that it was voluntary and would not affect their employment in any way for completing or not completing the survey. See Appendix G for the survey questionnaire.

Surveys were handed out to the bus operators of the control group and demonstration buses by the yard dispatchers at each depot during morning service. Each bus operator at morning service was given three surveys, one for themselves and the other two for the bus operators at shift change. Additional surveys were available in the storage compartment behind the bus operators' seat in each of the buses. A VTTI researcher was on-site during the first week of deployment at each depot to ensure a smooth rollout process, collect and analyze the data on a daily basis, and address any issues or question that arose with the bus operators or depot management.

Deployment

The first depot to go into service with the semi-curved mirrors was the West Farms Depot in the Bronx. Deployment commenced on April 26, 2021. The second depot to deploy the semi-curved mirrors was the Jackie Gleason Depot in Brooklyn. Deployment at this depot commenced on June 15, 2021. The third depot was the Casey Stengel Depot in Queens. The final deployment commenced on July 6, 2021. Overall, the field demonstration lasted six months. The West Farms Depot collected data for the full six months, and Jackie Gleason collected data for 5 months and the Casey Stengel Depot collected data for four months.

Participants and Results

In total, 200 surveys were captured across all three depots during the field demonstration. This included 151 surveys completed from the demonstration buses with the semi-curved mirror and 49 surveys completed from the control group buses with the current NYCT flat mirror.

In total, 89 surveys were completed (62 semi-curved mirror and 27 control group) at the West Farms Depot, which represents approximately 11.1% of the bus operators assigned at that depot, with 66 surveys completed (49 semi-curved mirror and 17 control group) at the Jackie Gleason Depot, which represents 8.3% of the bus operators assigned at that depot. In total, 45 surveys were completed (40 semi-curved mirror and 5 control group) at the Casey Stengel Depot, which represents 8.2% of the bus operators assigned at that depot.

The following analyses presented in the subsequent subsections of this section follow a top-down evaluation. This ensures that all relevant variables and potential confounding factors were evaluated, as transit agencies typically have many aspects to take into consideration (e.g., bus configuration, route configuration, roadway configuration, rural vs. urban, etc.). A "one size fits all" approach cannot be applied across all transit agencies.

Demographics

Overall, bus operators completing a survey had a mean age of 50.1 years with a minimum age of 26 years and maximum age of 76 years. The overall mean years of service was 13.5 years with a minimum of 1 year of service and maximum of 28 years of service. Overall, 82% of survey respondents were male and 19% were female. Table 18 shows the demographics across depot and mirror type. It should be noted that the demographics are based on 146 survey respondents, as some respondents did not provide gender, age, or years of service information.

Table 4-8 *Field Demonstration Participant Demographics*

Depot	Mirror Type	Mean Age	Mean Service Years
West Farms Depot	Semi-curved Mirror	50.1	13.7
	Flat Mirror	51.7	15.6
Jackie Gleason Depot	Semi-curved Mirror	47.0	11.9
	Flat Mirror	56.1	16.3
Casey Stengel Depot	Semi-curved Mirror	49.7	15.8
	Flat Mirror	54.3	17.5

Semi-curved Mirror vs. Flat Mirror Ratings

The initial analysis focused on the semi-curved mirror as a whole combined across all three bus depots. Each of the three rating categories (Field of View, Image Quality, Forward Obstruction) was evaluated. Figure 4-15 provides the mean bus operator ratings combined across depots by rating category.

Figure 4-15 *Mean bus operator ratings combined across depots by rating category*

Each rating category was analyzed independently using the Mann-Whitney-Wilcoxen statistical method. Significant differences were observed in the bus operator ratings for the field of view. Bus operators found the semi-curved mirror to have a significantly larger field of view than the current NYCT flat mirror. However, no significant differences were observed between the two mirror types for image quality and forward obstruction. Table 4-9 provides the results from the analyses.

Table 4-9 *Analyses of Mean Bus Operator Ratings Combined Across Depots*

Mirror Rating Category	Result
Field of View	W = 15,898.00; p = 0.000*
Image Quality	W = 14,860.00; p = 0.745
Forward Obstruction	W = 13,837.00; p = 0.214

** Indicates significance*

Mirror Type vs. Bus Configuration

The next set of analyses involved assessing differences, if any, between the different bus configurations (i.e., 40-ft or 60-ft articulated) and the bus operator ratings combined across all depots. Analysis of field of view found that both the 40-ft buses and 60-ft articulated buses were rated as having a significantly larger field of view with the semi-curved mirror than the current NYCT flat mirror. Figure 4-16 shows the mean bus operator ratings by bus configuration and mirror type combined across all depots. Table 4-10 provides the results from the analysis.

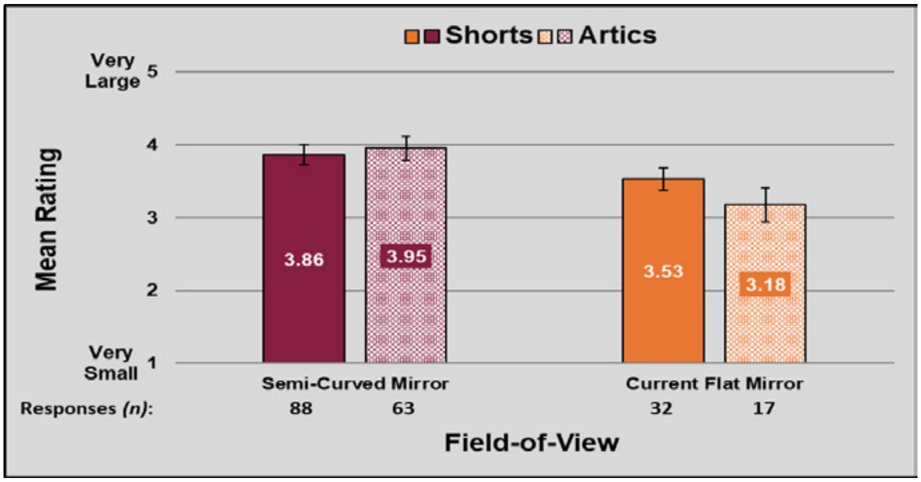


Figure 4-16 *Mean bus operator ratings by bus configuration and mirror type: Field of View*

Table 4-10 *Analyses of Mean Bus Operator Ratings by Bus Configuration and Mirror Type Combined Across All Depots: Field of View*

Bus Configuration	Result
40-ft Shorts	W = 5,693.50; $p = 0.022$*
60-ft Articulated	W = 2,795.50; $p = 0.003$*

** Indicates significance*

When analyzing the bus operator ratings on image quality, no significant differences were observed in the 40-ft buses; however, significant differences were observed in the 60-ft articulated buses, with bus operators rating the image quality better with the semi-curved mirrors. Figure 4-17 shows the mean bus operator ratings by bus configuration and mirror type combined across all depots. Table 4-11 provides the results from the analyses.

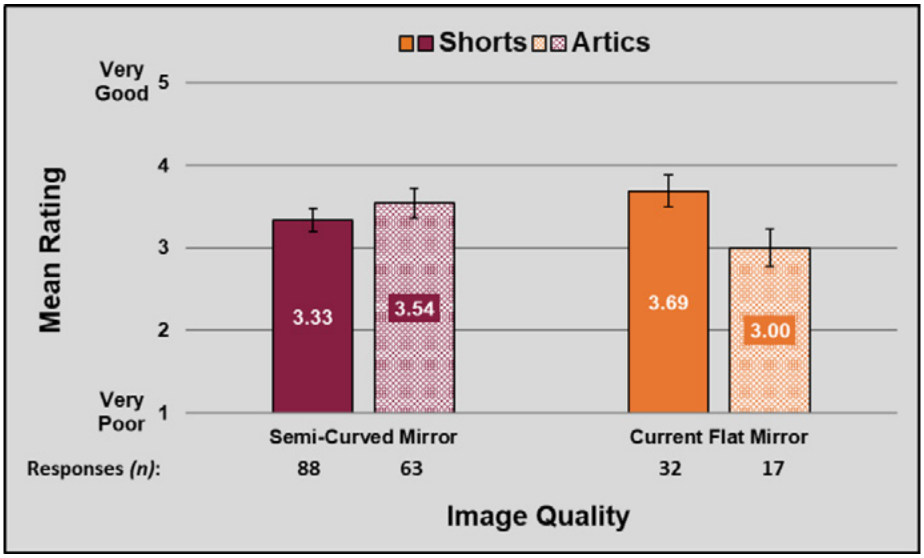


Figure 4-17 *Mean bus operator ratings by bus configuration and mirror type: Image Quality*

Table 4-11 *Analyses of Mean Bus Operator Ratings by Bus Configuration and Mirror Type Combined Across All Depots: Image Quality*

Bus Configuration	Result
40-ft Short	W = 5,194.50; p = 0.430
60-ft Articulated	W = 2,715.50; p = 0.048*

** Indicates significance*

For the final rating category, forward obstruction, no significant differences were observed between the semi-curved mirror and the current NYCT flat mirror for either the 40-ft buses or 60-ft articulated buses. Figure 4-18 provides the mean bus operator ratings by bus configuration and mirror type combined across all depots. Table 4-12 provides the results from the analyses.

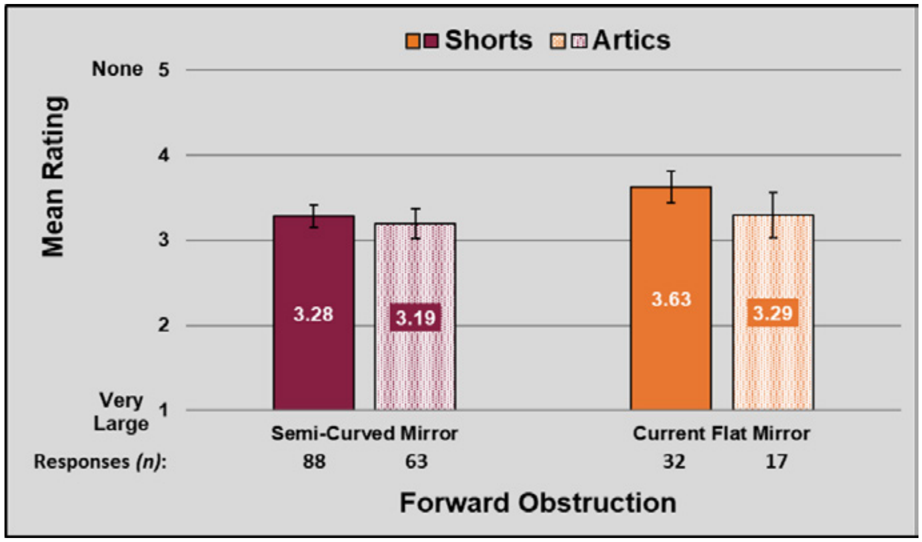


Figure 4-18 *Mean bus operator ratings by bus configuration and mirror type: Forward Obstruction*

Table 4-12 *Analyses of Mean Bus Operator Ratings by Bus Configuration and Mirror Type Combined Across All Depots: Forward Obstruction*

Bus Configuration	Result
40-ft Short	W = 4,906.00; p = 0.176
60-ft Articulated	W = 2,460.00; p = 0.806

Mirror Type vs. Bus Configuration by Depot

The third set of analyses assessed whether there were differences, if any, in bus operator ratings between mirror type and bus configuration within the depot level. Figure 4-19, Figure 4-20, and Figure 4-21 provide the mean bus operator ratings by depot for mirror type and bus configuration for field of view, image quality, and forward obstruction, respectively.

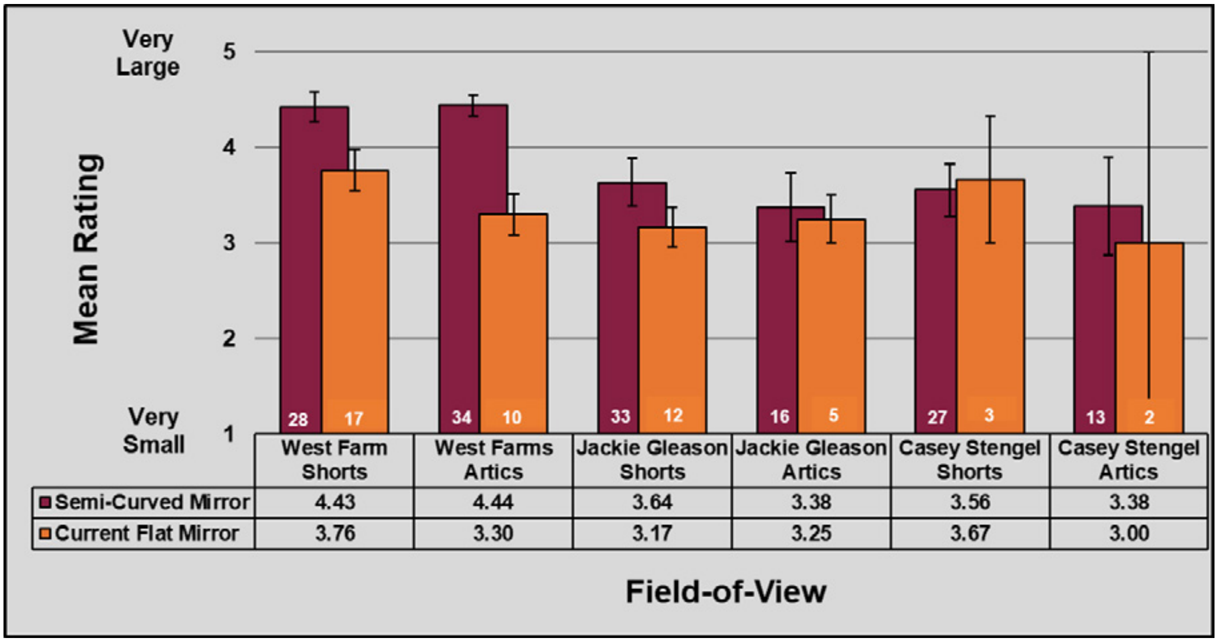


Figure 4-19 *Mean bus operator ratings by depot: Field of View*

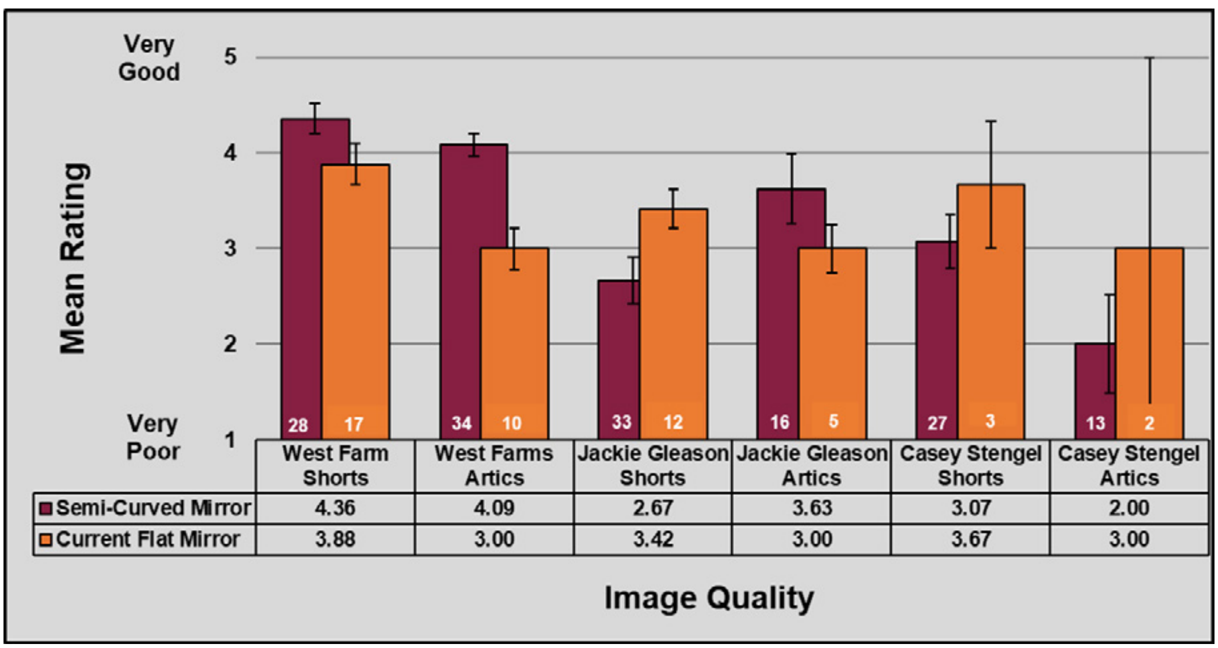
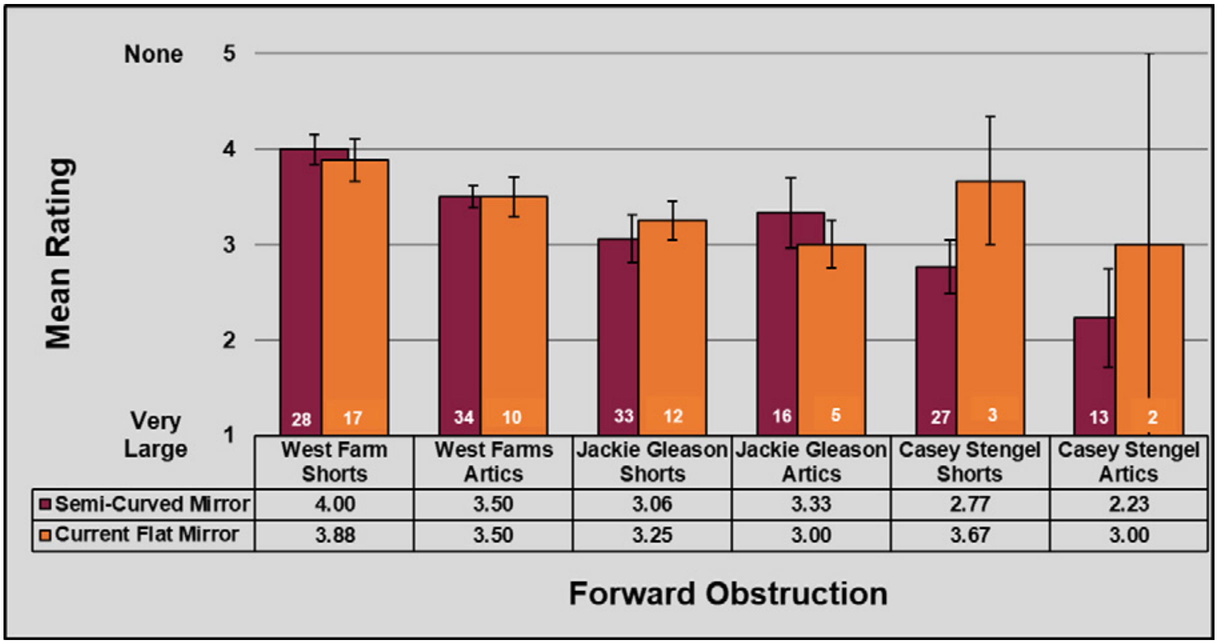


Figure 4-20 *Mean bus operator ratings by depot: Image Quality*



	West Farm Shorts	West Farms Artics	Jackie Gleason Shorts	Jackie Gleason Artics	Casey Stengel Shorts	Casey Stengel Artics
Semi-Curved Mirror	4.00	3.50	3.06	3.33	2.77	2.23
Current Flat Mirror	3.88	3.50	3.25	3.00	3.67	3.00

Figure 4-21 *Mean bus operator ratings by depot: Forward Obstruction*

Note that due to the low number of survey responses for the 40-ft buses and 60-ft articulated buses in the control group at the Casey Stengel Depot (n = 3 and n = 2, respectively) and for the 60-ft articulated buses in the control group at the Jackie Gleason Depot (n = 5), these cohorts were not included in the analyses.

Significant differences were observed at the West Farms Depot for the field of view and image quality bus operator ratings; however, no significant differences were observed between mirror type or bus configuration for the forward obstruction bus operator ratings. Table 4-13 provides the results of these analyses.

