U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

DOT HS 812 652 May 2019

Human Factors for Connected Vehicles Transit Bus Research

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Suggested APA Format Citation:

Graving, J. L.; Bacon-Abdelmoteleb, P.; & Campbell, J. L. (2019, May). *Human factors for connected vehicles transit bus research* (Report No. DOT HS 812 652). Washington, DC: National Highway Traffic Safety Administration.

Technical Report Documentation Page

1. Report No. DOT HS 812 652	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Human Factors for Connected Vehicles Transit Bus Research		**5. Report Date** May 2019 **6. Performing Organization Code**
7. Authors Graving, Justin L; Bacon-Abdelmoteleb, Paige; Campbell, John L.; Battelle		**8. Performing Organization Report No.**
Performing Organization Name and Address Battelle Seattle Research Center 1100 Dexter Avenue North, Suite 400 Seattle, WA 98109		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTNH22-11-D-00236, Task Order 18, Subaward 451329-19615
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration Office of Behavioral Safety Research 1200 New Jersey Avenue SE. Washington, DC 20590		**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code**
15. Supplementary Notes Ritchie Huang was the Contractor Office Representative for this report.		

16. Abstract

This report describes the tasks and demands associated with driving a transit bus, and directly supports the development of design guidelines for future transit safety technologies. The frequency and costs of bus-pedestrian accidents have created considerable interest in technologies that detect pedestrian hazards and warn the bus operator in time to mitigate or prevent an accident. This project addressed a lack of data on bus operator task demands through a mix of surveys, literature reviews, ride-alongs, cognitive task analyses, prototyping activities, and focus groups. The project team was aided tremendously by the support and involvement of transit agencies and their drivers in Seattle, Washington, and Portland, Oregon (King County Metro & TriMet). Key findings from the task analyses illustrated the high demand and complicated nature of bus operator specific activities such as the management of passenger boarding/payment, the navigation of intersections, and the driving on roadways where there is the co-occurrence of visual demands in disparate portions of the roadway scene and bus interior. The project also identified: safety issues (e.g., the impact of current riders on hazard detection, possible conflict between drivers' behaviors and local laws/policy, and impacts of new technologies on rider perceptions about driver behaviors) that are critical to the introduction of safety technologies for transit, additional research questions about bus operators' tasks, and the implications of these tasks for the design of pedestrian detection and alerting systems.

17. Key Words connected vehicles, bus operators, transit, driver-vehicle interfaces (DVI), pedestrians, crash warning systems, task analysis	**18. Distribution Statement** This document is available to the public through the National Technical Information Service, www.ntis.gov.

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	223	

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EXECUTIVE SUMMARY

This research supports the Human Factors for Connected Vehicles (HFCV) research program. This program seeks to transform Connected Vehicle (CV) data into useful information, and to manage and present that information to the driver. Additionally, the HFCV research program seeks to understand, assess, plan for, and counteract the effects of system-generated messages on visual, cognitive, and manual distractions.

The *Human Factors for Connected Vehicles Transit Bus Research* project answers a set of specific questions with regard to transit operations and tasks performed by bus operators. Given the lack of past research and available information on these topics, the research approach taken in this study was broad and multi-faceted. Specifically, a variety of analytical and empirical methods were used to refine the research questions and to generate findings that would be both valuable and valid. The findings are indeed relevant to the design of transit in-vehicle systems -- including controls and displays -- and help set the stage for future research. The key questions addressed by the research – as well as the findings specific to each question – are summarized below.

What does the literature tell us about the crashes involving transit vehicles and the contributions of driver tasks and workload to these crashes? A literature review was conducted to examine injuries and fatalities involving buses, research efforts to understand contributing factors to these crashes, and technology solutions to improve safety by reducing crashes. The review determined that while bus crashes and rider safety problems are rare, safety problems for pedestrians near buses remain and related injury and fatality rates remain problematic, unpredictable, and expensive. The existing research provided very little information about bus operator tasks, how existing tasks impact safety issues, nor how new technology (e.g., pedestrian detection and warning systems) would affect operator tasks and transit vehicle operations. A key outcome of the literature review was a set prioritized knowledge gaps, and a description of the near-term research needed to address a prioritized set of those gaps for contribution to the next generation HFCV design guidance, which is the primary product of the HFCV program. This literature review is summarized in Chapter 1 (*Introduction and Literature Review*); subsequent sections describe the methods and findings from a set of research activities intended to address some of the high-priority gaps identified in the review.

What Intelligent Transportation Systems (ITS) technologies are being adopted by transit agencies and how are bus operators interacting with those technologies? A transit technology questionnaire was sent to 44 transit agencies across the United States – 18 agencies responded. The questionnaire asked about fleet characteristics (e.g., number of buses, bus routes, and average daily ridership) and asked respondents to indicate their use of ITS technologies such as automatic fare collection, annunciators, and blind spot detection systems (among others). For those technologies that were in use at a particular agency, respondents were asked if there is a display or control (i.e., a driver-vehicle interface, DVI) that the transit operator must interact with, if the systems are integrated or stand-alone, and if any technology was retrofitted. The systems used by most of the agencies automate announcements to passengers about bus stops; change the signage on the outside of the bus; collect fares; and count passengers. There are also agencies using technologies to mitigate buses striking pedestrians, as indicated by the use of a "talking bus" to notify pedestrians of turning buses, as well as more limited use of systems that alert bus operators to pedestrians. In addition, a key objective for the questionnaire – aside from providing a sense of the current state of practice across transit agencies – was to provide topics to explore in the research phase of this project. While the responses identified those ITS technologies/systems that require interaction with the bus operator, operator workload and the information processing requirements associated with using the technologies/systems was not. Thus, these topics were explored in the task analysis, prototyping, and validation studies. The transit technology questionnaire activity is summarized in Chapter 2 (*Transit Technology Questionnaire*).