Table 4-13 *Kruskal-Wallis Analyses Between Mirror Type and Bus Configuration: West Farms Depot*

Kruskal-Wallis Analyses	Result
Field of View	$H(3) = 19.50$; $p = 0.000$*
Image Quality	$H(3) = 14.85$; $p = 0.002$*
Forward Obstruction	$H(3) = 3.34$; $p = 0.341$

Post hoc analyses were conducted using the Mann-Whitney-Wilcoxen method, which revealed significant differences. Bus operators rated the field of view for both the 40-ft buses and 60-ft articulated buses with the semi-curved mirror significantly larger than the current NYCT flat mirror. Bus operators also rated the image quality of the semi-curved mirror on the 60-ft articulated buses significantly better than the 60-ft articulated buses with the current NYCT mirror. Interestingly, significant differences were also observed in image quality between the 40-ft buses and 60-ft articulated buses with the current NYCT flat mirror. The current NYCT flat mirror on the 40-buses were rated as having significantly better image quality than the same mirror type on the 60-ft articulated buses. No significant differences were observed within the same mirror type between bus configurations for either the semi-curved mirror or current NYCT flat mirror on field of view. Additionally, no significant differences were observed for either mirror type or bus configuration relating to forward obstruction. Table 4-14 provides the results of these post hoc analyses.

Table 4-14 *Post Hoc Analyses Between Mirror Type and Bus Configuration: West Farms Depot*

Rating Category	Bus Configurations	Result
Field of View	40-ft Semi-curved Mirror vs. 60-ft Semi-curved Mirror	W = 902.00; $p = 0.756$
	40-ft Flat Mirror vs. 60-ft Flat Mirror	W = 112.00; $p = 0.131$
	40-ft Semi-curved Mirror vs. 40-ft Flat Mirror	W = 743.50; $p = 0.013$*
	60-ft Semi-curved Mirror vs. 60-ft Flat Mirror	W = 888.50; $p = 0.000$*
Image Quality	40-ft Semi-curved Mirror vs. 60-ft Semi-curved Mirror	W = 972.00; $p = 0.131$
	40-ft Flat Mirror vs. 60-ft Flat Mirror	W = 98.00; $p = 0.030$*
	40-ft Semi-curved Mirror vs. 40-ft Flat Mirror	W = 710.00; $p = 0.093$
	60-ft Semi-curved Mirror vs. 60-ft Flat Mirror	W = 874.00; $p = 0.001$*
Forward Obstruction	40-ft Semi-curved Mirror vs. 60-ft Semi-curved Mirror	W = 966.00; $p = 0.119$
	40-ft Flat Mirror vs. 60-ft Flat Mirror	W = 123.00; $p = 0.365$
	40-ft Semi-curved Mirror vs. 40-ft Flat Mirror	W = 659.50; $p = 0.708$
	60-ft Semi-curved Mirror vs. 60-ft Flat Mirror	W = 767.50; $p = 0.952$

** Indicates significant differences*

No observed significant differences were found at the Jackie Gleason Depot. Note that the 60-ft articulated buses included only five survey responses; therefore, that cohort was not included in the analyses. Table 4-15 provides the results of these analyses.

Table 4-15 *Kruskal-Wallis Results Between Mirror Type and Bus Configuration: West Farms Depot*

Rating Category	Result
Field of View	$H(2) = 2.86$; $p = 0.239$
Image Quality	$H(2) = 5.47$; $p = 0.065$
Forward Obstruction	$H(2) = 1.01$; $p = 0.604$

Bus Operator Age and Years of Service vs. Ratings

Following the analyses by depot, the research team assessed whether age or years of service affected how the bus operators rated the semi-curved and current NYCT flat mirror. Linear regression models were used to measure the relationship between driver age and survey response choice. No significant differences were observed between either age or years of service and the bus operators survey response choices. Figure 4-22 provides mean bus operator age by response. Table 4-16 provides the results of the linear regression model. Figure 4-23 provides mean bus operator years of experience by response. Table 4-17 provides the results of the linear regression model.

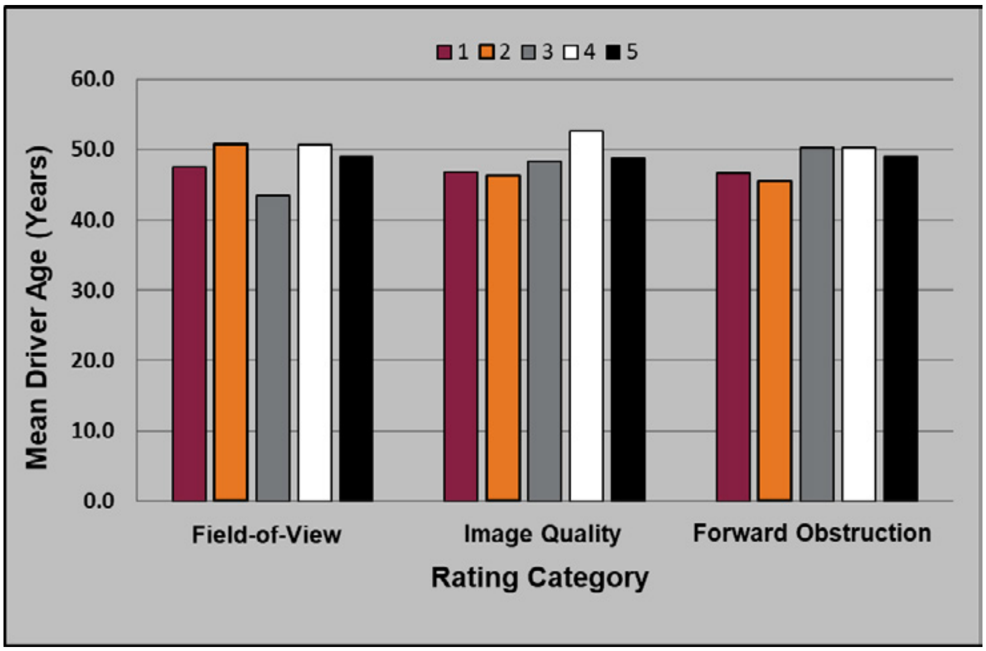


Figure 4-22 *Semi-curved mirror bus operator responses: Mean age by response choice*

Table 4-16 *Linear Regression Model Results: Mean Age by Response Choice*

Rating Category	Result
Field of View	$p = 0.420$
Image Quality	$p = 0.080$
Forward Obstruction	$p = 0.270$

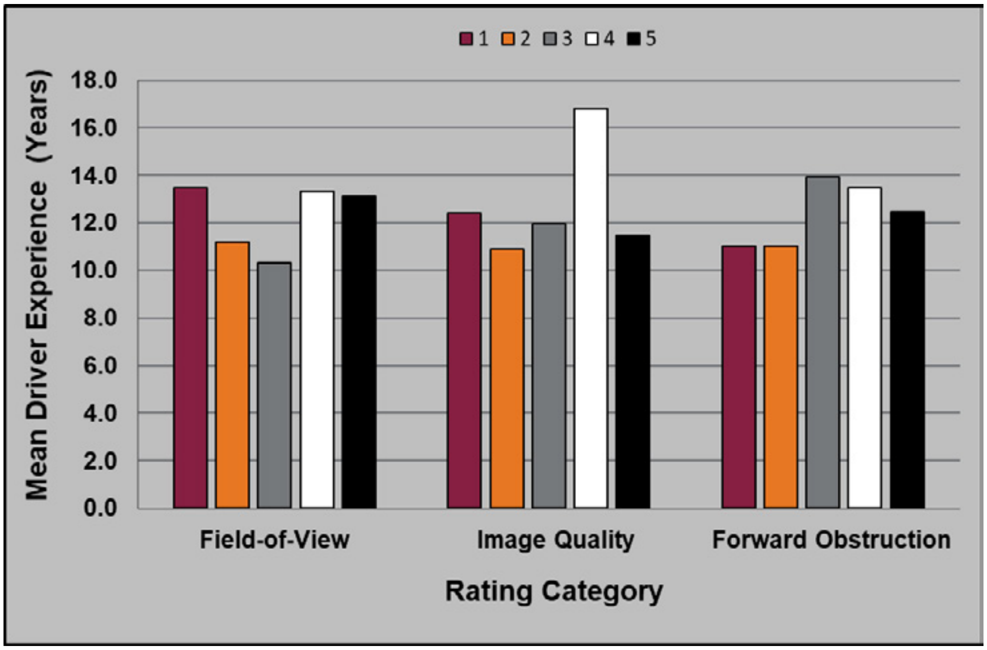


Figure 4-23 *Semi-curved mirror bus operator responses: Mean experience by response choice*

Table 4-17 *Linear Regression Model Results: Mean Age by Response Choice*

Rating Category	Result
Field of View	$p = 0.940$
Image Quality	$p = 0.600$
Forward Obstruction	$p = 0.610$

Other Potential Influencing Factors

As noted, transit agencies encounter a multitude of factors daily that impact operations and safety. These factors were also to be taken into consideration when evaluating the bus operator ratings comparing the semi-curved mirror to the current NYCT flat mirror to determine if these factors affected their rating response.

The first potential influencing factor evaluated was the average route speed. NYCT provided average route speeds for all routes the demonstration and control group buses drove throughout the field demonstration. An analysis of variance statistical test was used, and significant differences in route speed were observed—$F(2, 36) = 24.88$; $p < 0.0001$. Post hoc comparisons, using Tukey's adjustment for multiple comparisons, revealed significant differences in average bus route speed between the Casey Stengel Depot and both the Jackie Gleason and West Farms Depots. No significant difference was observed between the Jackie Gleason Depot and West Farms Depot. Figure 4-24 provides the mean route speeds by depot. Table 4-18 provides the post hoc results.

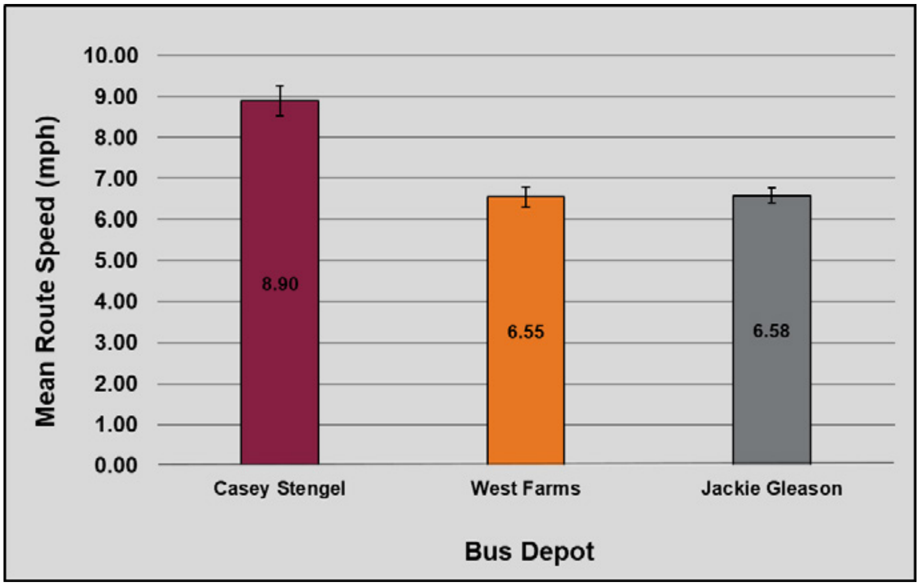


Figure 4-24 *Mean route speed (mph) by depot*

Table 4-18 *Post Hoc Tukey's Adjustment Results for Mean Route Speed by Depot*

Depot Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
Casey Stengel vs. Jackie Gleason	2.3214	1.4042	3.2387*
Casey Stengel vs. West Farms	2.3500	1.3966	3.3034*
Jackie Gleason vs. West Farms	0.0286	-0.9083	0.9654

** Indicates significance*

Other potential factors influencing the bus operator ratings were route and road configurations. Although no statistical analyses were performed due to the limited number of routes driven at some depots, the routes that were driven were researched and are described below.

At the West Farms Depot, eight different routes were driven by the 40-ft transit buses and five different routes were driven by the 60-ft articulated transit buses. The West Farms depot routes driven in this field demonstration contained two-lane, two-way divided roads (i.e., center median) with parking along both sides, four-lane undivided roads with parking along both sides, dedicated bus-only lanes, overhead rail lines, dedicated bicycle lanes, and only a single one-way street encountered.

At the Jackie Gleason Depot, 14 different routes were driven by the 40-ft transit buses and only a single route was driven by the 60-ft articulated transit buses. These routes consisted of two-lane, two-way undivided roads with parking along both sides, four-lane undivided roads with parking along both sides, and minimal overhead rail lines and bicycle lanes. No dedicated bus-only lanes or one-way streets were encountered on the routes driven during the field demonstration.

At the Casey Stengel Depot, seven different routes were driven by the 40-ft transit buses and only two routes were driven by the 60-ft articulated transit buses. These routes consisted of two-lane, two-way undivided roads with parking along both sides, one-way streets with parking along both sides, and minimal dedicated bus-only lanes.

Overall, all three depots experienced a variety of routes with the 40-ft transit buses; however, only one depot (West Farms) experienced a variety of routes with the 60-ft articulated transit buses. This is potentially one reason that may be affecting the bus operator ratings. Additionally, variables such as overhead rail lines and dedicated bus-only lanes, which were primarily seen at the West Farms Depot, may also play an important role in bus operator preferences on ratings.

Bus Operator Subjective Feedback

Bus operators were asked to provide feedback on the adjustment of the semi-curved mirror and to indicate if they would like to operate a transit bus with the semi-curved mirror on a permanent basis. Overall, 90% of the 40-ft transit bus operators indicated that the semi-curved mirror adjusted to their preferred viewing position, and 95% of the 60-ft articulated transit bus operators indicated the same.

Differences did appear between depots when bus operators indicated if they would like to drive with the semi-curved mirror on a permanent basis or not. Table 4-19 provides the results of driver preference.

Table 4-19 *Driver Preference for Using Semi-curved Mirror on Permanent Basis*

Depot	40-ft	60-ft
West Farms	87%	86%
Jackie Gleason	34%	53%
Casey Stengel	42%	23%

Bus operators also had the opportunity to provide open-ended feedback on any positive or negative experiences while using either the semi-curved mirror or current NYCT flat mirror during the field demonstration. Overall, 144 of 200 survey respondents provided comments. This included 86 comments provided about the semi-curved mirror and 58 about the current NYCT flat mirror. The comments ranged from each end of the spectrum from “love it” to “hate it.” The majority of positive comments with the semi-curved mirror mentioned being able to see two lanes adjacent to the bus and not having to lean into the mirror to be able to see more. The majority of negative comments related to the semi-curved mirror were making the vehicles, objects, pedestrians seem further away than what they really are. The majority of all comments on the current NYCT flat mirror were negative, with the main concern being that they have to lean and rock to see more in the mirror to reduce the blind spots.

Safety Improvement

In addition to capturing bus operator ratings and feedback on both the semi-curved mirror and current NYCT flat mirror, the research team also investigated incidents, maintenance tickets, cost, and potential return on investment of the mirrors.

Bus Incidents

During the field demonstration from April 26, 2021, through October 31, 2021, four left-side preventable (as rated by the NYCT investigator) incidents occurred with the demonstration and control group buses. One incident occurred with the semi-curved mirror on a 40-ft transit bus at the Jackie Gleason Depot. Three incidents occurred with the current NYCT flat mirror, one at the West Farms Depot in a 60-ft articulated transit bus and two 40-ft transit buses at the Jackie Gleason Depot. Due to the limited number of incidents, no analyses were conducted.

To provide a snapshot into the number of incidents that occur on a yearly basis, NYCT provided the research with information on the total incidents from January 1, 2021, through November 30, 2021. During this time period, there were 7,038 total incidents, of which 3,268 were categorized as left-side incidents (2,874 on 40-ft transit buses, 394 on 60-ft articulated transit buses). Breaking down the left side incidents by NYCT investigator rating, there were 508 incidents deemed preventable, 2,303 incidents deemed non-preventable, 266 incidents that occurred on the bus operator's probationary period, and 183 incidents listed as not rated. The final eight did not have any rating provided.

Mirror Costs

The mirror vendor, Safe Fleet, provided the research team with the costs of the current NYCT flat mirror and the semi-curved mirror. Table 4-20 provides the cost breakdown between the mirrors.

Table 4-20 *Mirror Costs*

Parts Description	Current NYCT Flat Mirror	Semi-curved Mirror
Mirror w/ Assembly	$262	$285
Mirror Only	$123	$146

Maintenance Tickets

Maintenance tickets were also provided to the research team. Overall, 15 maintenance tickets relating to street-side mirror were submitted during the field demonstration. This included 11 maintenance tickets for the semi-curved mirror and 4 maintenance tickets for the current NYCT flat mirror. Table 4-21 provides a breakdown of the maintenance tickets across depots by mirror type and includes total labor hours and materials cost. It is important to note that materials costs listed in the maintenance ticket did not provide a breakout of each part that was needed.

Table 4-21 *Maintenance Tickets by Depot and Mirror Type*

Depot	Duration (m)	Mirror	Tickets (n)	Labor Hours	Materials Cost
West Farms	6	Flat	3	13.25	$440.34
		Semi-curved	1	1.08	$466.75
Jackie Gleason	5	Flat	0	0	$0.00
		Semi-curved	2	2.33	$191.28
Casey Stengel	4	Flat	1	0.5	$0.00
		Semi-curved	8	25.58	$1,316.27

Of the 11 maintenance tickets involving the semi-curved mirror, 2 were listed as vandalism and 2 were listed as damaged/broken (cause not provided). The remaining 7 maintenance tickets were listed as loose mirror or arm. The likely cause of the seven loose mirrors or arms were due to the lack of training provided on the use of the semi-curved mirror. As intended, all bus operators were naïve in this field demonstration. The VTTI researcher on-site for the first week of mirror deployment at each depot noted multiple bus operators trying to adjust the entire mirror head and even putting their entire body weight into trying to move the mirror head. These actions would potentially strip the set screws that hold the mirror in place. In fact, the VTTI researcher had to tighten the set screws of one mirror while on-site the first week. The current NYCT flat mirror head is mounted on a ball mount, so the entire mirror head is adjusted. This differs from the semi-curved mirror, which was designed to add heat and power adjustment in the future. The entire mirror head does not adjust; rather, only the glass inside of the mirror head adjusts. With bus operator training, these seven incidents would likely be eliminated, thus lowering the number of maintenance tickets and overall cost.

Mirror Component Life

Mirror component life focused on the current NYCT flat mirror. NYCT currently has a total of 257 2019 model New Flyers (145 40-ft transit buses and 112 60-ft articulated transit buses). NYCT provided all reported mirror issues for the one-year period from December 10, 2020, through December 9, 2021, during which there were 937 reported mirror issues. This includes both street-side and curb-side mirrors. Table 4-22 provides the breakdown of reported mirror issues, including the number or replacements and repairs.

Table 4-22 *2019 Model Year New Flyer Reported Mirror Issues: 12/10/20–12/9/21*

Mirror Issues	Reported	Replaced	% Replaced/Year
Head or Glass	852	281	109.3%
Arm	85	34	13.2%

The data show that the current NYCT flat mirror is being replaced at least once per year and in some cases more than once per year on these 2019 model year New Flyer buses. Based on the cost of these mirrors provided by Safe Fleet, this equates to approximately $74,000 per year in materials costs just for the mirrors. It is likely this trend holds true across the entire NYCT fleet regardless of make of bus or model year.

Section 5 Conclusions

Evaluation Metrics

The Center for Urban Transportation Research (CUTR) at the University of South Florida was contracted by FTA to serve as an independent evaluator of this project. NYCT and VTTI worked with CUTR and FTA to ensure that the project met FTA's Safety Research Demonstration goals and objectives.