What strategies do bus operators employ to detect and address potential hazards and how can new collision avoidance technologies be used to address bus-pedestrian crashes? Eight bus operators from two major metropolitan transit agencies participated in focus group discussions that explored their ideas for technologies that could reduce pedestrian strikes. Focus group participants were shown a series of pedestrian strike scenarios and then asked to think about, draw, and discuss bus-operating tasks and to share their ideas for technologies to reduce pedestrian strikes. In addition to providing valuable insights and ideas about hazard detection and alerting technologies that could be developed to improve safety, the focus groups yielded fascinating insights and details about the nature of critical driving activities, including visual scanning requirements and techniques, and unusually demanding tasks. The methods and results from the scenario-based focus groups are summarized in Chapter 3 (*Prototyping Study*).

What visual, cognitive, and manual demands are imposed by current driver interfaces and what are the implications of these demands for the design of new safety technologies? The prototyping study identified three operational situations and bus operator tasks that have a critical impact on detecting and avoiding pedestrian strikes: (1) boarding and alighting passengers at bus stops, (2) navigating intersections, and (3) driving on the highway and other roadways. We conducted task analyses on these activities with four participants from two major metropolitan transit agencies, and obtained detailed information about how transit bus operators approach these situations and perform these tasks. Data collection methods included workplace observations (ride-alongs) and interviews with the operators. The goal was to capture authentic bus operator behavior in revenue-generating runs (i.e., while driving passenger routes) and use it to determine the visual, physical, and mental demands. Key questions addressed through the task analyses included:

- What information are you looking for - both inside and outside of the bus - during this time;
- What cognitive activities are involved;
- What makes this task difficult or easy;
- Are there any aspects of this task where the procedure/training doesn't work;
- What technology or aids are present, and how do they help; and
- What kinds of errors can be made?

For each of the three activities under investigation, we identified the sequence of tasks, sub-tasks and contingencies. Subtasks were broken down into specific visual, physical, and mental demands. The analyses yielded valuable insights into the demands associated with operating a bus. Very clearly, operating a bus is a difficult task, but the specific demands are highly variable, even when performing the same task across different trips. Sometimes multiple demands co-occur; mental, visual, motor, and executive demands happening at the same time may overwhelm the bus operator. The analyses helped to identify tasks that lead to overwhelming amounts of demand, especially during task transitions, such as when passengers complete boarding and the bus operator is preparing for departure. The methods and results from the ride-alongs and bus-operator interviews are summarized in Chapter 4 (*Task Analysis*).

How can we verify and extend the initial task analysis results? The results from the initial task analyses were interesting and – if valid – pointed to some potentially important considerations in the design of advanced safety technologies for transit vehicles. We decided to collect additional data through focus groups to verify the accuracy of the original task analyses, identify additional relevant tasks, and provide demand estimates. Four focus groups were conducted with 16 bus operators from two major metropolitan bus agencies in the United States. Importantly, none of the operators had participated in the initial tasks analyses, and one of the transit agencies had not participated in any of the earlier research tasks in this project. We provided focus group participants with graphical diagrams of the tasks and subtasks associated with two of the three bus operator activities under investigation (boarding and alighting passengers at bus stops and navigating intersections), and asked them to verify the accuracy of the tasks and to identify tasks or subtasks that were not in the diagrams but should be. Inputs were received from the participants individually, and then discussed as a group to until consensus was obtained. The participants also answered questions about how often the tasks occurred, and the mental and physical demands of the tasks. The methods and results from the validation efforts are summarized in Chapter 5 (*Task Analysis Validation Study*).

What has this research project yielded: (1) transit operations and tasks performed by bus-operator as they relate to pedestrian detection, and (2) future research needs in this area? Overall, this research has produced a number of important findings in this area. First, the initial literature review and technology questionnaire highlighted both the need to design new transit technologies in a manner that complements the information-processing requirements of bus operators' activities, as well as the relative paucity of detailed information about these information-processing requirements. The more we know about the activities that compete for bus operators' time and attention, the better we can design transit technologies that are consistent with their capabilities and limitations as they relate to key tasks. Second, the prototyping study identified tasks and safety issues that are critical to thinking about the introduction of new technologies, such as the impact of current riders on hazard detection, possible conflict between drivers' behaviors and local laws or policy (e.g., use of the horn), and impacts of new technologies (e.g., tablets) on rider perceptions about driver behaviors. Third, the task analyses yielded perhaps the most substantive findings in this project, and provided considerable insight into the temporal demands, information-processing needs, and variability across driving situations associated with key operator activities. No previous task analyses of transit operators have yielded this kind of information. Not only did the task analyses specify the demanding and complicated nature of specific activities (i.e., boarding/alighting riders, navigating intersections, and driving on roadways), they highlighted the frequent co-occurrence of many demands and especially the co-occurrence of visual demands in disparate portions of the roadway scene and the bus interior. Very clearly, the ongoing visual demands of the primary driving task should inform the placement and information content associated with the addition of new technologies to the vehicle cab.

ABBREVIATIONS AND ACRONYMS

ACC	autonomous cruise control
AC Transit	Alameda-Contra Costa Transit District
AFC	automatic Fare collection
AG	automated guideway
AHS	automatic head signs
AIA	automatic in-vehicle announcements/annunciators
APC	automatic passenger counter
API	application programing interface
APTA	American Public Transportation Association
ART	Arlington Transit
AVL	automated vehicle location
BFT	Ben Franklin Transit
BIFA	buses involved in fatal accidents
BOS	bus only shoulder
BSDS	blind spot detection system
BV	broad Visual Inspection
C-Tran	Clark County Transit
CA	covert alert
CAD	computer-aided dispatch
CAD/AVL	computer aided dispatch or automatic vehicle location
CAS	collision avoidance system
CATA	Capital Area Transit Authority
CATS	Charlotte Area Transit System
CB	commuter bus
CCP-Transit	Columbia County Public Transportation
CP	connection projection
CR	commuter rail
CTA	cognitive task analysis
CTA	Chicago Transit Authority
CV	connected vehicle
CVRIA	Connected Vehicle Reference Implementation Architecture
DART	Dallas Area Rapid Transit
DAS	driver assistance system
DDU	driver display unit
DMV	Department of Motor Vehicles
DOT	Department of Transportation
DR	demand responsive
DT	demand responsive taxi
DVI	driver-vehicle interface
Ex	executive function
FARS	Fatality Analysis Reporting System
FCW	forward collision warning
FG	focus group
FHWA	Federal Highway Administration
FMCSA-AD	Federal Motor Carrier Safety Administration – Analysis Division

FOV	field of view
FTA	Federal Transit Administration
FV	focused visual search
GCRTA	Greater Cleveland Regional Transit Authority
GES	General Estimates System
GTA-Ride	Grant Transit Authority
GUI	graphical user interface
HFCV	Human Factors for Connected Vehicles
HOT	high occupancy toll
HTA	hierarchical task analysis
HR	heavy rail
HUD	head-up display
IEEE	Institute of Electrical and Electronics
ISO	International Organization for Standardization
ITS	Intelligent Transportation Systems
LCD	liquid crystal display
LDW	lane departure Warning
LED	light Emitting diode
LIDAR	light detection and ranging
LR	light rail
LTD	Lane Transit District
M	mean
MB	motor bus
MBTA	Massachusetts Bay Transit Authority
MCDOT	Montgomery County Department of Transportation Ride On
MCMIS	Motor Carrier Management Information System
MD	motor demand
MDT	mobile data terminal
MG	monorail/guideway
MO	monorail
MPO	Metropolitan Planning Organization
MTA	Metropolitan Transportation Authority
MTA Maryland	Maryland Transit Administration
MTS	San Diego Metropolitan Transit System
NTD	National Transit Database
NT	non-typical
OEM	original equipment manufacturer
PCW	pedestrian collision warning
POS	point of sale
RB	bus rapid transit
RITA	Research and Innovative Technology Administration
RT	Sacramento Regional Transit District
RTD-Denver	Denver Regional Transportation District
SAE	Society of Automotive Engineers
SD	standard deviation
SEPTA	Southeastern Pennsylvania Transportation Authority

SME	subject matter expert
SODS	side object detection system
SPA	Spokane Transit
SR	streetcar rail
TARC	Transit Authority of River City
TB	Trolley bus
TB	Talking bus
TCRP	Transit Cooperative Research Program
TMC	traffic management center
TRID	Transportation Research International Documentation
TriMet	Tri-County Metropolitan Transportation District of Oregon
TSP	transit signal priority
UTA	Utah Transit Authority
VGC	vehicle guidance and control
VHM	vehicle health monitoring
VMS	video monitoring system
VP	van pool
VTTI	Virginia Tech Transportation Institute
WhMD	wheeled mobile device
WMATA	Washington Metropolitan Area Transit Authority
YR	hybrid rail

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CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

PROJECT OVERVIEW

This research supports the Human Factors for Connected Vehicles research program. This program seeks to transform connected vehicle data into useful information, and manage and present that information to the driver. A few examples of CV data are latitude, longitude, time, heading angle, speed, lateral acceleration, longitudinal acceleration, yaw rate, throttle position, brake status, steering angle, headlight status, turn signal status, vehicle length, vehicle width, vehicle mass, bumper height, the number of occupants in the vehicle, and intersection signal timing. CV technology uses high-speed and secure wireless networks to exchange information between vehicles and across transportation infrastructure. This innovation encourages the development of safety, mobility, and sustainability applications.

The Federal investment in HFCV research aims to develop unbiased knowledge about drivers' capabilities and limitations. The objective of this research is to gain an understanding of driver-vehicle interface needs for transit applications for CV systems.

OBJECTIVES

This project, *Human Factors for Connected Vehicles Transit Bus Research*, answers a set of identified knowledge gaps. The results are relevant to the design of transit in-vehicle systems, including controls and displays.

The United States Department of Transportation wants to publish a human factors reference document applicable to all vehicles that use the U.S.transportation network. However, at the beginning of this project in October 2014, information on transit operators in the human factors body of knowledge was insufficient and subsequently, the USDOT funded this project to fill the research gap.

Additionally, the HFCV research program seeks to understand, assess, plan for, and counteract the effects of system-generated messages on visual, cognitive, and manual distractions.

LITERATURE REVIEW

This literature review discusses injuries and fatalities involving buses, research efforts to understand contributing factors to these crashes, and technology solutions to improve safety by reducing crashes. It emphasizes the rarity of bus crashes and rider safety problems, while focusing on the safety problems for pedestrians near buses. Pedestrian-bus incidents have become less frequent in recent years, but injury and fatality rates remain problematic, unpredictable, and expensive.

In 2010 the United States had 9.6 million vehicles involved in crashes and only 0.6 percent of these involved buses (NHTSA, 2010). Furthermore, passenger vehicles kill far more pedestrians than buses. Passenger vehicles are responsible for 85 percent of the pedestrian deaths on roadways in the United States, while buses, heavy trucks, and motorcycles cause the remaining 15 percent (Paulozzi, 2005). However, when calculated by mileage traveled, fatality rates are much greater for transit buses compared to passenger vehicles and large trucks. Fatalities per million miles traveled for buses have surpassed rates for large truck and passenger vehicles for many decades.

Figure 1 depicts this trend using data aggregated from multiple sources[1] by the Federal Motor Carrier Safety Administration-Analysis Division. Overall, the fatality rate on U.S. roadways is now approaching one-third of the rate in 1975, showing an overall improvement.