NYCT and VTTI regularly reported the status of data collection to CUTR and FTA during all appropriate phases of the project to ensure a reliable and consistent collection of information. A metric plan was established in the project work plan. These metrics were organized by three categories: Safety Improvement, System Effectiveness, and Return on Investment. NYCT and VTTI produced data and deliverables for these metrics. The findings pertaining to these metrics are listed in Table 5-1.

Table 5-1 *Project Safety Research Demonstration Metrics and Findings*

Evaluation Metrics	Sub-Metrics	Findings
Safety Improvement	Visibility Modeling	• The direct visibility obstructions and mirror rear-view visibility performance of four transit and two motorcoach buses were produced for a range of bus operators that represent the North American population. The performance of 40-ft and 60-ft articulated transit bus configurations were also modeled. • High-mount and low-mount flat and convex mirror assemblies were modeled. High-mount mirrors demonstrated no visibility obstruction for some users (i.e., short and average sitting height bus operators). However, the high-mount mirror assembly with flat and convex mirrors produced large obstructions for tall bus operators when viewing objects in the crosswalk. • An optimized low-mount semi-curved mirror was developed with improved gap between the bus body "A-pillar" and the mirror head to view objects close to the bus. This design maintains a high-quality image of the rear-view scene in the mirror face and provides a field of view to the ground near the bus operator and across two lanes to view articulated bus axles during turns and oncoming traffic.
Safety Improvement	Incidents and Near Misses	• No operators participating in the field demonstration noted any near misses with the semi-curved mirror. Based on incident data provided by NYCT, incidents of collisions occur approximately once for every bus in the fleet every year. • Based on comments from the bus operator surveys during the field demonstration, the larger field of view provided by the semi-curved mirror helped reduce potential near misses in two ways: allowing bus operators to see two adjacent lanes and by reducing the need to lean and rock in the seat to adjust viewing angle in the mirror, thus reducing time away from viewing the forward roadway. • Negative comments on the semi-curved mirrors were related to the image quality. This issue may be resolved with training, which was not provided to the drivers prior to the field demonstration.

Evaluation Metrics	Sub-Metrics	Findings
System Effectiveness	Visibility Modeling	• A comparison of the visibility obstructions and mirror rear field of view to the ground for 360 degrees around the bus was produced for the current production mirror, a prototype low-mount flat and convex combination, and a prototype semi-curved mirror. The two prototype mirror assemblies reduced forward visibility obstructions and increased rearward field of view.
	Pilot Evaluations	• Static and dynamic pilot evaluations were performed, and these evaluations produced guidance for NYCT, VTTI researchers, and the industry partners to make decisions that would be supported by transit bus operators during the field demonstration. The outcome of these evaluations made it clear that the semi-curved mirror was as good as the current NYCT flat mirror and even better in some instances.
System Effectiveness	Field Demonstration	• Thirty mirrors were evenly distributed across three bus depots and boroughs in the NYCT system. Bus operator acceptance, incidents, and maintenance data were tracked on all 60 buses over a period of six months. Acceptance was positive but varied by bus depot.
Return on Investment		• There was a $23 difference between the current NYCT flat mirror assembly and the semi-curved mirror assembly. Due to the limited number of incidents that occurred during the field demonstration, analyses could not be conducted to determine if the semi-curved mirror would result in NYCT replacing fewer mirror assemblies yearly and, thus, reducing the materials costs and seeing a positive return on investment

Safety Improvement

Visibility Modeling

NYCT and VTTI demonstrated safety improvement by modeling visibility obstruction zones in a real-world scenario. This was measured using the results of the transit bus scans, transit bus modeling, and visibility modeling to develop a pedestrian crossing simulation. A sample of these results are provided in Figure 5-1 for the production transit street-side mirror assembly, Figure 5-2 for a prototype transit street-side flat and convex mirror assembly, and Figure 5-3 for a prototype transit street-side semi-curved low-mount mirror assembly.

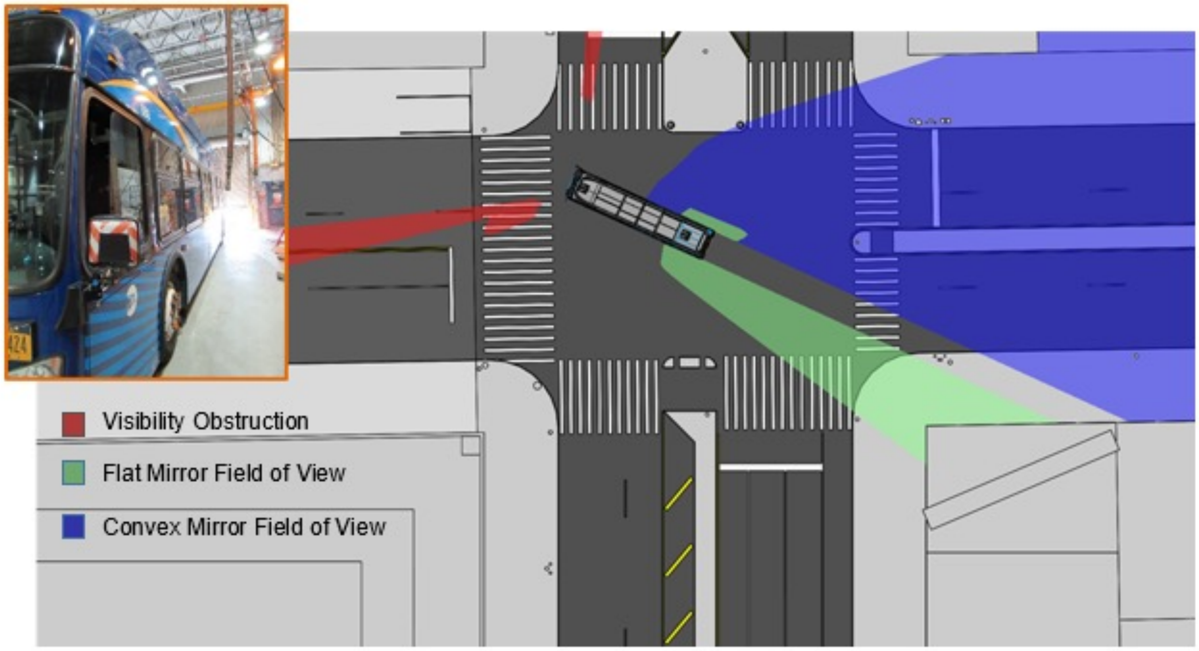


Figure 5-1 *Street simulation of left turn and short female view of A-pillar and mirror obstructions with rearward view zones of NYCT production mirror*

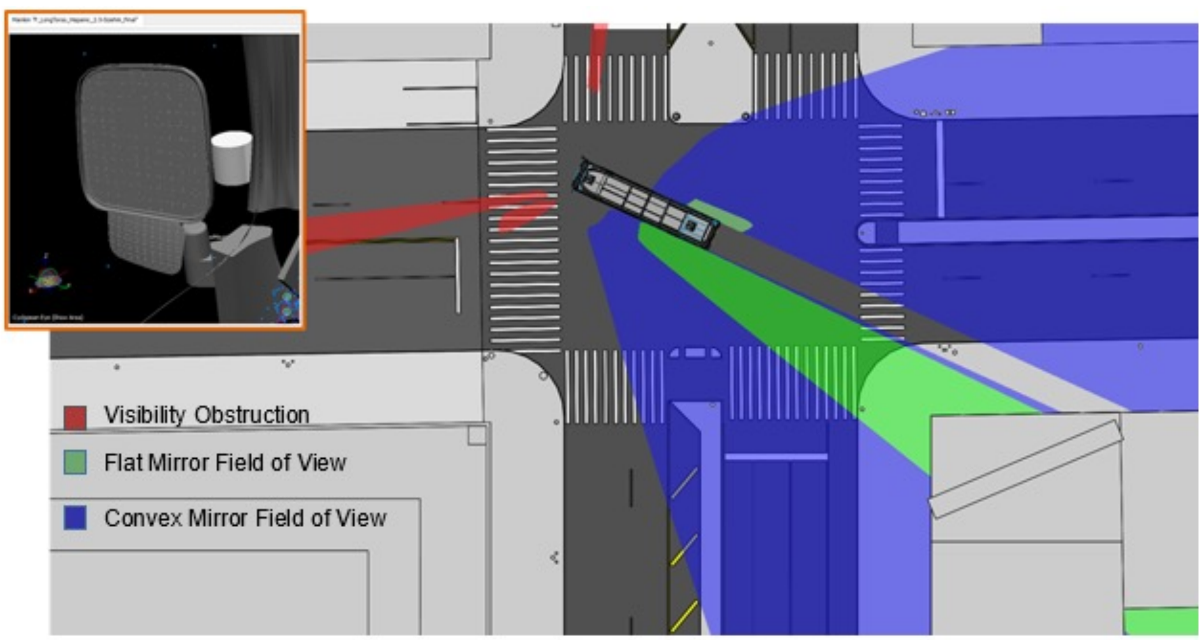


Figure 5-2 *Street simulation of left turn and short female view of A-pillar and mirror obstructions with rearward view zones of flat and convex prototype mirrors*

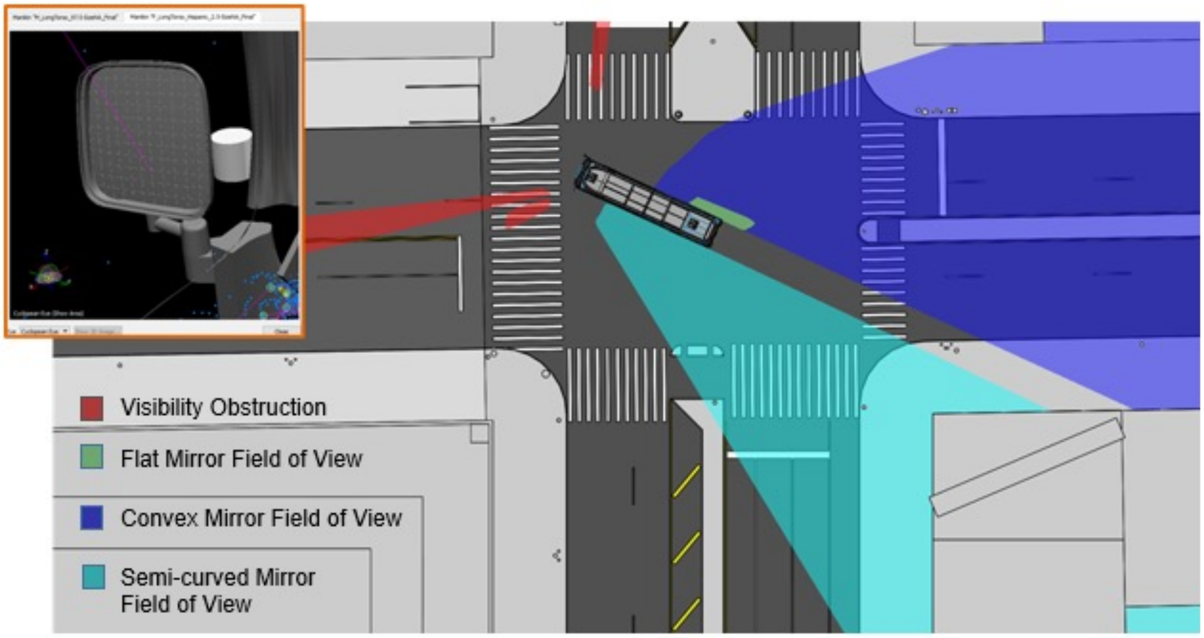


Figure 5-3 *Street Simulation of left turn and short female view of A-pillar and mirror obstructions with rearward view zones of semi-curved low-mount prototype mirror*

Incidents and Near Misses

It is clear from the incident data provided by NYCT that low-floor transit buses are involved in a relatively high number of incidents each year. New York City is a densely populated urban environment, and bus operators encounter high volumes of traffic on tight city streets along with pedestrians, bicyclists, and scooters daily so one would expect an increase in the number of incidents compared to more rural and less populated cities. Based on the data provided, incident rates are occurring at approximately one incident for every low-floor transit bus per year. NYCT does not track near misses, and none of the bus operators completing a survey during the field demonstration reported any near misses. However, the overall positive feedback from bus operators indicated the larger field of view provided by the semi-curved mirror helped reduce potential near misses in two ways. First, bus operators noted the larger field of view allowed them to see two adjacent lanes on their street-side, which increases their chances of seeing another vehicle, pedestrian, bicyclist, or scooter approaching, crossing, or weaving through traffic or parked vehicles. Second, with the larger field of view provided by the semi-curved mirror, bus operators also noted not having to lean and rock in their seat to adjust their viewing angle in the mirror. Bus operators indicated that leaning and rocking can divert their eyes off the forward roadway and curb-side mirrors for longer periods of time, which in turn may cause them to miss something and lead to a near miss or even worse, an incident. Based on comments from the bus operators, the semi-curved mirror reduced this risk. Several bus operators also noted that constant leaning and rocking puts a strain on the body, which would be lessened with the semi-curved mirror.

Conversely, bus operators that did provide a negative comment almost entirely noted the image quality in those comments. The semi-curved mirror does have some distortion and makes the images viewed in the mirror seem farther away than they are in reality. Although the distortion is not as great as in a traditional convex mirror, the distortion of the semi-curved mirrors made some bus operators feel as if they could not judge the distance of approaching vehicles when pulling out of a bus stop or when attempting to change lanes. This issue could potentially lead to near misses or an actual incident if bus operators cannot properly judge distances. Whereas this issue may arise from previous experiences of individual bus operators and/or receiving no prior training on this type of mirror, it is an issue that needs to be considered.

System Effectiveness

Visibility Modeling

NYCT and VTTI demonstrated the effectiveness of the prototype mirror solutions by producing a comparison of the direct and indirect mirror visibility improvements from the production NYCT New Flyer. This comparison was made using model representations of the obstructions and rearview visibility zones projected onto the ground in a five-lane roadway. Images of these models for female (left) and male (right) direct and indirect mirror visibility performance are provided for the production flat mirror (Figure 5-4), prototype flat and convex combination (Figure 5-5), and prototype semi-curved low-mount mirror (Figure 5-6). Larger representations of these images are provided in Appendix D. Percentages of the obstruction and rearview visibility zones to the ratio of each of the 14 zones were calculated and are provided in Appendix D.

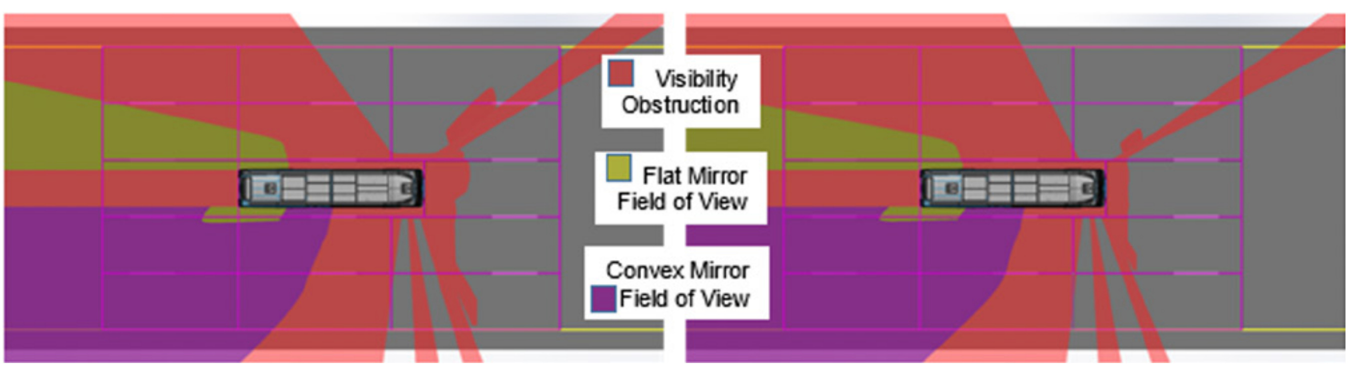


Figure 5-4 *Top view of short female (l) and tall male (r) direct and mirror visibility performance of the NYCT production mirror set on New Flyer bus*

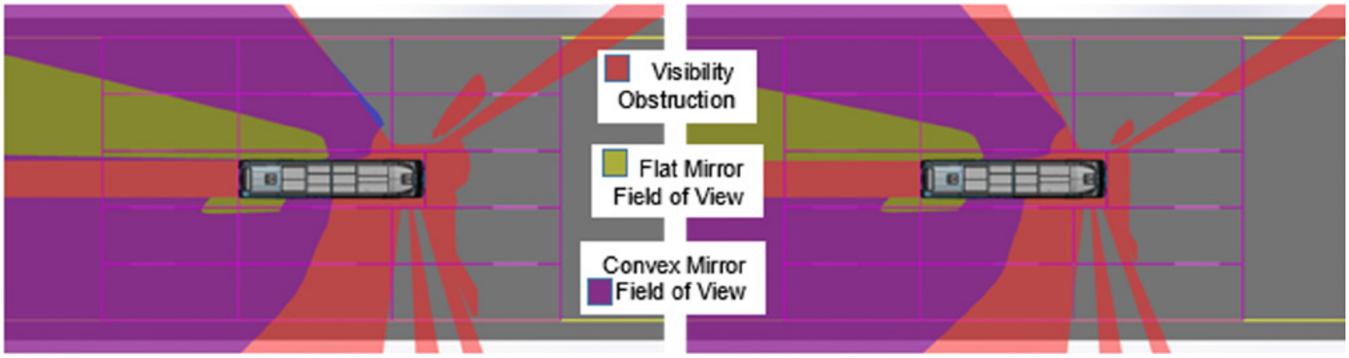


Figure 5-5 *Top view of short female (l) and tall male (r) direct and mirror visibility performance of flat and convex combination prototype mirror set on New Flyer bus*

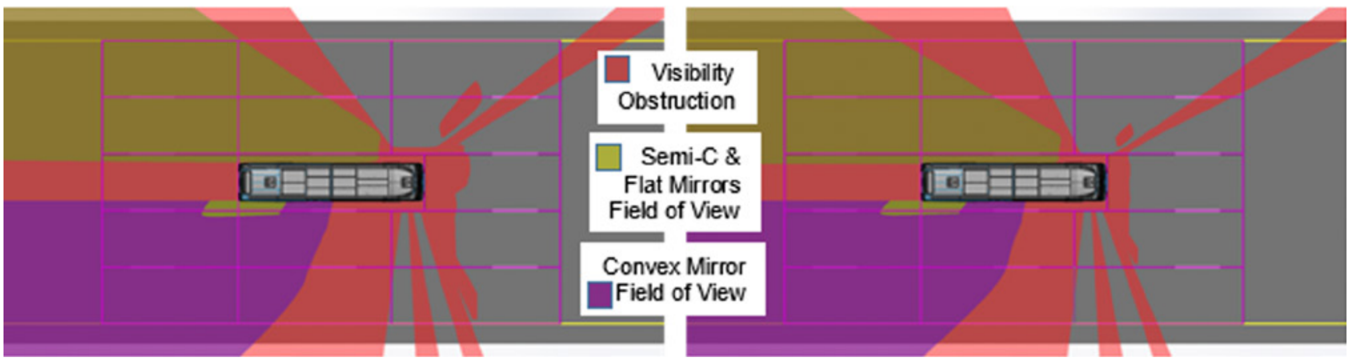


Figure 5-6 *Top view of short female (l) and tall male (r) direct and mirror visibility performance of semi-curved low-mount prototype mirror set on New Flyer bus*

Pilot Evaluations

NYCT and VTTI demonstrated the effectiveness of the concept mirror development through the bus operator evaluations of the physical prototype mirrors in NYC. The result of the evaluation performed with transit bus operators in a static setting that allowed the bus operators to compare three different prototype mirror assemblies was positive acceptance of the prototype semi-curved (ECE-style) mirror assembly. Most bus operators picked the semi-curved mirrors for vehicle and pedestrian traffic. Only one bus operator in the static evaluation stated that they would not want to use the low-mount semi-curved mirror on their daily route. However, NYCT management requested that an additional design be considered.