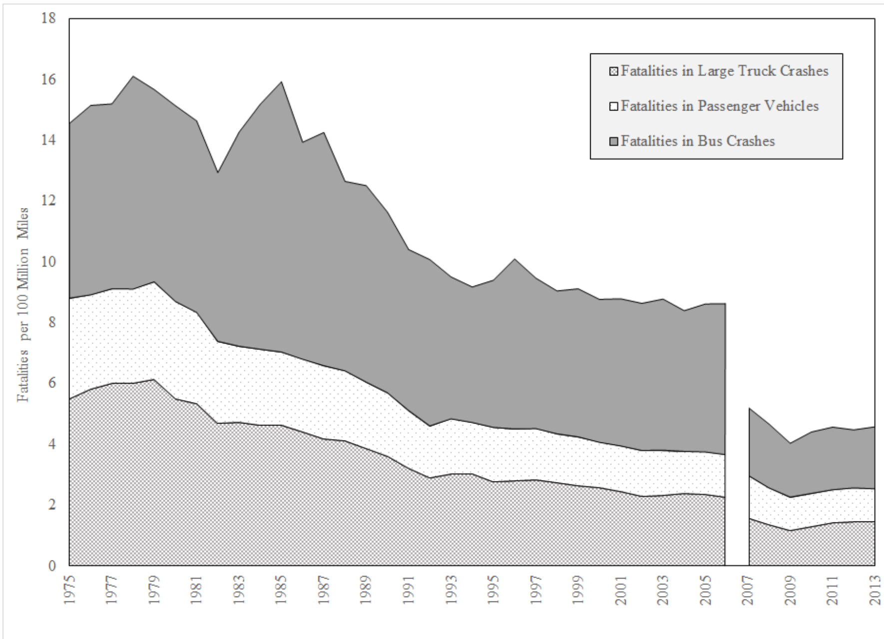


Figure 1. Fatalities in Crashes Involving Buses, Large Trucks, and Passenger Vehicles per 100 Million Vehicle Miles Traveled by Vehicle Type, 1975–2013 (FMCSA-AD, April 2015)

Additionally, passenger fatality rates on buses[2] are very low, second lowest only to those in aviation (Savage, 2013; see also Table 1). However, a focused analysis on a single year of data asserts that there is a pedestrian mortality problem associated with transit buses. Paulozzi (2005) combined Fatality Analysis Reporting System data and Federal Highway Administration highway statistics from 2002 to compute fatality rates per billion miles of bus transit travel. Buses killed eight times as many pedestrians per mile as cars, and were more likely to kill pedestrians in urban areas. Bus mortality rates result from a higher "degree of interaction with pedestrians," which greatly increases the risk of fatality by bus compared with passenger vehicles. Fortunately, fatality rates have shown negative trends over the years, suggesting that transportation in general has become considerably safer over the years.

[1] Sources include Fatality Analysis Reporting System, General Estimates System, the Motor Carrier Management Information System Crash File, and the Federal Highway Administration Highway Statistics. None of these sources includes data on causation or fault.

[2] Defined by the National Safety Council as holding 10 or more people.

Table 1. Passenger Fatalities, 2000–2009 (Savage, 2013)

Transportation Mode	Fatalities (per billion passenger miles)
Riding a motorcycle	212.57
Driving or passenger in a car or light truck	7.28
Passenger on a local ferryboat	3.17
Passenger on commuter rail and Amtrak	0.43
Passenger on urban mass transit rail (2002–2009)*	0.24
Passenger on a bus (holding more than 10 passengers, transit, inter-city, school, charter)	0.11
Passenger on commercial aviation	0.07

*While onboard a train includes assaults and violent acts.

However, pedestrians are overrepresented in bus crashes. According to the Buses Involved in Fatal Accidents project, pedestrians represent a large percentage of roadway fatalities involving buses. Nationwide crash data from BIFA represent the years 1999 to 2005. During that time, there were 731 fatal transit bus collisions in the United States, with 46 percent involving a bus striking a pedestrian (Blower, Green, & Matteson, 2008).

Furthermore, historical data from the Federal Transit Authority National Transit Database show that buses strike more than a hundred pedestrians per year in the United States.[3] Unfortunately, crosswalks do not help. Roughly the same number of pedestrians are struck and injured in crosswalks (M = 138 injuries per year, SD = 21) as outside of crosswalks (M = 158 injuries per year, SD = 29). Similar numbers of pedestrians are killed inside and outside of crosswalks (M = 12 fatalities per year, SD = 3; and, M = 15 fatalities per year, SD = 4, respectively; FTA NTD, September 2015).

In addition to injuries and lives lost, there are substantial insurance claims costs to transit agencies when a bus strikes a pedestrian. As shown in Table 2, liability and casualty expenses paid by transit bus agencies totaled $5.7 billion from 2002 to 2013, which is 81 percent higher than other types of transit like rail. More than half (59%) of these costs are from individual claims costing less than $100,000. The remaining losses (41%) are claims costing more than $100,000 (Lutin, Kornhauser, Spears, & Sanders, 2016). In other words, there are more low-cost claims for injuries and fatalities and fewer high-cost claims. However, the high-cost claims can have enormous expense. Lutin et al. (2016) found that the minimum and maximum cost of the top five most-expensive claims from a handful of agencies[4] were $3.3 million and $5 million, respectively. Furthermore, most of their large-loss claims involved pedestrians (46%).

Because of the higher cost and frequency of claims involving pedestrians, transit agencies stand to benefit considerably with interventions that effectively reduce or eliminate pedestrian strikes. Efforts to reduce pedestrian strikes include banning left turns at intersections in pedestrian-dense

[3] FTA began tabulating bus transit pedestrian crashes in 2008.