The VTTI research team and Safe Fleet mirror development partner worked together to produce an additional prototype mirror that maintained the unit magnification in the section of the mirror closest to the bus body while splitting the mirror with a convex section on the outside section of the mirror to provide a view of the second lane. This design maintained the low mirror mount and similar head size to the production NYCT flat mirror. A pilot evaluation was performed with this split vertical flat/convex mirror. This prototype split-glass mirror was not rated favorably by the bus operators while driving with it during a non-revenue training event. As a result of this evaluation, NYCT management and the VTTI research team decided to reconsider the low-mount semi-curved mirror in a driving evaluation.

The mirror developer provided a pre-production semi-curved mirror that could be adjusted and evaluated in another pilot driving evaluation. During this pilot evaluation, drivers operated both 40-ft and 60-ft transit buses with the pre-production semi-curved mirror on the street-side of the bus. The ratings of field of view, image quality, and forward obstruction were all very positive for the semi-curved mirror. Therefore, the research team prepared a summary of the static evaluation and two driving pilot evaluations to consider the semi-curved mirror for field study.

The outcome of these evaluations made it clear that the semi-curved mirror was as good as, the current NYCT flat mirror and even better in some instances. NYCT management and the training department, after reviewing and discussing these results with the research team, agreed to proceed with the field demonstration with the low mount semi-curved mirror in a staggered approach across three depots, one demonstration of 10 mirror assemblies in each borough within the city.

Field Demonstration

The field evaluation was organized as a between-configuration comparison of 40-ft and 60-ft transit buses where half of the buses were operated with pre-production semi-curved mirrors and the other half were operated with the current production flat mirror. Thirty mirrors were evenly distributed across three bus depots and boroughs in the NYCT system. Bus operator acceptance, incidents, and maintenance data were tracked on all 60 buses over a period of 6 months. The evaluation did not last for 6 months at all depots, because the semi-curved mirrors were implemented on a delayed schedule based on feedback from the first and then second depot before being released for test at the third depot. Cumulatively, the evaluation covered 15 months combined across the three depots.

The bus operator ratings and comments for the semi-curved mirror were positive overall across the entire field demonstration. In fact, the semi-curved mirror was rated significantly better than the flat mirror in field of view for both transit bus configurations. Likewise, the image quality was rated positively for both configurations, and it was rated significantly better than the flat mirror on the 60-ft articulated bus configuration. The ratings of obstruction were not different between the flat and semi-curved mirrors, suggesting that while the field of view had been improved the obstruction had not been increased, meeting a critical objective of the study.

Some drivers, especially at one depot, commented negatively on the image quality of the semi-curved mirror. However, driving experience, age, and operational traffic or roadway settings did not explain the difference. One difference noted between the depot where the semi-curved mirror was rated low on image quality and the other depots was a statistically higher average operating speed, which was approximately 2 mph faster than the other two depots. However, the surveys for both the semi-curved and flat mirrors were negative, which suggests that resistance to change may have been a critical issue for that depot. One other observation made by the research team was the lack of training provided on the adjustment of the semi-curved mirror, where only the mirror face was designed to be adjusted rather than the entire mirror head like the current NYCT flat mirrors. Training on the adjustment may have improved reception of the mirrors at all the depots.

Return on Investment

As noted, NYCT low-floor transit buses experience a high number of incidents along with mirror-related maintenance tickets. The mirror development partner, Safe Fleet, provided the cost breakdowns of both the pre-production semi-curved mirror and the current NYCT flat mirror. These cost breakdowns included the entire mirror assembly and just the mirror. There was a $23 difference between the current NYCT flat mirror assembly and the semi-curved mirror assembly. There was also a $23 difference between just the mirrors as well. In both instances, the semi-curved mirror assembly or only the mirror is the more costly component. Based on mirror replacement costs for the 2019 model year New Flyers in service at NYCT, the semi-curved mirror would have resulted in an approximate $6,100 increase in material costs. However, due to the limited number of incidents that occurred during the field demonstration, analyses could not be conducted to determine if the semi-curved mirror would actually result in NYCT replacing fewer mirror assemblies yearly and thus reducing the materials costs and seeing a positive return on investment.

Lessons Learned

A few lessons learned were noted during this project. Some positive outcomes came from the design of the information gathering. The level of data on the buses, bus operator anthropometry, and CAD modeling led the research team and industry partners to respond quickly to information gathered during the stages of the study. The research team made multiple deviations to the design of the optimized mirror based on the data from vehicles, focus groups, review of existing incidents, and manager and bus operator pilots. Although each of these deviations delayed the field demonstration, each led to significant findings. These review opportunities with stakeholders and users are recommended to ensure that new technologies meet or exceed the needs of users rather than introducing new problems. It is also recommended to plan for multiple interactions with stakeholders, including agency management, suppliers, manufacturers, and—importantly—the bus operators. Although many opportunities for interactions with stakeholders and design refinement were planned, still more were needed, especially in the case of the field demonstration, which is discussed below.

The number of completed surveys rating the current NYCT flat mirror returned from the field demonstration was much lower than expected at some depots. This was somewhat surprising, as the management at each depot and the union representatives were fully briefed and supported and pledged their assistance. However, at the depot level, the research team later learned that the multiple layers of management (e.g., transportation superintendent, maintenance superintendent, route dispatchers, yard dispatchers, etc.) made the task of survey implementation more difficult.

Another issue encountered was the lack of enthusiasm from some bus operators. Earlier in the project during the focus groups, bus operators stated that management usually never asked for their input, although they felt that management should, as the bus operators are the ones actually driving the buses. This field demonstration was the perfect opportunity for bus operators to give their input on a safety-related issue. However, during the field demonstration, a number of bus operators mentioned a lack of interest in filling out the surveys due to a lack of faith that the results would be heard by management. These issues limited the number of post hoc analyses that could be conducted for these depots due to fewer than expected completed surveys.

Similar issues with sample size were seen in other aspects of the demonstration. The number of routes driven with the 60-ft articulated transit buses were a potential limitation. The Jackie Gleason Depot only had one route where drivers had the chance to experience the semi-curved mirror, and the Casey Stengel Depot only had two routes where the semi-curved mirror was in operation. During the experimental design of this study, the team recognized the need to balance the between-subjects data collection across routes to gain the best understanding of how the prototype semi-curved mirror was being used across different road configurations and conditions. The lesson again relates to communication with a broad range of stakeholders.

One solution to this challenge in future implementation efforts is to interact with a sample of bus operators at each depot prior to determining the locations and routes for deployment. This might improve the rate of survey completion on both the current and prototype-equipped buses. This interaction may also lead to insights about the routes for the buses at each depot and inform the rollout or limit which buses to deploy test systems. It would also serve as an informational session for the bus operators, who could then pass along the information to their colleagues.

Another lesson from the field demonstration would be to provide training to the bus operators. For this field demonstration, they were naïve to the semi-curved mirror. Clear and open lines of communication with bus operators would potentially improve the number of survey responses and limit any bias resulting from the mirror being unfamiliar technology. As the mirror adjustment was different from their current NYCT flat mirror and they were not trained on the proper adjustment method, they may have formed a negative bias against the semi-curved mirror. By not providing training, the functionality and benefits of the semi-curved mirror may not have been understood equally at all depots. As seen in the varying responses from each depot, some bus operators may have immediately liked the novel technology whereas others may not have been more averse to it. Communication and training can improve the rollout and information sharing both ways. This warrants extra time and resources in the future.

Future Research

In summary, detailed full-context visibility performance models were produced to provide NYCT and FTA with benchmarking and guidance to continually improve transit and motorcoach bus technology. The research team observed that optimal bus visibility performance depends on vehicle configuration, roadway, training, and bus operator behavior. The NYCT low-floor transit bus street-side flat mirror assembly is an optimal solution to reduce obstructions, but bus operators were still seeking a better field of view due to the lack of convex mirror. One concept for improvement, mounting the curb-side mirror high, would eliminate the mirror head obstruction, but at this agency the training system focuses heavily on scanning the roadway to maximize direct visibility. Moving the mirror head to a high position may interfere with visibility in this dense vehicle and pedestrian/bicycle/scooter urban environment.

The research team also observed that the low-floor transit curb-side mirror set has room for improvement due to the very small section of roadway and curb visible in the flat mirror. Furthermore, the distance to the curb-side convex mirror combined with that mirror's curvature leads to the size of the objects that are visible to the bus operators on the face of the mirror being very small. New solutions (e.g., cameras) are needed to continuously improve and optimize the street-side and curb-side transit bus visibility. Technology such as cameras may give bus operators the field of view and image quality they desire while reducing or eliminating obstructions and frequent mirror strikes. Given the high rate of repair and replacement of mirrors on the transit buses, there may be a positive return on investment within a relatively short period of time on these technologies if cameras are mounted close to the bus body. The research team also observed that the motorcoach mirrors can be improved due to the significant body obstructions inherent in the architecture of these express service buses that operate across larger distances between cities and boroughs.

Acronyms and Abbreviations

CAD	Computer-aided drawing
CUTR	Center for Urban Transportation Research
DOB	Department of Buses
ECE	Economic Commission for Europe
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
HSNA	Human Solutions North America
MTA	Metropolitan Transportation Authority
MVMT	Million vehicle miles traveled
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
NYCT	New York City Transit
VTTI	Virginia Tech Transportation Institute

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[3] Regulation No. 46-02 of UN/ECE, Uniform Provisions Concerning the Approval of Devices for Indirect Vision and of Motor Vehicles with Regard to the Installation of These Devices, 2011.

[4] SAE International (2008). SAE J826: Devices for Use in Defining and Measuring Vehicle Seating Accommodation. Warrendale, PA.

[5] SAE International (2010). SAE J941: Motor Vehicle Drivers' Eye Locations, Appendix E: Eyellipses for Class B Vehicles [Informative]. Warrendale, PA.

[6] SAE International (2009). SAE J1050: Describing and Measuring the Driver's Field of View, Appendix C: Approximating the Obstruction Angle from A-Pillars. Warrendale, PA.

Appendix A Literature Review

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
1	SAE	Surface Vehicle Recommended Practice: Describing and Evaluating the Truck Driver's Viewing Environment	Recommended Practice	High	10	2010	Details target evaluation method, polar plot, and horizontal planar projection for direct and indirect (mirror) visibility.
2	Georgia Association for Pupil Transportation	Presentation of FMVSS 111	Presentation	High			Discusses FMVSS 111 and provides details on how to set up cones for school bus mirror positioning.
3	Ohio Casualty	Mirrors for Heavy Trucks and Tractor-Trailers	Reference Note	Medium	8	2008	Overviews truck no-zones and FMVSS 111. Provides some details on proper mirror adjustments for large trucks.
4	Daniel Blower (UMTRI)	Truck Mirrors, Fields of View, and Serious Truck Crashes	Report	Low	6	2007	Briefly discusses FMVSS 111 and then identifies mirror-relevant crash types in tractor-trailers.
5	Vision Zero International	Buses and Coaches	Newsletter	Medium	1	2017	Provides some EU statistics on bus crashes, quotes Kevin Grove (VTTI), and suggests the US can pull from EU on bus safety. Identifies Volvo pedestrian and cyclist detection launched in IAA Hanover 2016, announcing field tests in city buses in 2017.
6	NHTSA	Mirror Reply Letter to Alliance of Automobile Manufacturers	Letter	Low	6	2016	NHTSA reply to a petition from the AAM to amend FMVSS 111 to allow camera-based monitoring system as a replacement to mirrors.
7	Riley Garrott & Elizabeth Mazzare (NHTSA)	Methodology for Measuring the Ability of Convex Mirrors to Improve Rear Visibility	Presentation	Low	?	?	Focused on the use of rear mount convex mirror(s).
8	Elizabeth Mazzae & W. Riley Garrott (NHTSA)	Vehicle Rearview Image Field of View and Quality Measurement	Report	Medium	9	2011	Contains details supporting Dec. 2010 FMVSS 111 NPRM which proposed improved vehicle rear visibility requirements. Description of the analysis performed to identify the area that should be visible to drivers to avoid backover crashes. It also contains a description of the basis for determining the proposed criteria for minimum image quality to view child-sized obstacles in the rearview.

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
9	Transit Cooperative Research Program (TCRP)	Bus Operator Workstation Design for Improving Occupational Health and Safety	Report	High	?	2016	Conducted literature review on bus operator health, bus technologies, and operator workstation areas. Gathered input from stakeholders in these areas and developed training recommendations for procurement teams and bus operators and developed CAD model for transit bus operator workstations to enhance safety and health.
10	TCRP	Design Tool	Guidelines	High	2	2016	Guidelines for bus operator workstations.
11	New Flyer	A-Pillar Design Constraints and Improvements	Presentation	High	5	2016	Provides renderings and specifications of different mirror configurations and the A-pillar.
12	CALTRANS & PATH	Vehicle Assist and Automation Demonstration	Report	Low	8	2017	This project focused on aspects of automation including lane keeping and automatic docking and platooning.
13	Carnegie-Mellon	Mirror Location on the Vehicle and Adjustment	Paper	Medium	?	?	One page about transit bus mirrors.
14	TMC's Recommended Practices	Mirror Positioning and Aiming Guidelines	Guidelines	Medium	7	1999	Guidelines on proper mirror adjustment for tractor-trailers.
15	NHTSA	FMVSS 111	Standard	High	4	2004	NHTSA FMVSS 111 details the standard for rearview mirrors; note there is no standard for transit buses other than a minimum of 323 square centimeters in reflective surface, stable supports, unit magnification, rearview, and adjustable in vertical and horizontal directions.
16	VTTI	FAST DASH Project #3: Novel Convex Mirrors	Report	High	11	2016	Independent evaluation of novel convex mirrors on a tractor-trailer. Driver input on FOV, distortion, acceptance, etc. Drivers indicated preference for current production mirrors. Analyses showed a larger FOV but increased distortion. No difference in distance judgement between prototype and production mirrors.
17	VTTI	Study of Driver Performance/ Acceptance Using Aspheric Mirrors in Light Vehicle Applications	Report	Medium	7	2008	Provides an overview on aspheric mirrors and comparisons to flat and spherically convex mirrors. Aspheric are common in Europe. Pros and cons in light vehicles are discussed.
18	TMC's Recommended Practices	Guidelines for Vision Devices (RP 428A)	Guidelines	High	9	2016	Specifies vision zones and details a method of placing targets to optimally adjust mirrors to view as much as possible

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
19	Alexander de Vos (TNO Human Factors Research Institute; The Netherlands)	Non-Planar Driver's Side Rearview Mirrors: A Survey of Mirror Types and European Driver Experience and a Driver Behavior Study on the Influence of Experience and Driver Age on Gap Acceptance and Vehicle Detection	Two versions: report and journal article	Medium	9	2000	Survey of mirror use and assessment of driver performance when making lane changes based on mirror information in Europe. Survey found only 1/3 of drivers knew what mirror type they had. Assessment quantified differences between wider FOV and decisions to make lane changes at smaller gaps due to minified image. Conclusion found the benefits of non-planar mirrors outweigh any negative effects.
20	D'Souza et al.	Multivariate Statistical Analysis of Public Transit Bus Driver Distraction	Journal article	Low	Vol. 15	2012	Discusses methods of assessing bus operator distractions and establishes links to demographic background, driving hours, and location. Conducted at a regional public transit agency with annual ridership of 18 million.
21	Andrew Krum	Visibility Modeling from a Heavy-Vehicle OEM's Perspective	Presentation	High	5	2009	Visibility modeling of heavy vehicles. Details North American and global standards for measurement of visibility and mirrors.
22	Economic Commission for Europe (ECE)	Consolidated Resolution on the Construction of Vehicles	Regulation	High	1	2014	Identifies vehicle classifications for application of visibility and mirror requirements for vehicles in Europe, including passenger carrying M2 and M3 vehicles with greater than 22 passengers in Class I and II vehicle buses which include standing passengers (transit) and Class III vehicle buses which exclude standing passengers (motorcoach similar).
23	ECE	Devices for Indirect Vision and of Motor Vehicles with Regard to the Installation of these Devices	Regulation	High	12	2011	Detailed specifications on the use of mirrors in Europe including M2 and M3 buses.
24	ECE	Devices for Indirect Vision and of Motor Vehicles with Regard to the Installation of these Devices, Amendment	Regulation	High	10	2014	Amendment to the detailed specifications on the use of mirrors in Europe including M2 and M3 buses.
25	ECE, Other (?)	Directive 35b	Specifications	High	?	?	Specifications regarding blind spots along an arc of vision.
26	ECE	Council Directive 77/649: Motor Vehicles Drivers Forward Visibility (M1 Vehicles)	Directive	Medium	11	1991	European directives regarding forward visibility for M1 vehicles.

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
27	Greg Fitch et al.	Towards Developing an Indirect Video Visibility System for Large Trucks	Conference proceedings	Low	?	2008	Discusses camera/video imaging research to eliminate blind spots in tractor-trailers that was conducted on the Virginia Smart Road.
28	James Jenness et al.	Static Testing Method for Assessing Quality of Indirect Visibility on Heavy Trucks	Report	Low-Medium	6	2008	Though the report does discuss measuring the FOV of different mirror configurations of truck drivers, the primary goal was assessing methodology of testing indirect visibility systems.
29	European Bus Systems of the Future	Recommendation for a Code of Practice of Driver's Cabin in Line Service Buses	Recommendation	Medium	10	2011	Recommendations including CAD drawings of visibility of the bus operator's compartment. Mentions both lateral and forward visibility as well as front blind spot.
30	Greg Fitch et al.	Field Demonstration of Heavy Vehicle Camera/ Video Imaging Systems: Final Report	Report	Low	6	2011	Discusses camera/video imaging research to eliminate blind spots in tractor-trailers. This was a field demonstration using a revenue-generating fleet with 12 drivers participating.
31	VTTI	Transit Bus Visibility Measures	Guidelines	High	9	2016	Overview of benchmarking procedures including bus operator's compartment and FOV using H-point machine and 3D measuring arm.
32	TMC	Future Truck Program Position Paper 2015-1: 360 Driver Awareness Expectations	Report	Medium	7	2015	Discusses SAE standards relating to mirrors and visibility. Also discusses windshields, lights, and clarity.
33	Zaindl et al.	Simulation of Visual Field Extensions in the Mirrors of Commercial Vehicles	Presentation	High	9	2014	Discusses types of mirrors in use in Europe along with potential for camera systems and how to model mirror view enlargement
34	V.A. Millington et al.	Investigation into A-pillar Obscuration - A Study to Quantify the Problem Using Real World Data	Report	Medium	3	2006	Evaluated if A-pillar obscuration was a problem in light vehicles in the United Kingdom (UK). Used real-world data to construct 3-D visual models of crashes. Crash data was obtained from previous studies. Study found that, in some cases, A-pillar obscuration was at least, in part, the cause of the crash.
35	Michael Wade & Curtis Hammond	Forward Looking Blindspots: A Report of a A-Pillar Induced Field of Obscuration and Driver Performance in a Simulated Rural Environment	Report		3	2002	
36	RECARO	Ergo Metro/Coach [Seat] Operating Instructions	Informative	Low	9	2012	Figures and descriptions of seat adjustment features.