[4] The California Transit Indemnity Pool, the Ohio Transit Risk Pool, and The Washington State Transit Insurance Pool and King County Metro Transit provided the financial data.

areas, pedestrian awareness campaigns, pedestrian safety training, and implementing technology systems. Several agencies have made public announcements about their pedestrian safety efforts. In Iowa, Des Moines Area Regional Transit banned left turns in built-up areas after their fleet struck seven pedestrian within two years (Ryan, 2009). In Minnesota, Metro Transit's pedestrian awareness campaign distributes weekly bulletins and places stickers that say "Look & See" inside its fleet to remind operators to scan for pedestrians (Conlon, Himrich, & Feiner, 2013). The Greater Cleveland Regional Transit Authority implemented a pedestrian safety-training program for operators. GCTRA also installed external and internal pedestrian alerts (APTA, 2010). The Tri-County Metropolitan Transportation District of Oregon tested a "talking bus" with external warnings that deliver auditory warnings directed at pedestrians on the sidewalk (Altstadt, 2014; Pecheux, Strathman, & Kennedy, 2015). King County Transit in Seattle has 10 buses that say, "Caution, bus is turning, autobús está virando" when buses are turning right (Lindblom, 2015). The effectiveness of interventions like these needs verification. At the time of writing, there are no published research studies with proper controlled trials or longitudinal data of before and after implementation of an intervention. Additionally, research on bus operators to determine contributing factors has been limited to evaluations of crash configurations from incident reports (Schneeberger, Torng, Hardesty & Jacobi, 2013), which are limited to geographic information on the relationships between the bus and other vehicles or pedestrians involved in the crash.

The goals for the current project are to explain bus-operating tasks and to identify the information needs of bus operators with technologies designed to reduce pedestrian incidents. Additionally, the user experience of these and other systems is addressed.

Table 2. Collisions, Fatalities, Injuries, Casualty, and Liability Expenses by Transit Mode 2002–2014

FTA NTD from Lutin, Kornhauser, Spears, & Sanders, 2016

Mode	Reporting Period 2002–2014 Except as Noted					Reporting Period 2002–2013 Except as Noted		
	Collisions	Fatalities		Injuries		Total Casualty and Liability Expenses by Mode	Average Annual Vehicle Fleet	Average Annual Cost of Casualty and Liability Expenses per Vehicle
		Employees[a]	Total	Employees[a]	Total			
Commuter Bus[b]	94	0	3	33	390	$34,599,730[b]	2,357	$4,894
Demand Responsive	14,513	6	120	3,055	19,833	$668,245,896	28,449	$1,957
Demand Responsive Taxi[c]	144	0	3	33	262	$2,123,284[c]	3,960	$134
Motor Bus	69,722	49	1,185	13,079	177,931	$4,908,851,572	62,307	$6,565
Bus Rapid Transit[b]	55	0	0	18	358	$2,752,895[b]	137	$6,714
Trolley Bus	486	0	10	59	2,096	$57,539,948	581	$8,257
Van Pool	377	1	19	35	512	$79,677,613	9,581	$693
Total Bus, Demand Responsive and Van Pool	85,391	56	1,340	16,312	201,382	$5,753,790,938	N/A	N/A
Total Rail[d,e]	6,118	36	1,303	1,462	89,806	$3,174,067,800	N/A	N/A

[a] Includes transit operators, transit employees, and other workers

[b] Data reporting started in 2012, included in Motor Bus for prior years

[c] Data reporting started in 2011, included in Demand Responsive for prior years

[d] Rail includes Automated Guideway, Cable Car, Commuter Rail, Heavy Rail, Light Rail, Monorail/Guideway, Monorail, Streetcar Rail, Hybrid Rail

[e] Collisions, fatalities, and injuries are not reported for Commuter Rail. Casualty and liability expenses are included for Commuter Rail.

Pedestrian strikes that occur when a bus operator makes a left turn have received a great deal of attention in the media and by researchers; accordingly, left turns have been a focus for engineering solutions. However, there may actually be a higher rate of pedestrian strikes when bus operators drive through intersections (Schneeberger et al., 2013). Schneeberger's group calculated percentages of crashes by collision type using crash data from the NTD from 2005 to 2010. The data in Table 3 shows that the highest percentage of collisions with pedestrians occurred when buses were "going straight" at intersections (28.9%) and near mid-block crosswalks (25.9%). Left-turn incidents between pedestrians and bus operators were also prominent (16.2%).

Table 3. Motor Bus Collisions With Pedestrians (from Schneeberger et al., 2013)

Category	Collision Type	Number of Collisions	Percent of Collisions
Collisions at Intersections	Going Straight	130	28.9%
Collisions at Intersections	Turning Left	73	16.2%
Collisions at Intersections	Turning Right	29	6.5%
Collisions at Mid-Block	Going Straight	117	25.9%
Collisions at Mid-Block	Leaving a Bus Stop	58	12.8%
Collisions at Mid-Block	Stopping at a Bus Stop	42	9.3%
	Total	449	100%

Like drivers of other vehicles, bus operators occasionally may not fully process roadway and environmental information to navigate roadways safely. The nature of the bus operator's job requires thinking about a much larger variety of items while drivers of other types of vehicles think about much less. Furthermore, evidence shows that the amount of information bus operators keep in mind creates significant stress, which has been associated with rates of absenteeism and work-related and personal behavioral issues (Tse, Flin, & Mearns, 2004). However, the link between the quantity and quality of ongoing mental processing to the occurrence of pedestrian strikes has limited qualitative research suggesting a relationship (Wei et al., 2013, 2014).

There are individual differences in information processing capabilities. Not everybody processes information similarly due to unique understandings of the world and cognitive capabilities. An individual's cognitive capacity changes over time and during different circumstances (Hancock & Warm, 1989). The amount of mental resources available to devote to analyzing information within working memory, as well as the amount of information itself, determines how well the information is maintained for however long it is needed (Bays & Husain, 2008).