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
37	RECARO	Correct Seating in Commercial Vehicles	Informative	Low	?	2007	Marketing information: seat features, driver health, and seat adjustment steps.
38	U.S. Department of Defense	Department of Defense, Design Criteria Standard, Human Engineering	Standard/ Certification	Moderate	1	2012	This standard establishes general human engineering criteria for design and development of military systems, equipment, and facilities.
39	U.S. Department of Transportation, Urban Mass Transportation Administration	Baseline Advanced Design Transit Coach Specifications	Standard/ Certification	High	11	1978	This document is to be used by Procuring Agencies in competitive procurement of production advanced design transit coaches under the UMTA Capital Grants program.
40	American Public Transportation Association	Standard Bus Procurement Guidelines	Standard/ Certification	High	5	2013	This document outlines a request for proposals for a negotiated bus procurement contract.
41	W. Wierwille et al.	Development of a Performance Specification for Camera/Video Imaging Systems on Heavy Vehicles (Final Report: Specifications)	Report	Moderate	7	2008	This document provides revised final performance specifications for Camera/Video Imaging Systems (C/VISs) used in heavy vehicles. The specifications are based on a combination of analyses including driver needs and human factors, current and future video technology, systems analyses, focus groups, preliminary tests, and formal on-road tests.
42	M. Reed	Intersection Kinematics: A Pilot Study of Driver Turning Behavior with Application to Pedestrian Obscuration by A-Pillars	Report	High	11	2008	A-pillar geometry from 56 vehicles was analyzed to develop representative and extreme cases of A-pillar obscuration. A new methodology was developed for quantifying plan-view obscuration in intersections during left turns.
43	M. Wade & C. Hammond	Forward Looking Blindspots: A Report of A-Pillar Induced Field of View Obstruction and Driver Performance in a Simulated Rural Environment	Report	High	3	2002	This study analyzed the relationship between the size of the forward looking blindspot (FLB) produced by vehicles' A-post (windshield frame), the speeds of two vehicles approaching an intersection at right angles, and driver behavior relative to a likely accident event based on simulation tasks in a rural scenario.
44	International Organization for Standardization	ISO 16121-1; Road Vehicles -- Ergonomic Requirements for the Driver's Workplace in Line-Service Buses, Part 1: General Description, Basic Requirements	Standard	Moderate	10	2012	Provides bus operator workstation criteria for the use and position of the seat, steering wheel, pedals, and other controls.

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
45	International Organization for Standardization	ISO 16121-2; Road Vehicles -- Ergonomic Requirements for the Driver's Workplace in Line-Service Buses, Part 2: Visibility	Standard	High	8	2011	Provides bus operator workstation criteria for positioning reference eye points and direct visibility requirements.
46	International Organization for Standardization	ISO 16121-3; Road Vehicles -- Ergonomic Requirements for the Driver's Workplace in Line-Service Buses, Part 3: Information Devices and Controls	Standard	Low	8	2011	Provides bus operator workstation criteria for positioning devices and controls.
47	International Organization for Standardization	ISO 16121-4; Road Vehicles -- Ergonomic Requirements for the Driver's Workplace in Line-Service Buses, Part 4: Cabin Environment	Standard	Low	8	2011	Provides bus operator workstation criteria for climate, ventilation, and defrosting/demisting.
48	U.S. Army Natick Soldier RD&E Center (Paquette, S.)	U.S. Army Anthropometric Survey (ANSUR II)	Presentation	Low	5	2011	Summary of data collection activity and human scans.
49	Human Solutions	Size North America	Presentation	Low	na	na	Overview of Size North America 3-D scan activity.
50	U.S. Army Natick Soldier RD&E Center (Paquette, S.)	1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics	Report	Low	9	1989	The methods and analysis for ANSUR I anthropometric survey of 1,774 men and 2,208 women sampled from the active-duty Army of June 1988.
51	U.S. Army Natick Soldier RD&E Center (Paquette, S., Gordon, C, and Bradtmiller, B.)	Anthropometric Survey (ANSUR) II Pilot Study: Methods and Summary Statistics	Report	Low	4	2009	The methods and analysis for ANSUR II Pilot anthropometric survey of 2,714 men and 602 women sampled from the Army Active Duty, Army Reserve, Army National Guard, and U.S. Coast Guard from June 2006 through September 2008.
52	J. Guan et al. (NIOSH)	U.S. Truck Driver Anthropometric Study and Multivariate Anthropometric Models for Cab Designs	Report	Low	4	2012	This study presents data from a large-scale anthropometric study of U.S. truck drivers and the multivariate anthropometric models developed for the design of next-generation truck cabs based on a collection of 35 anthropometric dimensions for 1,950 truck drivers (1,779 males and 171 females) across the continental United States.

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
53	J. Guan et al. (NIOSH)	Anthropometric Study of U.S. Truck Drivers: Methods, Summary Statistics, and Multivariate Accommodation Models	Report	Low	4	2015	Full Report: This study presents data from a large-scale anthropometric study of U.S. truck drivers and the multivariate anthropometric models developed for the design of next-generation truck cabs based on a collection of 35 anthropometric dimensions for 1,950 truck drivers (1,779 males and 171 females) across the continental United States.
54	na	Dimension 49, Eye Height Sitting	Informative	Low	na	na	NIOSH Truck Driver Survey extraction of eye height sitting dimension definition.
55	National Center for Health Statistics (CDC)	ANALYTIC AND REPORTING GUIDELINES: The Third National Health and Nutrition Examination Survey, NHANES III (1988-94)	Report	Low	10	1996	NHANES III national health survey.
56	Bucciaglia et al. (SAE)	Transit Bus Operator Work Station Design for a Diverse Population	Journal Article	Low	?	1995	The paper addresses the design of bus operator workstations to accommodate 5th percentile female to 95th percentile male. Results are provided from a jury of more than 100 participants.
57	Garrott et al. (NHTSA, SAE)	An Ergonomic Evaluation of School Bus Cross View Mirrors= Systems	Journal Article	High	?	1992	This research studied the problems and effectiveness of existing cross view school bus mirror systems. Interviews were conducted with 49 school bus drivers on perceived effectiveness of six cross view mirror systems.
58	Burger (SAE)	Evaluation of Innovative Passenger Car and Truck Rear Vision System	Journal Article	Moderate	10	1974	Evaluation of 12 innovative passenger and truck rear vision systems in on-road conditions using objective performance measures.
59	Henderson et al. (SAE)	Visibility from Motor Vehicles	Conference Proceedings	Moderate	4	1983	This paper assesses major problems associated with vehicle visibility systems, some concepts to mitigate reduced visibility, and future considerations for research. They identified relevant driver, vehicle, and environmental variables and their frequency and relationship to crashes. They reviewed and summarized previous engineering work and other research relating to visibility concerns.
60	SAE	J826 Devices for Use in Defining and Measuring Vehicle Seating Accommodation	Best Practice	High	11	2008	Discusses standards for obtaining seating dimensions using an H-point machine. Describes both two-dimensional and three-dimensional HPMs.

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
61	SAE	J833 Human Physical Dimensions	Best Practice	?	6	1962	Defines worldwide human dimensions to be used in construction, industrial, and agriculture. It notes that this standard was canceled in May 2003.
62	SAE	J941 Motor Vehicle Drivers' Eye Locations	Best Practice	High	3	2010	This standard describes statistical representation of driver eye locations which are used to facilitate design and evaluation of vision in motor vehicles.
63	SAE	J1050 Describing and Measuring the Driver's Field of View	Best Practice	High	2	2009	Establishes methods for measuring the driver's field of view. Describes three methods for the measure of direct and indirect FOVs and obstructions within the FOV. Refers to J941.
64	SAE	J1052 Motor Vehicle Driver and Passenger Head Position	Best Practice	Low	9	2010	Describes procedures for locating contours in vehicles and head position contours. Most useful in establishing head space accommodations.
65	SAE	J1100 Motor Vehicle Dimensions	Best Practice	High	11	2009	Defines a set of measurements and procedures for motor vehicle dimensions. Primarily designed to be used in a design environment such as CAD. All dimensions are with vehicle at curb weight and are measured normal to the three-dimensional reference system.
66	SAE	J1163 Determining Seat Index Point	Best Practice	Low	5	2012	Procedure and method for determining the seat index point.
67	SAE	J1516 Accommodation Tool Reference Point for Class B Vehicles	Best Practice	High	10	2011	Procedures for obtaining accelerator heel point and accommodation tool reference point. This point is on the seat H-point travel path which is used for locating various driver workspace accommodation tools in Class B vehicles. Applicable to both J826 and J4002.
68	SAE	J1517 Driver Selected Seat Position for Class B Vehicles - Seat Track Length and SgRP	Best Practice	Low	10	2011	Establishes procedure to locate driver seat tracks, seat track length, and define the SgRP in Class B vehicles. Three equations describe where drivers position horizontally adjustable seats depending on expected % of males to females. Equations can also be used to estimate level of accommodation of horizontally adjustable seat track. Applicable to J826 and J4002.
69	SAE	J1521 Truck Driver Shin-Knee Position for Clutch and Accelerator	Best Practice	Low	2	2009	Describes two-dimensional 95th percentile truck driver side view for seated shin-knee contours for accelerator operating leg and clutch operating leg horizontal adjustable seats.
70	SAE	J1522 Truck Driver Stomach Position	Best Practice	Low	2	2009	Describes two-dimensional 95th percentile truck driver side view for seated stomach contours for adjustable seats.

No.	Author/Org	Title	Type	Relevance	Month	Year	Summary
71	Manary et al. (UMTRI)	Development of an Improved Driver Eye Position Model	Conference Proceedings	Moderate	2	1998	Study conducted by UMTRI to improve J941, which describes eyellipses. The report suggests seat height, steering-wheel position, and seat-track rise are more accurate predictors of eyellipses.
72	Reinach et al.	Driver-Vehicle Interface Requirements for a Transit Bus Collision Avoidance System	Conference Proceedings	High	3	2001	Report details bus operator workstation environment, including windshield, mirror, etc., and the blind spots created. Also describes transit bus exterior environment. Project conducted at Massachusetts Bay Transit Authority. Overall, the project was assessing the needs of the DVI for crash warning systems.
73	Matthew Reed (UMTRI)	Development of a New Eyellipse and Seating Accommodation Model for Trucks and Buses	Report	Low	11	2005	Statistical models for creating new eyellipses and include effects of steering wheel position. Similar to J1517 but also includes predictions of vertical seat adjustment. Suggests this is improved over J941 at the time.
74	United Nations Economic Commission for Europe	Uniform Provisions Concerning the Approval of Devices for Indirect Vision and of Motor Vehicles with Regard to the Installation of These Devices	Standard	High	10	2011	Compulsory and optional devices for indirect or rearview vision, including ground zones that must be visible to the driver based on the application of mirrors or other vision support systems.