The mental workload of passenger-vehicle drivers increases at intersections, especially when turning (Hancock, Wulf, Thom, & Fassnacht, 1990). Moreover, left-turning vehicles (not including buses) are four times more likely to collide with pedestrians compared to vehicles traveling through the intersection (Lord, Smiley, & Haroun, 1998). Accordingly, there could be a relationship between left-turn crashes at intersections and high mental workload. However, to date there are no available data linking the two. Crash reports do not include measures of mental workload. Furthermore, the connection between workload and crash rates is theoretically tenuous. Many researchers are now indicating that available data sources do not conclusively link mental or cognitive demand, or distraction to crash risk (Strayer, Turrill, Cooper, Coleman, Medeiros-Ward & Biondi, 2015; Shinar, 2015; Fisher, 2015; Young, 2015). Research shows that people change their behavior to adapt to high demands by resorting to less-demanding strategies; this may be done by shedding any less-relevant, highly demanding tasks to reserve mental resources for completing high-priority tasks. For example, Cnossen, Eijman, and Rothengatter (2004) found that drivers in a simulated driving environment neglected driving-irrelevant tasks (e.g., mental arithmetic) more often than driving-relevant tasks (e.g., using route information). Although there are only a few research studies on mental workload for bus operators, self-directed management of attentional resources is a basic human activity and likely applies.

Furthermore, National Automotive Sampling System General Estimates System crash data indicates that 83 percent of bus drivers involved in bus accidents do not exhibit risky behavior. Only 13 percent drive inattentively, and only 4 percent are charged with serious offenses like speeding, driving drowsy, or being under the influence (Kaplan & Prato, 2012).

There is only one research study (Wei, Becic, Edwards, Graving, & Manser, 2014) on bus operators' mental workload as it relates to incidents with pedestrians. This work shows that when driving a bus, the bus operator's mental, visual, and physical workload will vary. High demands may occupy a large segment of all attentional resources needed for critical tasks such as detecting pedestrians at intersections. Tasks that are low in demand may be infrequent and may depend on congestion and ridership volume. Figure 2 is a published list of bus-operating tasks for turning left at an intersection. The list is in chronological order as identified by Wei, et al. (2014). It starts at the approach to the intersection and ends after exiting the intersection. Figure 3 maps these attentional demands over a schematic of an intersection. Mental resources can be exhausted when turning left as different types of demand overlap. The schematic shows that entering the intersection demands high amounts of both broad (e.g., obtain the big picture) and focused (e.g., monitor traffic lights and bus mirrors) visual resources; working memory (e.g., situational awareness of hazards like bicyclists); executive function (e.g., assessing space needed to merge and enter a stop), and some motor control (e.g., use of steering and brakes). In addition, operators need some available resources for monitoring for unplanned events (e.g., passengers asking the operator for directions).

Approach
1. Plan bus departure
   a. Determine how many lanes to be crossed
   b. Change lanes (4 lanes/ 3 lanes/ 2 lanes)
2. Assess tail-swing to ensure tail clearance from curb and maintain lane position
3. Scan surroundings for unsafe situations or obstacles
4. Look up at the intersection
5. Observe the traffic signal
6. Modulate approach velocity; at this position, if the light is red the driver may speed up in order reach the intersection when the signal changes to green
7. Check for relevant road features

Approach / Deceleration
1. Complete lane changing (if more than 2 lanes)
2. Maintain lane position
3. Check surroundings; scan for unsafe situations or obstacles and monitor position of bikers
4. Look up at the intersection; observe distance to intersection and modulate speed
5. Observe the traffic light to judge maneuver completion time based off of signal status:
   - If the driver saw the signal change from red to green (i.e., a fresh green) driver will estimate left-turn and modulate approach speed as needed.
   - If the driver did not see the signal change (i.e., stale green) driver will not estimate maneuver completion time and will anticipate stopping at the intersection. Brakes are always applied early ("easy on brakes", "smooth stop")
6. Determine location of next bus stop

Deceleration / Acceleration
1. Maintain lane position
2. Scan surroundings for unsafe situations or obstacles
3. Observe road features; if there is a median, bus is driven close to curb to prevent biker access
4. Look up at the intersection and observe distance to intersection
5. Observe traffic light
6. If stop is required: plan to stop 1 car length behind crosswalk or leave 1 car length between bus and lead vehicle at intersection to "leave an out"

Intersection Entry
1. Observe surroundings
   a. Determine the types of vehicles that will turn with the bus at the intersection
   b. Monitor oncoming traffic
   c. Observe for pedestrians
   d. Check mirrors
2. Wait for any leading traffic to turn left
   a. Allow for a 4-second pause before proceeding
   b. straighten bus to ensure no encroachment on adjacent lane
3. Scan to the right (for red light violators)
4. Scan to the left
5. Assess on-coming traffic for gaps
6. Scan for pedestrians and bicyclists
7. Glance down the sidewalk to the left of the driver
8. Turn the wheel
9. Check for curb on right of bus – avoid a curb strike

Prepare to Turn / Execute Turn
1. Observe road features
2. Glance again down sidewalk
3. Quick glances forward, left sidewalk, then right mirror
4. Maintain wheel position as straight to prevent collision with oncoming traffic from accidental acceleration of the bus
5. Determine entrance lane ("money lane", "right lane")
6. Determine angle of turn
7. Select gap in oncoming traffic or wait until signal turns red if traffic does not permit left turn

Post Turn
1. Reduce speed
2. Signal and move to the right lane
3. Locate bus stop position
4. Observe road features; if in left lane, determine how much time/space for merging right to prepare for bus stop
5. Check for pedestrians running for bus at the last minute

Figure 2. Transit Bus Driver Task Analysis for Minneapolis Metro Transit (Modified from Wei et al., 2014)

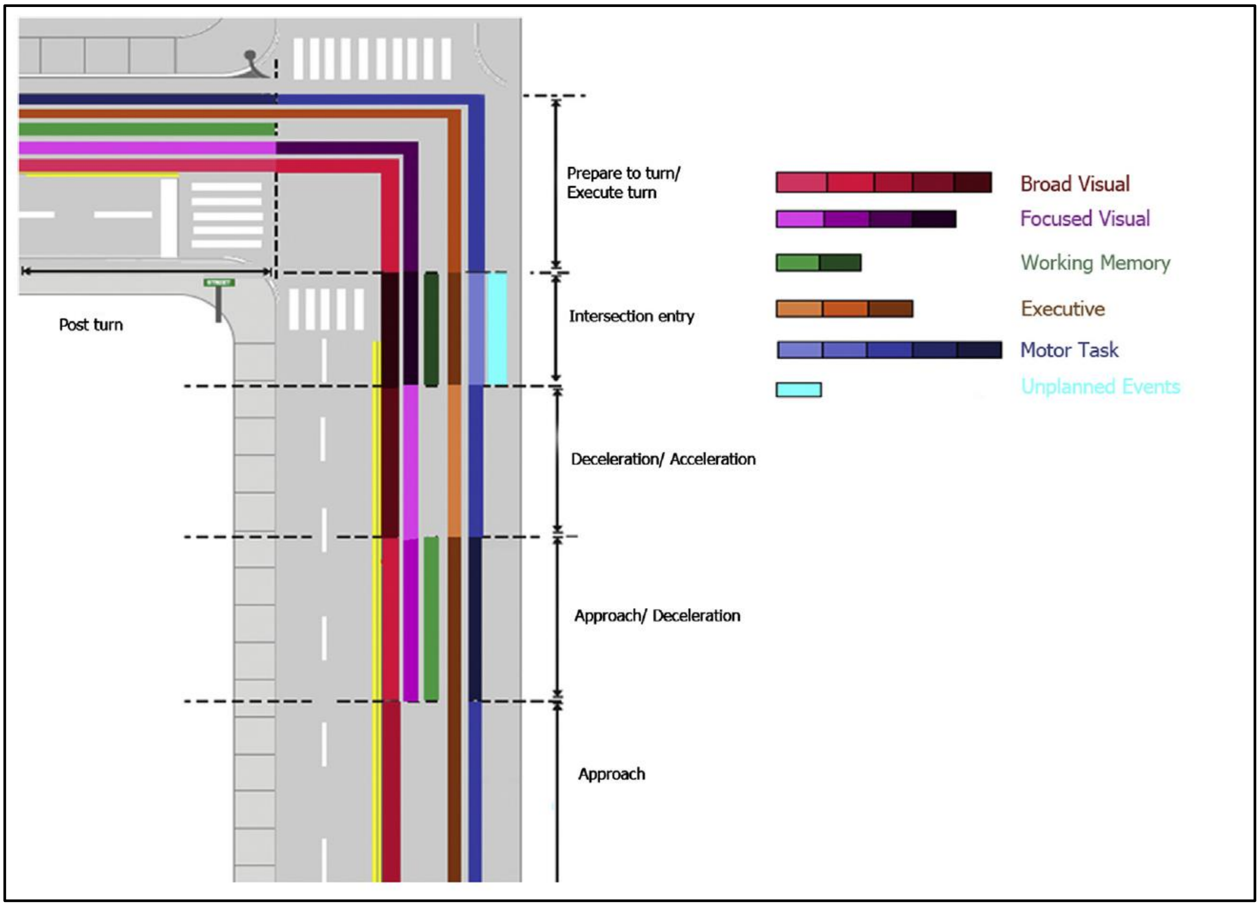


Figure 3. Mental Resources Required during Left-Turn Maneuvers (Wei et al., 2014)

Evidence of the connection between workload and pedestrian strikes is limited. However, Wei et al. (2014) looked at pedestrian strikes before and after the installation of permissive left-turn signals at an intersection. These signals permit left turns when opposite direction traffic is stopped. Wei's groupfound that bus operators still struck jaywalkers near an intersection with a protective left turn, but at a slightly decreased rate compared to without the protective left turn. Wei et al. also tested a pedestrian detection system that provided bus operators an auditory alert in the presence of pedestrians. The results were inconclusive, and the authors stated that the driving simulator environment was the limiting factor leading to the absence of a conclusion.

Although Wei et al. (2014) did not find that the protective left-turn signals reduced incidents; this finding should be taken lightly as it contradicts research on passenger drivers (Lord et al., 1998). Generally, the idea that an improvement to pedestrian detection occurs after removing the requirement for the driver to find a gap in traffic and decide to turn, i.e., make the turning task simpler by removing the most visually and mentally demanding task, and general improvements in detection performance should follow. Accordingly, due to the contrary finding, additional research is required on the effectiveness of protective left turns and pedestrian warnings for bus operators.

Apart from the act of driving the bus, researchers identified a few non-driving job-relevant tasks that may contribute to bus-operating problems. For instance, intrusions from passengers is a common distraction for transit operators (D'Souza & Maheshwari, 2012). It is easy to estimate that distraction can occur from tasks like fare collection, passenger counting, acknowledging and acting upon messages from dispatch, issuing transfers, communicating transit information to passengers, and route schedule adherence. Transit policy-makers recognize this fact, and the requisite training to overcome the problem, as exemplified by the Transit Cooperative Research Program Transit Distraction Policy report. Training for onboard bus electronics includes the following discussion on distraction created by onboard systems:

> "The introduction of advanced on-board E/E equipment, especially that related to information and communications systems, has added significantly to operators' responsibilities. The steady growth of telematics, the term used to describe a host of in-vehicle electronic devices that require interaction from the operator (e.g., radio, navigation, fare collection, and destination signs), has brought with it an increased need for training" (Schiavone, 2002, p.25).

To prelude the rationale for the needs of the research study discussed throughout the remainder of this report, there is much left to understand all the demands put on the operators by technology as compared to general bus-operating demands. This research takes a broad sweep to understand transit bus-operating tasks, workload, and information needs consistent with reducing the occurrence of pedestrian strikes. However, it should be recognized that the research efforts discussed next are superficial and broad reaching. In other words, as in keeping to the goal of the project to identify research gaps, many topics are covered; however, none are covered in great depth.