Appendix B Transit and Motorcoach Bus Scans

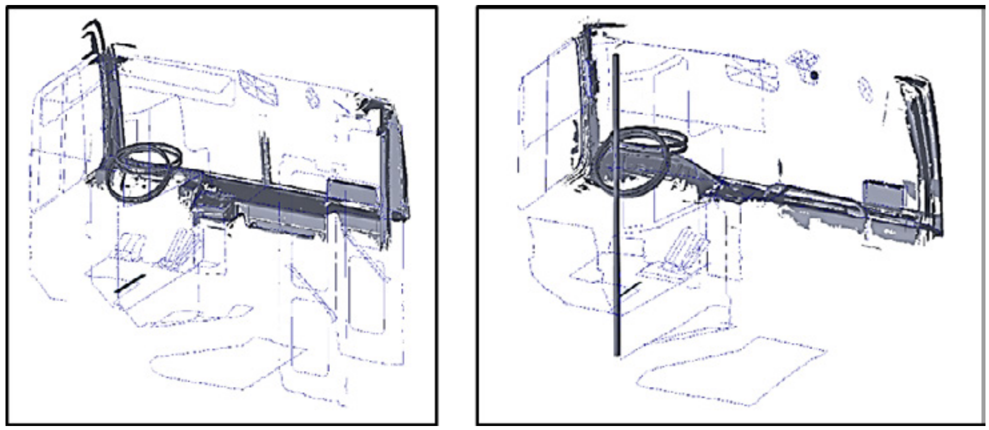


Figure B-1 *Bus interior scans: Orion (l) and New Flyer (r)*

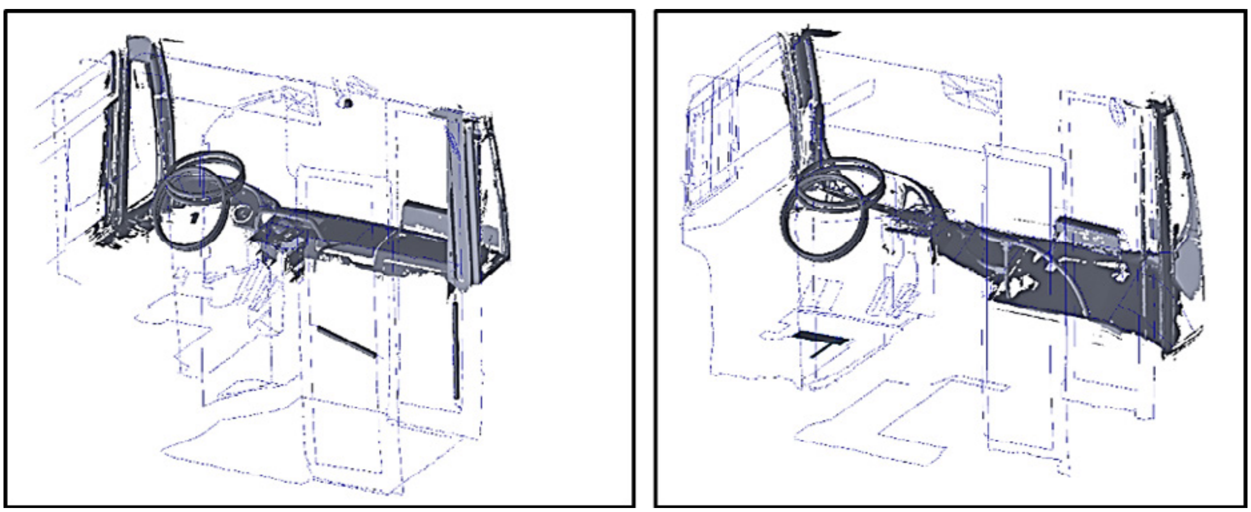


Figure B-2 *Bus interior scans: Nova (l) and Proterra (r)*

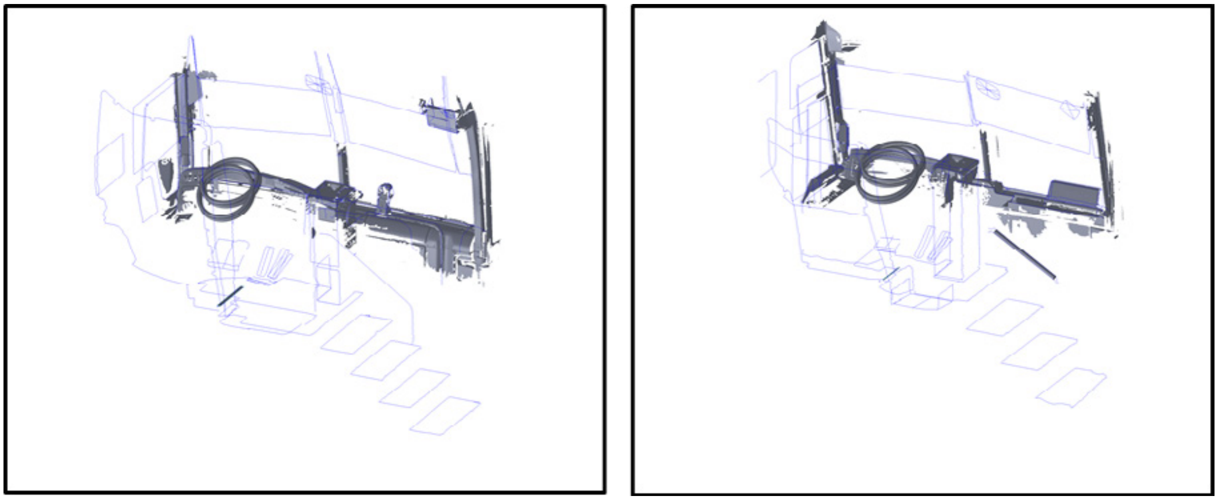


Figure B-3 *Motorcoach bus interior scans: Prevost (l) and MCI (r)*

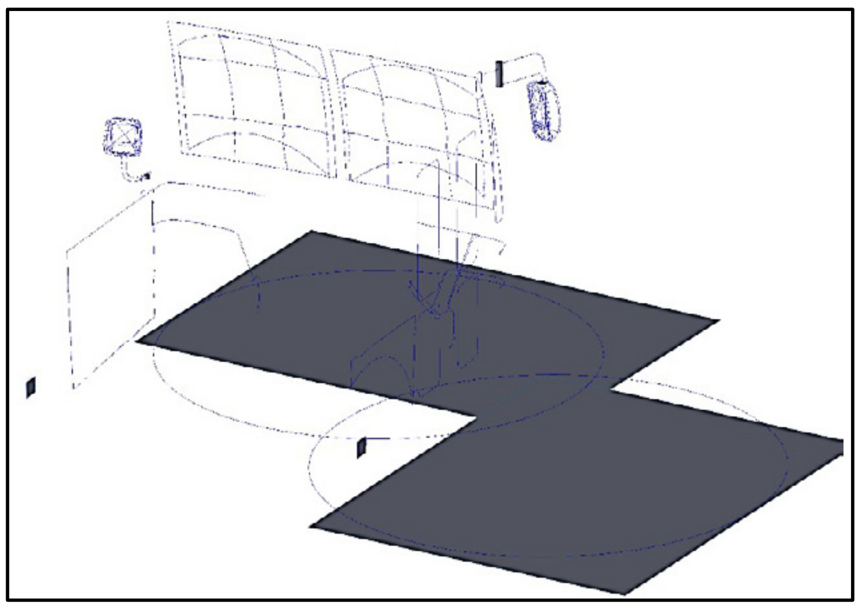


Figure B-4 *Orion exterior scan*

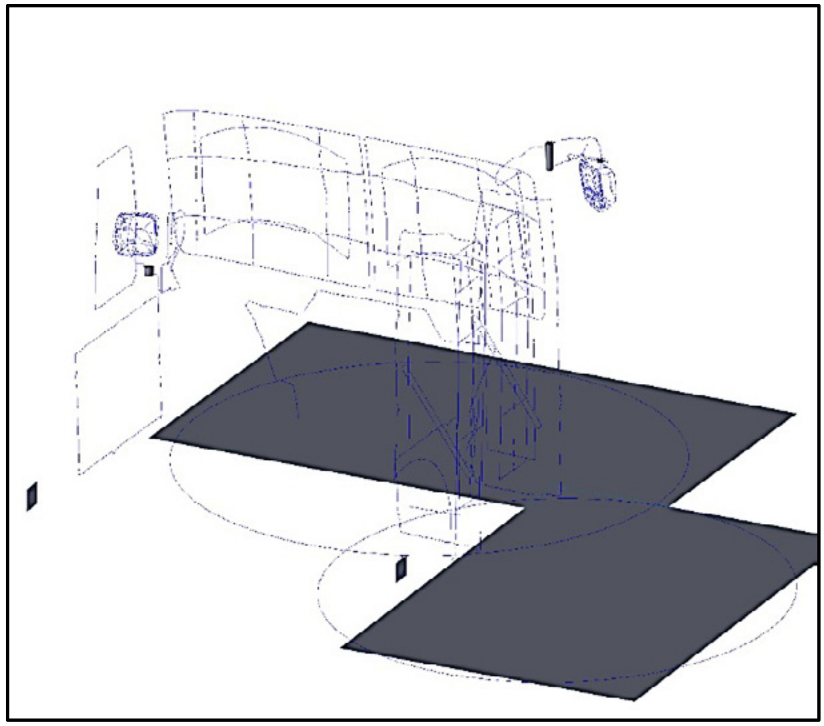


Figure B-5 *New Flyer exterior scan*

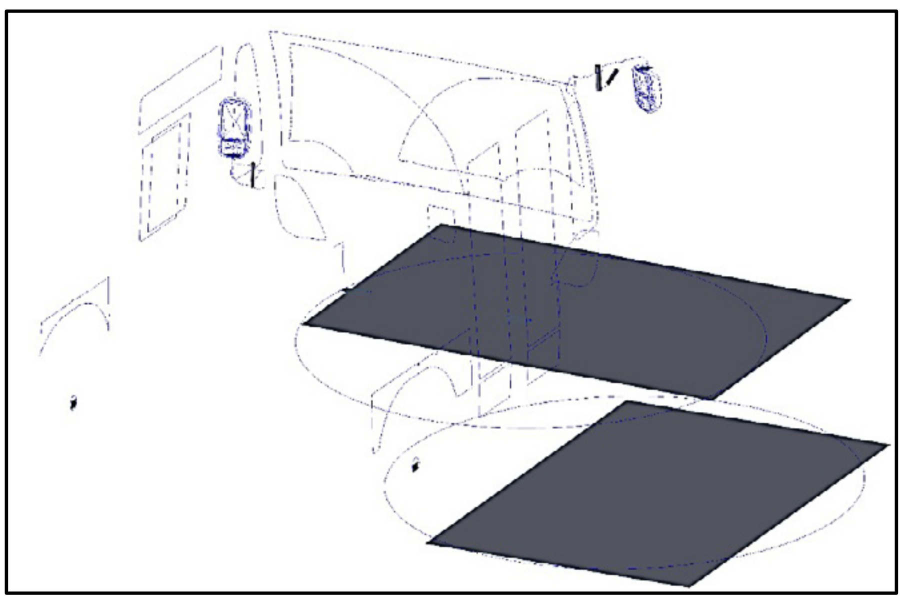


Figure B-6 *Nova exterior scan*

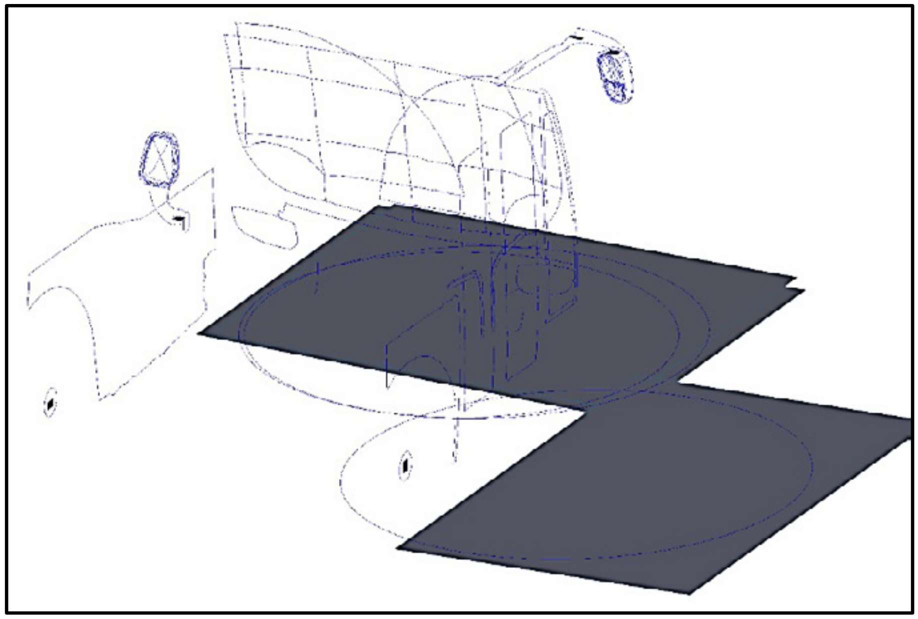


Figure B-7 *Proterra exterior scan*

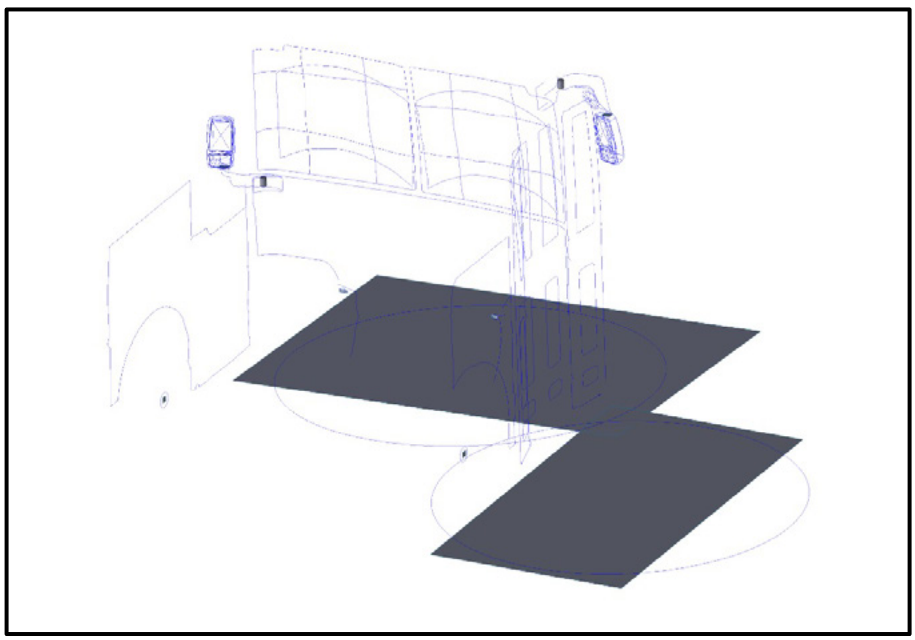


Figure B-8 *Prevost Motorcoach exterior scan*

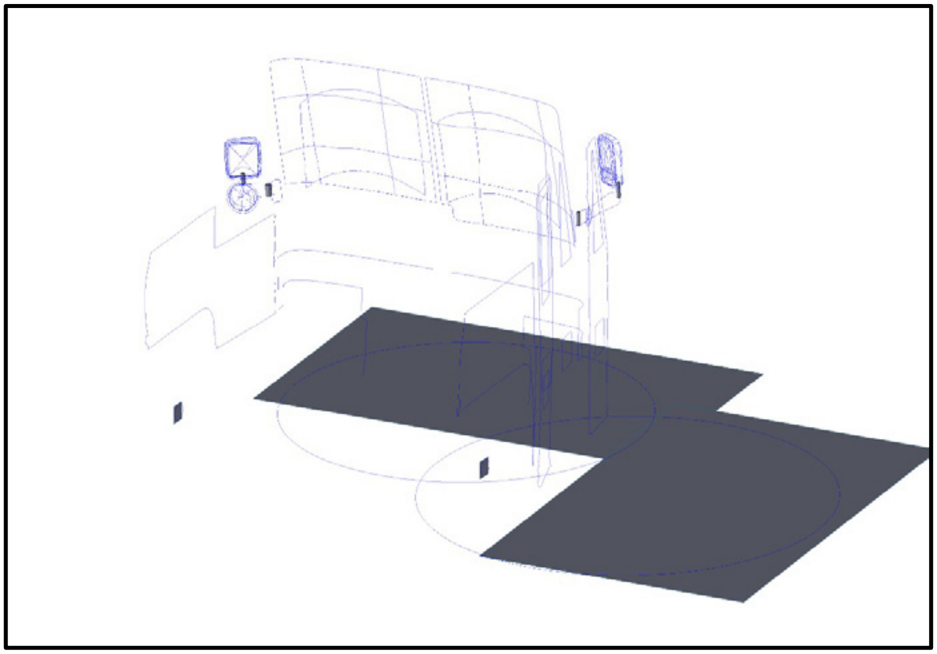


Figure B-9 *MCI Motorcoach exterior scan*

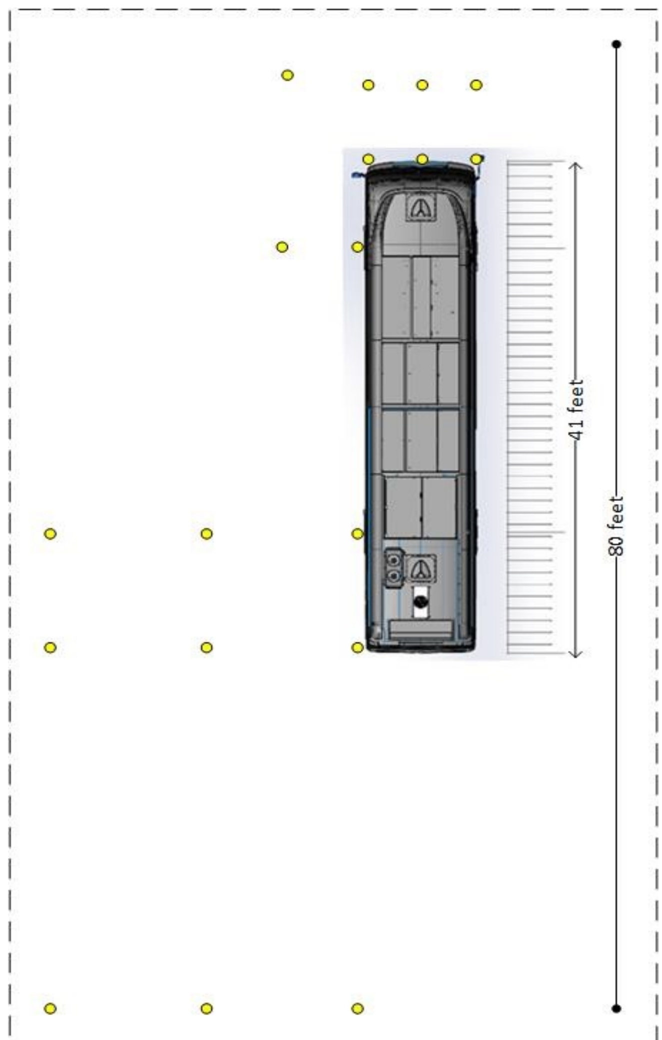
Appendix C

Bus Operator Mirror Evaluation Questionnaire

Questions on Mirror (1): ☐ A ☐ B ☐ C

1. Please study this diagram provided below. Note that it includes cylinders placed around the bus at positions that may be applicable to bus dimensions (e.g., axles) and locations where roadway objects, vehicles, or pedestrians may be present.

   - Mark an "E" along the grid wherever you see a cylinder directly with your eyes.
   - Mark an "M" along the grid wherever you see a cylinder reflected in the mirror.
   - Additionally, also mark each cylinder viewed with the mirror with a "P" if you see it with the primary mirror or an "S" if you see it with the secondary mirror.



2. How would you rate the rearward street-side field of view provided by mirror? Please circle one.

1	2	3	4	5
Very small	Small	Typical	Large	Very large

3. How would you rate the quality of the object shape and size when viewed in mirror? Please circle one.

1	2	3	4	5
Very poor	Poor	Acceptable	Good	Very good

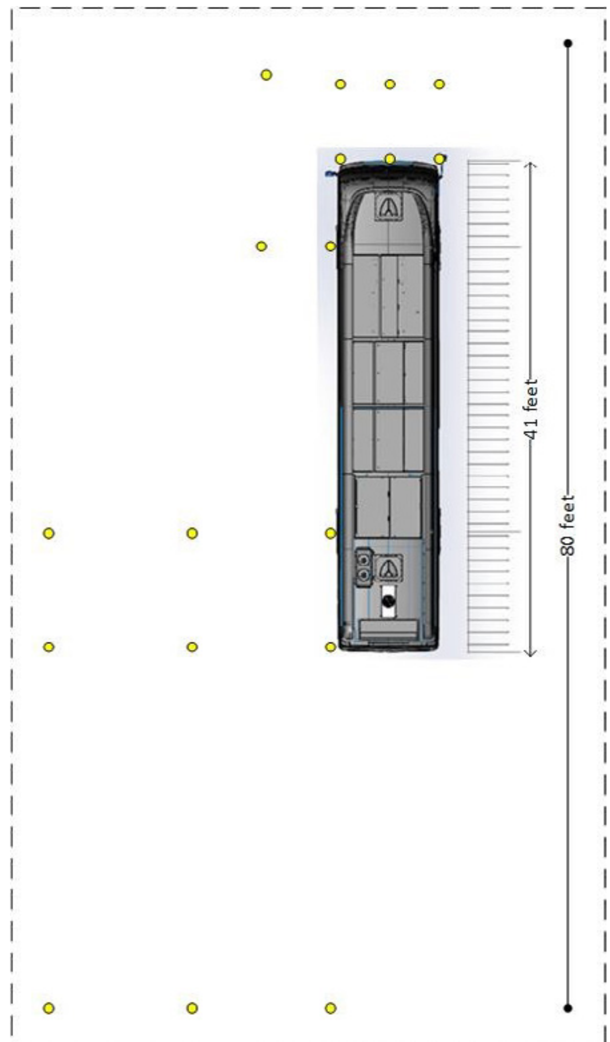
4. How would you rate the forward view obstruction of mirror? Please circle one.

1	2	3	4	5
Very large	Large	Typical	Small	None

5. Would you be willing to drive your daily route with mirror? ☐ Yes ☐ No
   Please explain: __________

Questions on Mirror (2): ☐ A ☐ B ☐ C

6. Please study this diagram provided below. Note that it includes cylinders placed around the bus at positions that may be applicable to bus dimensions (e.g., axles) and locations where roadway objects, vehicles, or pedestrians may be present.
   - Mark an "E" along the grid wherever you see a cylinder directly with your eyes.
   - Mark an "M" along the grid wherever you see a cylinder reflected in the mirror.
   - Additionally, also mark each cylinder viewed with the mirror with a "P" if you see it with the primary mirror or an "S" if you see it with the secondary mirror.



7. How would you rate the rearward street-side field of view provided by mirror? Please circle one.

1	2	3	4	5
Very small	Small	Typical	Large	Very large

8. How would you rate the quality of the object shape and size when viewed in mirror? Please circle one.

1	2	3	4	5
Very poor	Poor	Acceptable	Good	Very good

9. How would you rate the forward view obstruction of mirror? Please circle one.

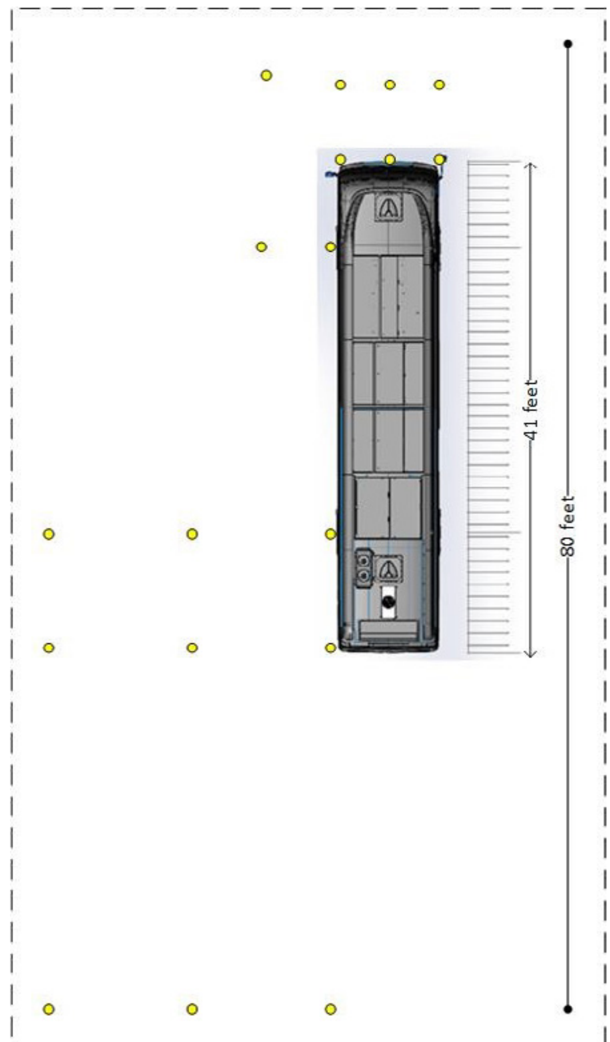
1	2	3	4	5
Very large	Large	Typical	Small	None

10. Would you be willing to drive your daily route with mirror? ☐ Yes ☐ No
    Please explain: __________

Questions on Mirror (3): ☐ A ☐ B ☐ C

11. Please study this diagram provided below. Note that it includes cylinders placed around the bus at positions that may be applicable to bus dimensions (e.g., axles) and locations where roadway objects, vehicles, or pedestrians may be present.

    - Mark an "E" along the grid wherever you see a cylinder directly with your eyes.
    - Mark an "M" along the grid wherever you see a cylinder reflected in the mirror.
    - Additionally, also mark each cylinder viewed with the mirror with a "P" if you see it with the primary mirror or an "S" if you see it with the secondary mirror.



12. How would you rate the rearward street-side field of view provided by mirror? Please circle one.

1	2	3	4	5
Very small	Small	Typical	Large	Very large

13. How would you rate the quality of the object shape and size when viewed in mirror? Please circle one.

1	2	3	4	5
Very poor	Poor	Acceptable	Good	Very good

14. How would you rate the forward view obstruction of mirror? Please circle one.

1	2	3	4	5
Very large	Large	Typical	Small	None

15. Would you be willing to drive your daily route with mirror? ☐ Yes ☐ No
    Please explain: __________

Post Evaluation Questions

16. Which mirror would provide the best view of the street to efficiently maneuver around roadway objects and heavy **vehicle** traffic on the streets? Please check one.

    ☐ A ☐ B ☐ C

17. Which mirror would provide the best view of the street to safely maneuver around roadway objects and heavy **pedestrian** traffic on the streets? Please check one.

    ☐ A ☐ B ☐ C

Appendix D System Effectiveness Mirror Percentage Metrics

Short Female Visibility Percentages of Current Production, Flat and Convex Combination, Semi-curved High Mount, and Semi-curved Low Mount

	Body Obstruction	Production			Flat and Convex Combination			Semi-curved High			Semi-curved Low		
		Mirror Obstruction	*Total Obstruction*	*Mirror View*	*Mirror Obstruction*	*Total Obstruction*	*Mirror View*	*Mirror Obstruction*	*Total Obstruction*	*Mirror View*	*Mirror Obstruction*	*Total Obstruction*	*Mirror View*
FFL	11.44%	2.54%	13.97%	0.00%	3.71%	15.14%	0.00%	0.00%	11.44%	0.00%	2.21%	13.64%	0.00%
FL	16.90%	9.09%	25.99%	0.00%	10.20%	27.10%	0.00%	0.00%	16.90%	0.00%	8.33%	25.23%	0.00%
FC	29.21%	0.00%	29.21%	0.00%	0.00%	29.21%	0.00%	0.00%	29.21%	0.00%	0.00%	29.21%	0.00%
FR	25.55%	0.00%	25.55%	0.00%	0.00%	25.55%	0.00%	0.00%	25.55%	0.00%	0.00%	25.55%	0.00%
FFR	25.88%	0.00%	25.88%	0.00%	0.00%	25.88%	0.00%	0.00%	25.88%	0.00%	0.00%	25.88%	0.00%
FBL	63.01%	0.00%	63.01%	0.00%	0.00%	63.01%	63.86%	0.00%	63.01%	31.16%	0.00%	63.01%	30.17%
BL	89.69%	0.00%	89.69%	13.10%	0.00%	89.69%	88.83%	0.00%	89.69%	81.16%	0.00%	89.69%	81.36%
BR	100.00%	0.00%	100.00%	54.21%	0.00%	100.00%	54.21%	0.00%	100.00%	54.21%	0.00%	100.00%	54.21%
FBR	99.14%	0.00%	99.14%	36.65%	0.00%	99.14%	36.65%	0.00%	99.14%	36.65%	0.00%	99.14%	36.65%
FRL	100.00%	0.00%	100.00%	0.18%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%
RL	100.00%	0.00%	100.00%	78.79%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%
RC	100.00%	0.00%	100.00%	34.80%	0.00%	100.00%	34.80%	0.00%	100.00%	31.72%	0.00%	100.00%	31.37%
RR	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%
FRR	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%

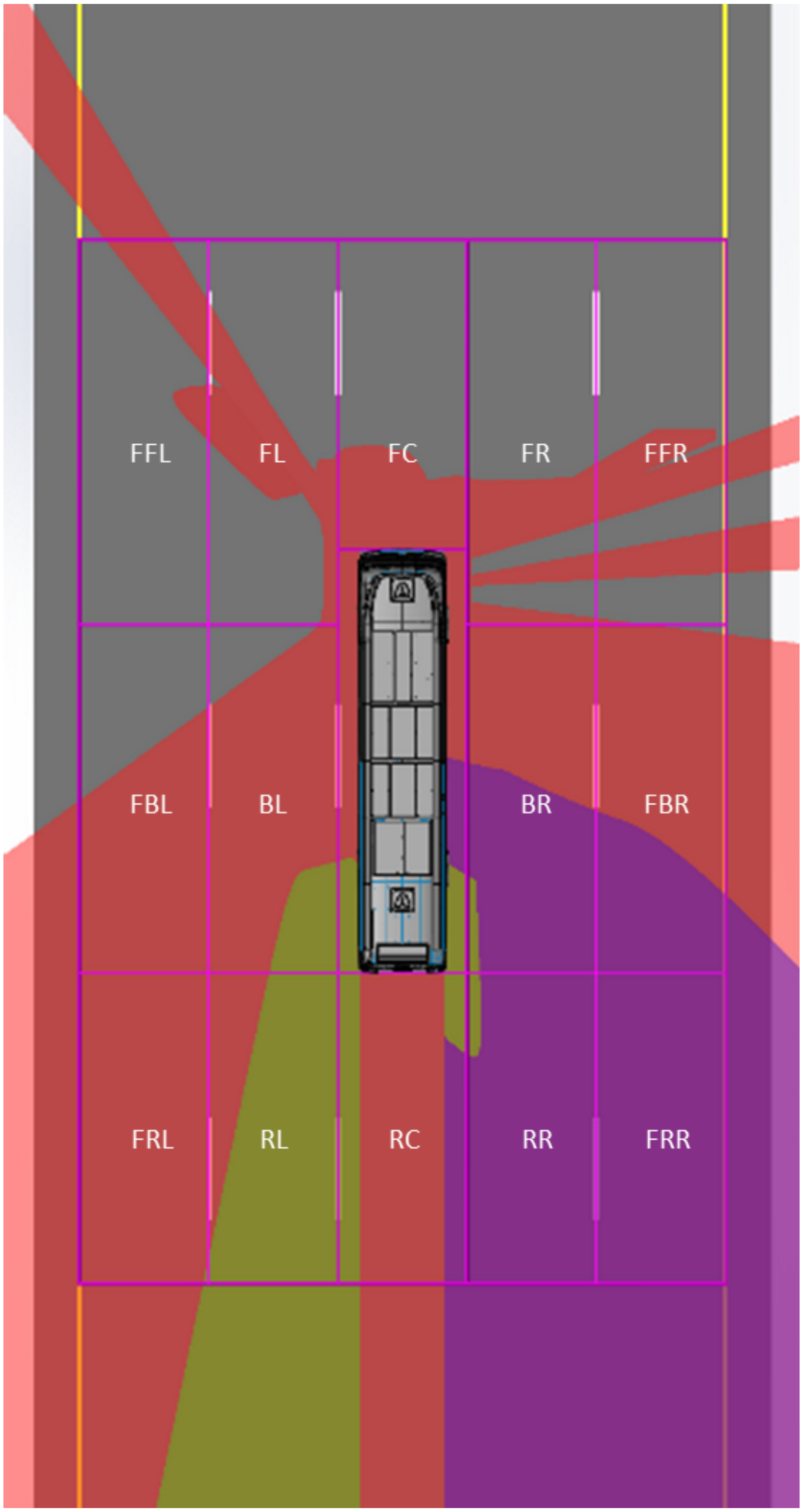
Section Label Legend:
Front Axle Forward: Far-Front Left (FFL), Front Left (FL), Front Center (FC), Front Right (FR), Far-Front Right (FFR)
Front Axle to Rear Bumper: Far-Body Left (FBL), Body Left (BL), [no label center bus body], Body Right (BR), Far-Body Right (FBR)
Rear Bumper Rearward: Far-Rear Left (FRL), Rear Left (RL), Rear Center (RC), Rear Right (RR), Far-Rear Right (FRR)

Tall Male Visibility Percentages of Current Production, Flat and Convex Combination, Semi-curved High Mount, and Semi-curved Low Mount

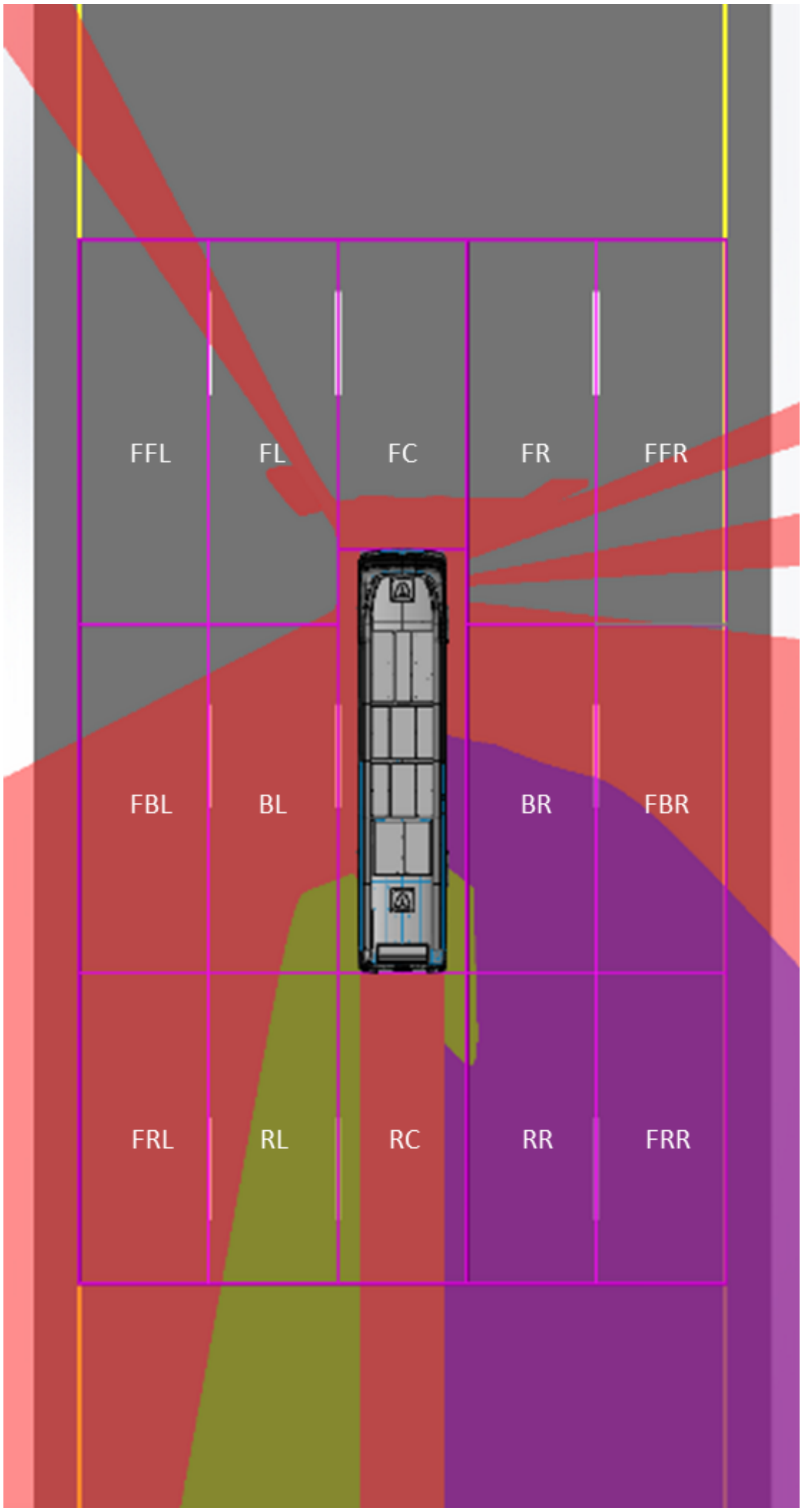
	Body Obstruction	Production			Flat and Convex Combination			Semi-curved High			Semi-curved Low		
		Mirror Obstruction	*Total Obstruction*	*Mirror View*	*Mirror Obstruction*	*Total Obstruction*	*Mirror View*	*Mirror Obstruction*	*Total Obstruction*	*Mirror View*	*Mirror Obstruction*	*Total Obstruction*	*Mirror View*
FFL	6.90%	0.00%	6.90%	0.00%	0.00%	6.90%	0.00%	0.00%	6.90%	0.00%	0.00%	6.90%	0.00%
FL	13.08%	3.05%	16.12%	0.00%	3.31%	16.39%	0.00%	0.00%	13.08%	0.00%	2.47%	15.55%	0.00%
FC	16.90%	0.00%	16.90%	0.00%	0.00%	16.90%	0.00%	0.00%	16.90%	0.00%	0.00%	16.90%	0.00%
FR	21.12%	0.00%	21.12%	0.00%	0.00%	21.12%	0.00%	0.00%	21.12%	0.00%	0.00%	21.12%	0.00%
FFR	17.50%	0.00%	17.50%	0.00%	0.00%	17.50%	0.00%	0.00%	17.50%	0.00%	0.00%	17.50%	0.00%
FBL	76.44%	0.00%	76.44%	0.00%	0.00%	76.44%	61.27%	0.00%	76.44%	22.18%	0.00%	76.44%	18.56%
BL	94.66%	0.00%	94.66%	9.21%	0.00%	94.66%	87.74%	0.00%	94.66%	76.11%	0.00%	94.66%	76.73%
BR	100.00%	0.00%	100.00%	61.64%	0.00%	100.00%	61.64%	0.00%	100.00%	61.64%	0.00%	100.00%	61.64%
FBR	99.63%	0.00%	99.63%	42.35%	0.00%	99.63%	42.35%	0.00%	99.63%	42.35%	0.00%	99.63%	42.35%
FRL	100.00%	0.00%	100.00%	0.00%	0.00%	100.00%	100.00%	0.00%	100.00%	98.96%	0.00%	100.00%	98.03%
RL	100.00%	0.00%	100.00%	67.75%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%
RC	100.00%	0.00%	100.00%	34.80%	0.00%	100.00%	34.80%	0.00%	100.00%	34.80%	0.00%	100.00%	34.80%
RR	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%
FRR	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%	0.00%	100.00%	100.00%

Section Label Legend:
Front Axle/Forward: Far-Front Left (FFL), Front Left (FL), Front Center (FC), Front Right (FR), Far-Front Right (FFR)
Front Axle to Rear Bumper: Far-Body Left (FBL), Body Left (BL), [no label center bus body], Body Right (BR), Far-Body Right (FBR)
Rear Bumper/Rearward: Far-Rear Left (FRL), Rear Left (RL), Rear Center (RC), Rear Right (RR), Far-Rear Right (FRR)

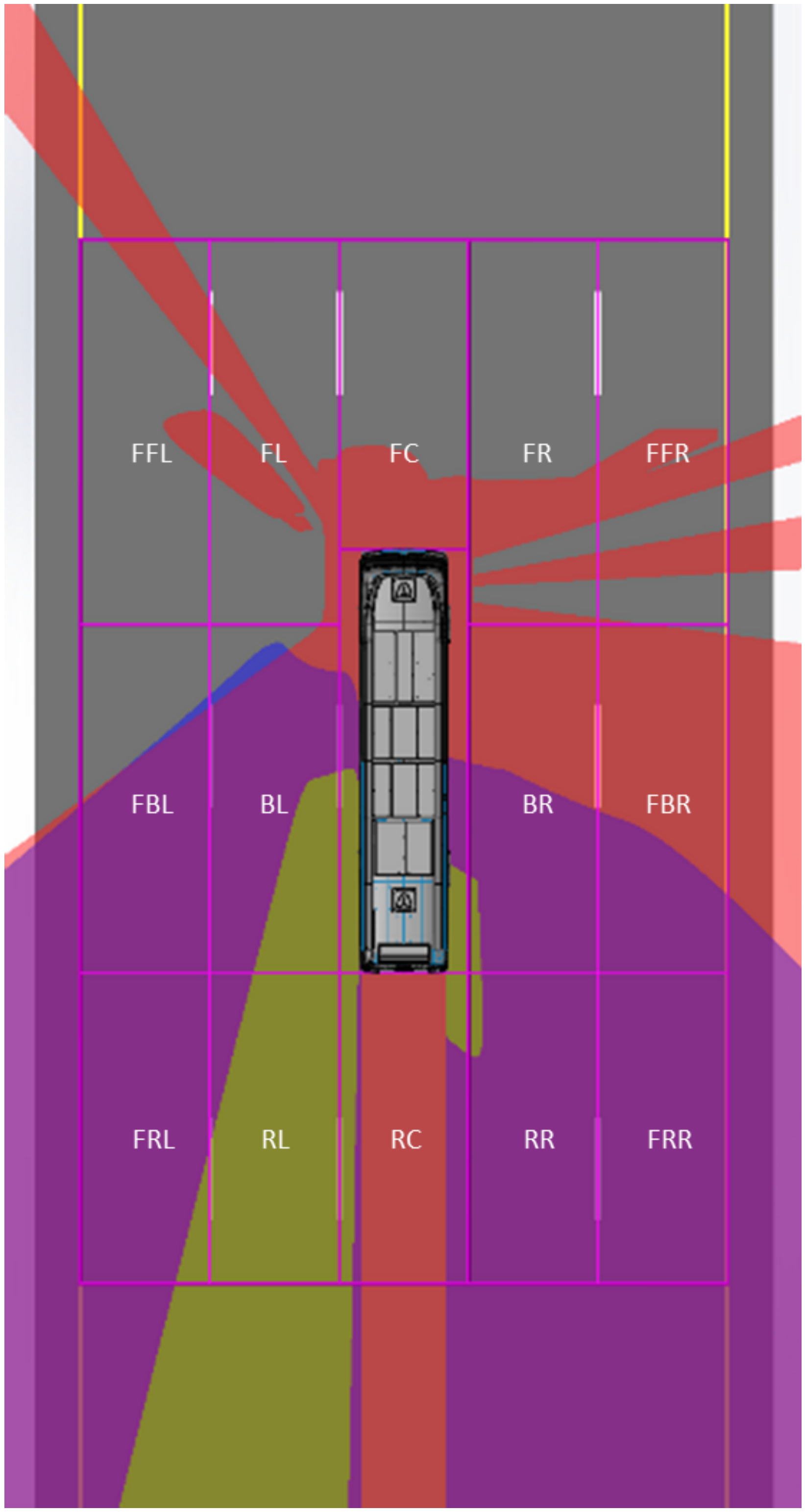
Short Female, Production Mirror



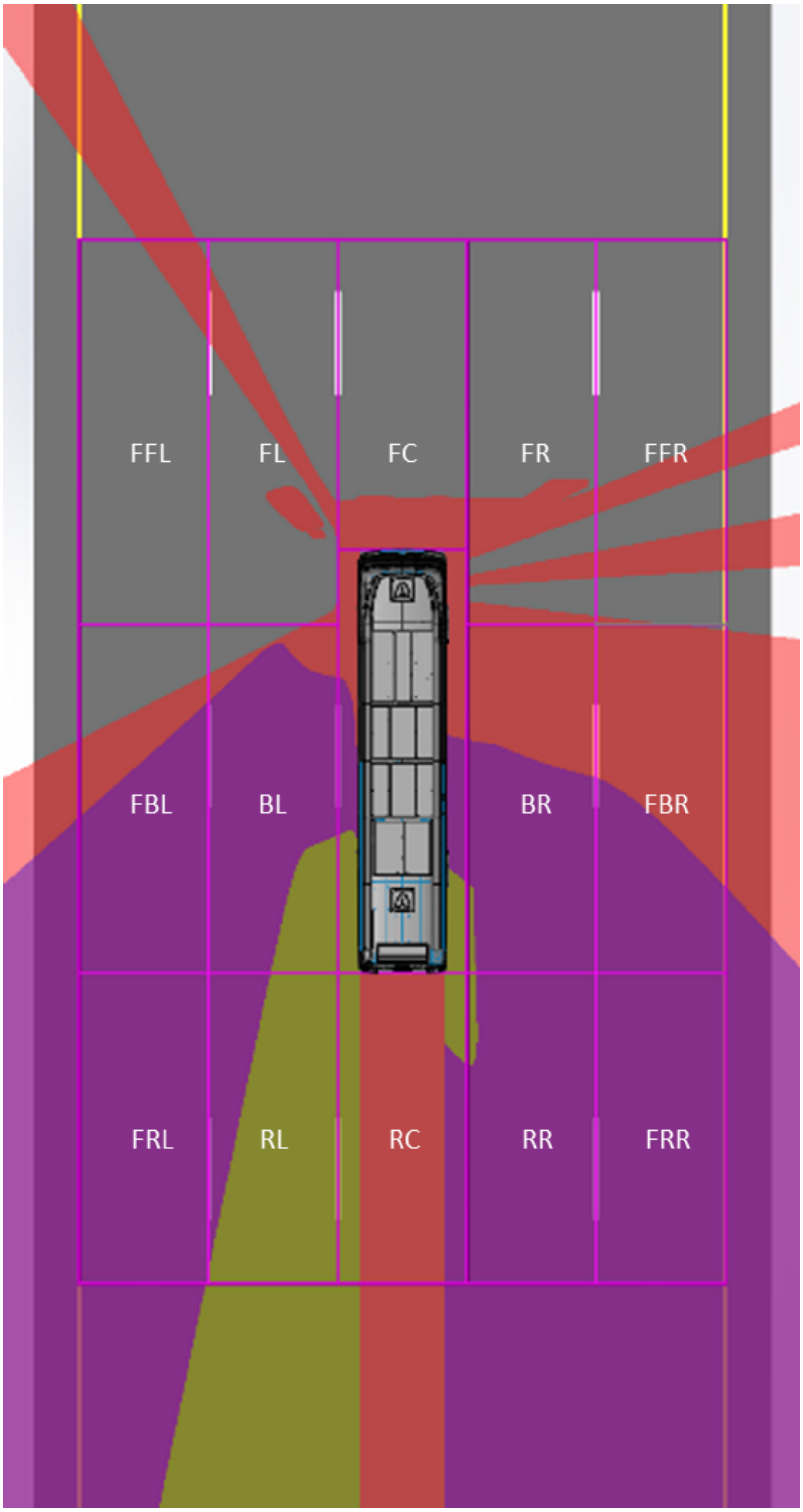
Tall Male, Production Mirror



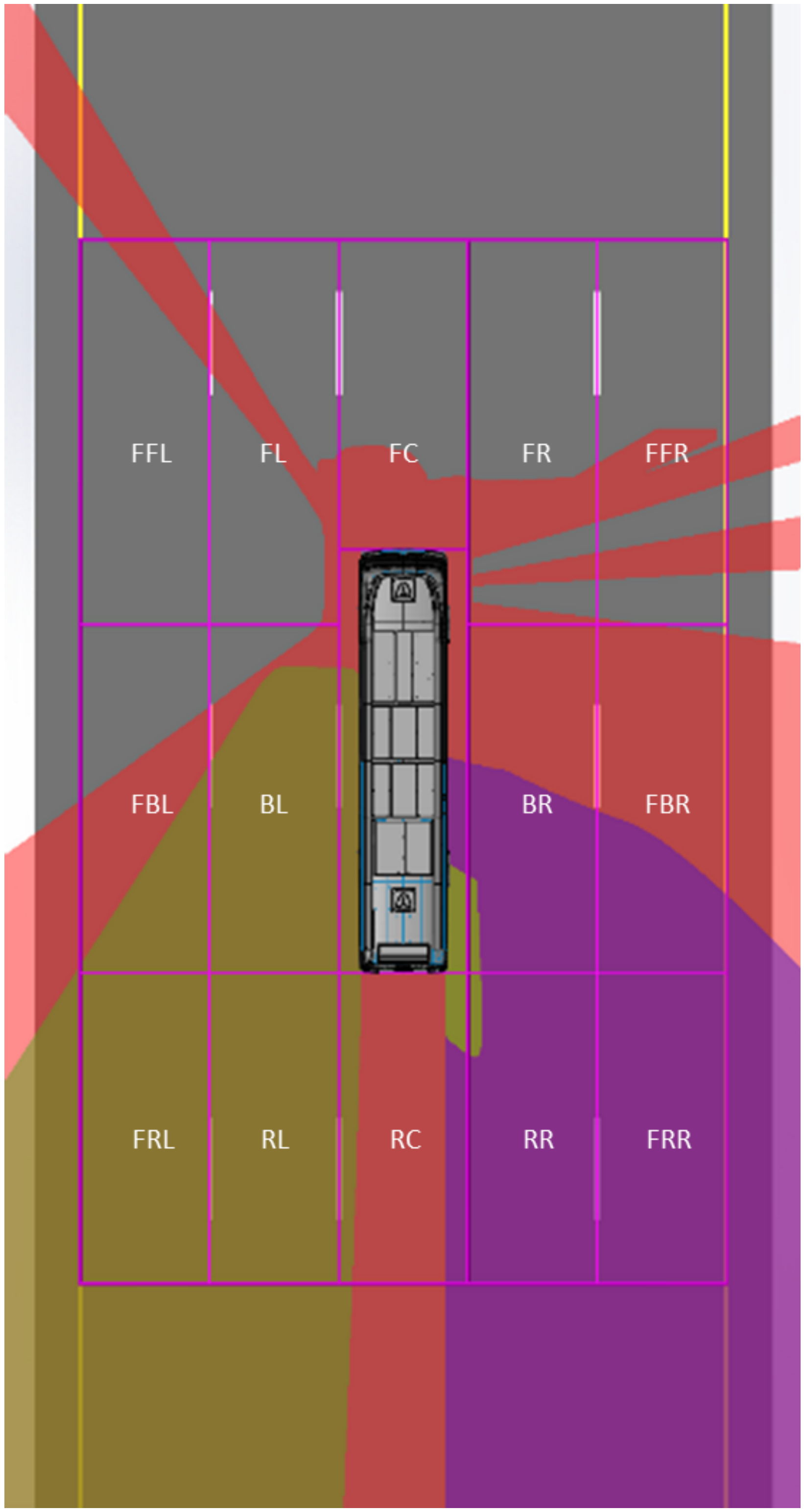
Short Female, Flat and Convex Mirrors



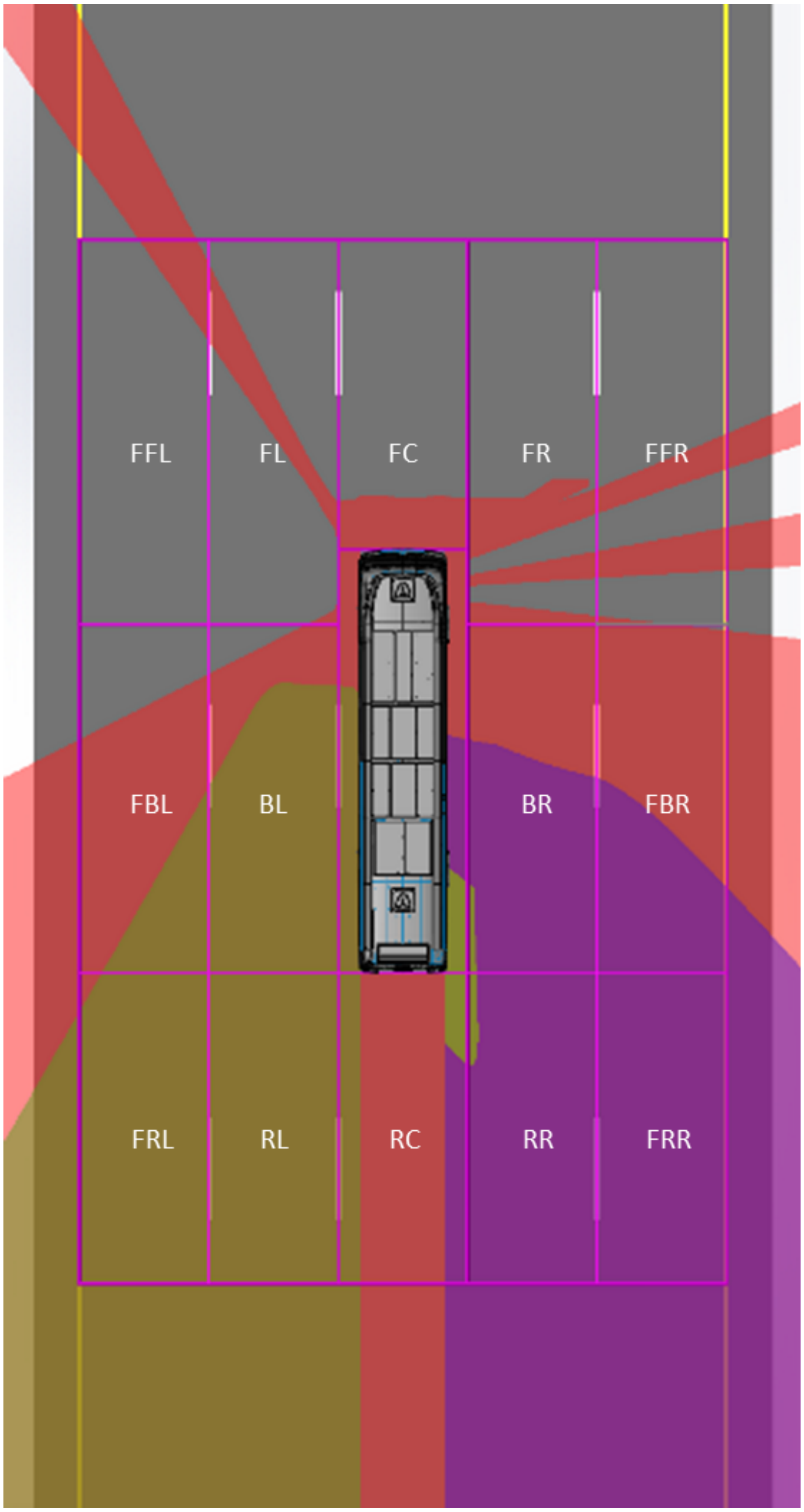
Tall Male, Flat and Convex Mirrors



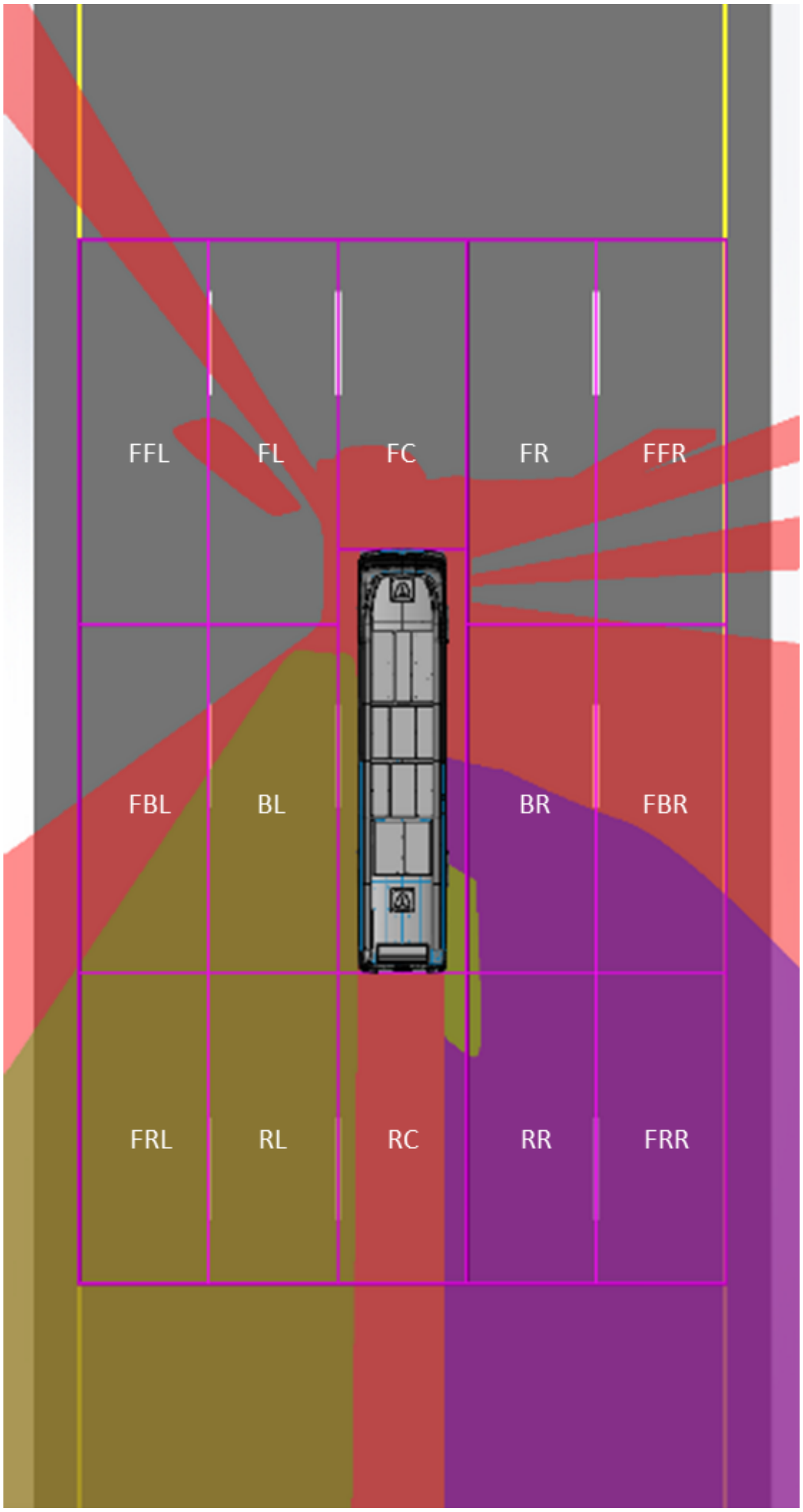
Short Female, Semi-curved High Mount



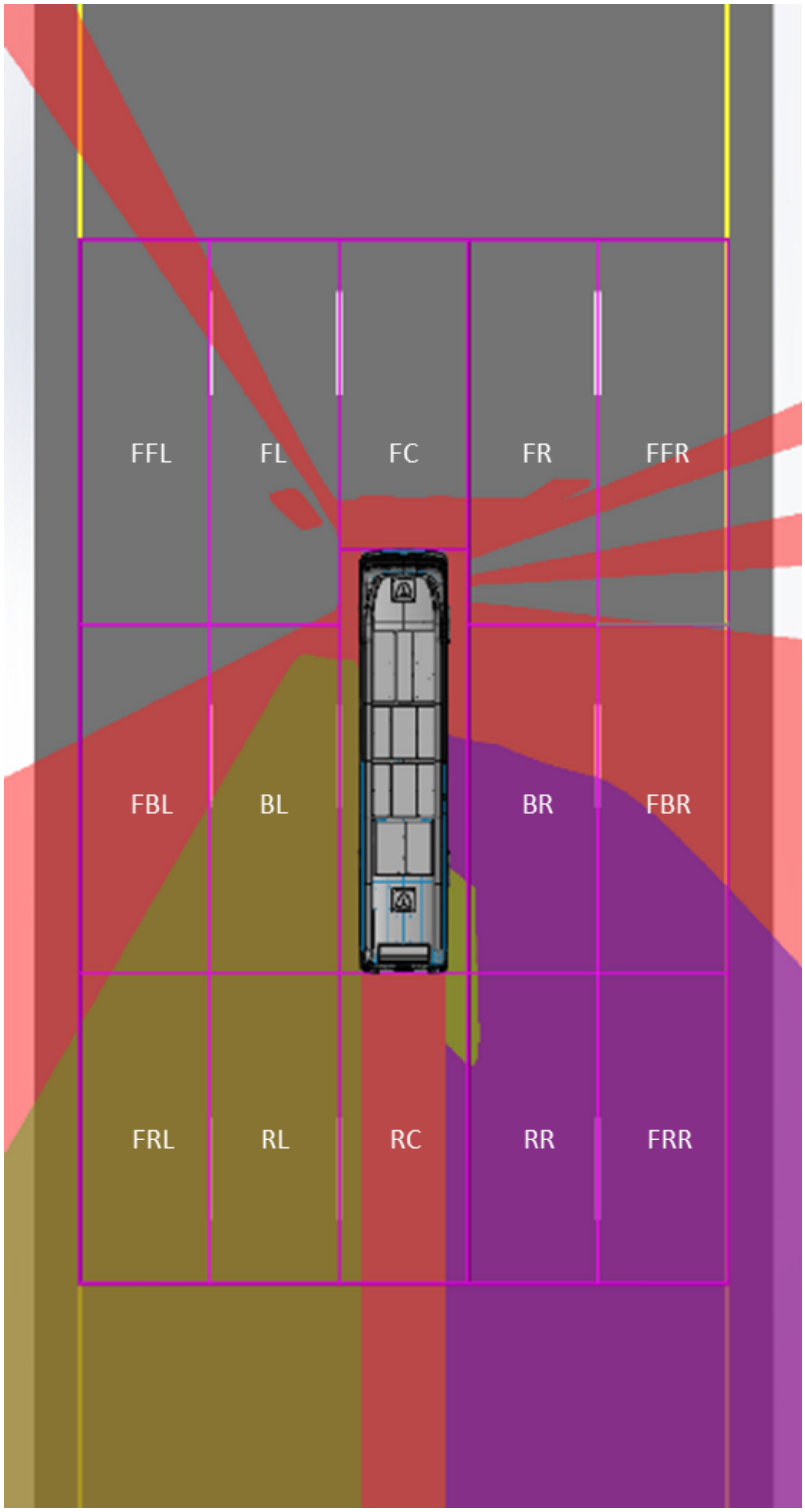
Tall Male, Semi-curved High Mount



Short Female, Semi-curved Low Mount



Tall Male, Semi-curved Low Mount



Appendix E Pilot Test 1 Bus Operator Feedback

P#	Q5 Open Ended Comments
1	The mirror was okay.
2	I just like the old ones.
3	While driving the bus, it gives you an outer view from the left side without leaning into mirror while you're driving.
4	Hard to get use to the split screen.
5	I feel the mirror is not helpful; I prefer to lean into the mirror.
6	The view is not wide enough; can't see approaching vehicles accurately.
7	No comments.
8	It’s all negative, it’s useless.
9	The convex mirror should be on the bottom just like the curb-side mirror. The current mirror test driven is a hazard the way it’s designed.
10	Totally distracted while driving.
11	It is hazardous and unsafe driving with mirrors like that.
12	It is not as adaptable like the old convex. Needs more work on improving the shape and placement - the mirror sucks. Needs more improvement.
13	No comments.

Appendix F

Pilot Test 2 Bus Operator Feedback

P#	Q5 Open Ended Comments
1	Wider view of left side huge plus.
2	No comments.
3	View is good, saw the entire left side to the rear bumper.
4	The mirror needs to be able to adjust (body itself), the mirror glass alone is not enough.
5	No comments.
6	Mirror arm goes in, but we can't turn the housing that holds the mirror; the mirror arm is too far out.
7	Would prefer motorized.
8	Very good experience.
9	It’s good.
10	I like it. Better view, less blind spot.
11	No comments.
12	No comments.
13	The mirror, it’s hard to see the wheel to judge how close you are to things.
14	No problems at all.
15	No comments.
16	Good view.
17	I like this mirror; you see a lot.
18	Would be willing to drive; view looks a little like a convex mirror.
19	Great mirror, would recommend using it.
20	Much better.
21	I see all of it very good.

Appendix G Field Demonstration Survey Questionnaire

Title of Project: Transit Bus Mirror Configuration Safety Research & Development

IRB#: 20-221

Bus Operator Acknowledgement: By completing this research study survey, you confirm that you are a current bus operator with New York City Transit and have driven this bus, which is equipped with a prototype street-side (driver's side) mirror or your current flat street-side mirror. In addition, you imply your voluntary consent to participate in this survey. All surveys are de-identified and completely confidential. The researchers will use your ID number to track how your opinion changes over time and to compare to demographics among your age group and years of experience. All survey data including opinions will remain confidential. This survey is optional and in no way will affect your employment for completion or non-completion. However, participating in these surveys and providing valuable input will assist us in assessing new potential mirror designs that may improve the safety of bus operators, riders, pedestrians, bicyclists, and other motorists. Additionally, your input will help inform mirror design guidelines for the Federal Transit Administration as well as state and local transit agencies.

Instructions: Please fill out both sides of this survey before you clock out at the end of your shift. In the following questions, you are being asked to describe your experiences only with the street-side (driver's side) mirror installed on this bus. Answer each question as accurately as possible regarding your experiences with this mirror. Please take this survey at least once a week when operating this bus or another bus with this type of mirror. You may choose to take it more often as needed to report your experience and opinion.

Date: __________ Bus #: __________ PASS #: __________ Route #: __________

1. How many days have you driven a bus with this type of **street-side** mirror set since the last time you filled out this questionnaire? (if first time write "0") _________days

2. Is the street-side mirror assembly functional today, meaning it is <u>**not**</u> damaged?

   ☐ Yes

   ☐ No   If no, please explain what is wrong: __________

3. Does the street-side mirror assembly adjust to your preferred viewing position?

☐ Yes

☐ No If no, please explain what is wrong: __________

4. How would you rate the size of the view that you can see reflected in the street-side mirror? Please circle one.

1	2	3	4	5
Very small	Small	Typical	Large	Very large

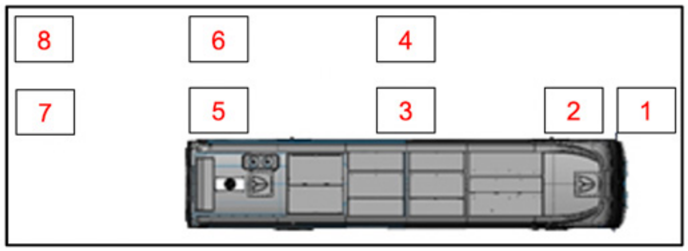
5. How would you rate the quality of the shape and size of objects, vehicles, pedestrians, and bicyclists when viewed in the street-side mirror¬? Please circle one.

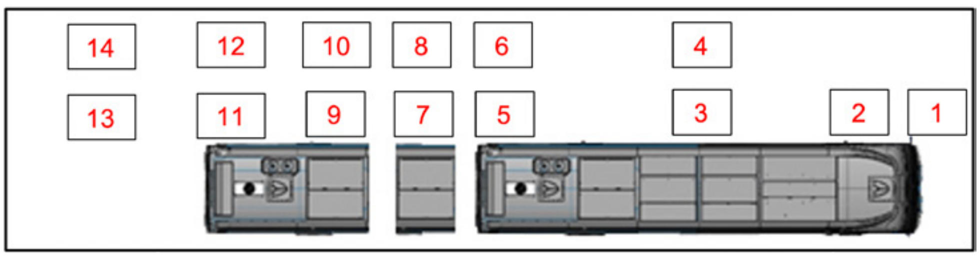
1	2	3	4	5
Very poor	Poor	Acceptable	Good	Very good

6. How would you rate the forward view obstruction caused by the street-side mirror? Please circle one.

1	2	3	4	5
Very large	Large	Typical	Small	None

7. Please describe any positive or negative experiences seeing objects, vehicles, pedestrians, or bicyclists in recent days while driving this bus or another bus with this mirror set. In addition to comments, please use the diagram below and circle the numbers/zones where you experienced this positive or negative event. ____________





8. Would you be willing to drive your daily route with this mirror on a permanent basis?

☐ Yes ☐ No

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