TASK GOALS AND OBJECTIVES

This project began with four research activities: a research gap analysis, a transit survey, a task analysis, and a participatory design study. A fifth task was added to confirm findings from work that was originally planned. This fifth task, a task analysis validation study, is discussed in Chapter 5 below. The chapter ends with a summary of the research tasks discussed in Chapters 2 through 5. It also summarizes an evaluation of the existing body of knowledge of bus-operating tasks that served as a formative research gap analysis that preceded the research activities.

RESEARCH GAP ANALYSIS

An analysis of literature identified a gap in understanding bus operator tasks and workload. Although broad, this knowledge gap guided the later focus of the research activities on human factors research on bus-operating tasks, pedestrian safety, and technologies to mitigate bus-pedestrian incidents. This report does not review the full analysis. A complete version of the analysis is provided in 0.

The research gap analysis began with a broad search of literature indexes (e.g., Transport Research International Documentation, IEEE Xplore, and SAE). Much of the uncovered literature was engineering documentation about Intelligent Transit Systemstechnologies for transit, including a small number of CV technologies. Very few sources discussed human factors, behavioral research on bus-operating tasks, or user-centered design of displays and controls. Therefore, researchers on the project identified gaps using human factors judgement and knowledge of heavy and passenger vehicle research, including the research discussed in the literature review that precedes this section.

Additionally, a group of subject matter experts rank ordered the importance of the gaps according to the instructions provided in Chapter 1.1.Appendix A. The group consisted of transit agency staff from across the country with the following titles.

- Transportation Manager
- Manager of Technology Systems
- Safety Director
- Transit Services Member
- Driver and Safety Committee Member
- IT Administrator

Additionally, there were three bus manufacturer SMEs with the following titles.

- Senior Director of Product Development
- Director of Community Relations
- Controls Engineer

Information from the literature review and feedback from SMEs led to a list of research gaps. The full list is in 0. The two top-ranked questions formed this project's research agenda, as listed below.

1. Is there more we can learn about what bus drivers are doing behind the wheel that can support system designs and designs for displays and controls?
2. What visual, manual, and cognitive demands are imposed by the use of mobile data terminals (MDTs) or systems with a similar driver interface?

The literature search did not identify many data sources that described transit bus operators' normal job functions. Through discussions with the SMEs, it became apparent that transit operators are engaged in a number of important, time-critical tasks. These tasks may increase workload at points where many safety-related decisions are required. Although many technologies seek to address transit operation needs or assist operators in their job functions, it does not appear that many have been designed and developed using basic information about bus-operating tasks.

Three related research activities addressed critical questions regarding bus-operating tasks and technology (Figure 4). The first activity, the transit technology questionnaire, assessed the technologies that transit agencies have implemented. Second, the task analysis assessed how operators use transit technologies and identified bus-operating tasks. Finally, a prototyping study examined user-centered designs for systems to circumvent pedestrian incidents. These three activities are briefly introduced here, and discussed in detail in the following sections.

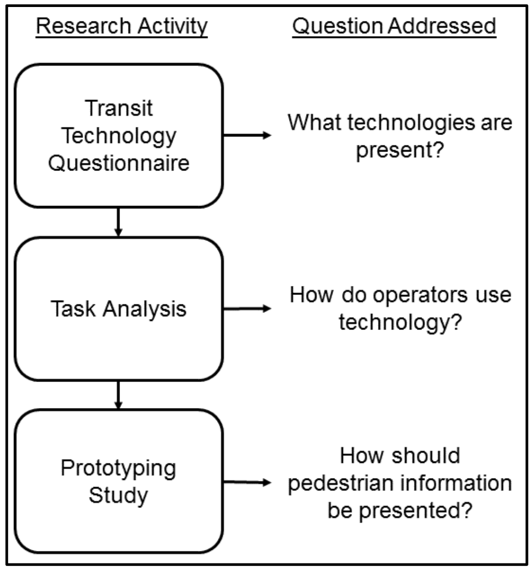


Figure 4. Research Activities and Research Questions

CONCLUSIONS AND RESEARCH APPROACH SUMMARY

Conclusions

CV communication holds the promise of enabling a number of new transit technologies that may increase the safety and efficiency of bus operations, especially with respect to pedestrian incidents. However, in order to provide the greatest safety benefit, these systems must be designed to account for transit operator needs. Furthermore, these systems must be designed with an understanding of the large number of tasks that simultaneously compete for bus operators' time and attention. These issues must be addressed in order to provide useful and actionable pedestrian presence information. The research in this report provides a broad view of issues, as well as insights into those issues (e.g., defining tasks, workflow, tasks demands, and operator preferences for technology).

Research Approach Summary

The remainder of this document presents the transit technology questionnaire, the task analysis, the prototyping study, and the validation study. The results are intended to strengthen the community's understanding of the demands facing transit bus drivers. All research activities relied upon transit agencies. Three agencies provided bus operators for focus groups, bus operator ride-alongs, and interviews. These agencies are not identified per se, but are reported as Agencies A, B, and C throughout the report. Agency A and B helped significantly with the task analysis and the prototyping study, while Agencies A and C helped significantly with the validation study. The research approach is summarized below.

Summary: Transit Technology Questionnaire (Survey to Agencies)

The transit technology questionnaire was designed to obtain information on technologies in bus operator workstations and to help inform the research team about common operator workstation layouts. The questionnaire link was sent to transit agency representatives via e-mail. This e-mail also provided respondents with an electronic briefing statement that described the project, the project goals, and what they may expect from participating in the research.

Respondents completed the questionnaire by indicating which technologies are present on their transit buses, if there are interactive DVIs onboard, and if the technology's DVI is integrated or stand-alone. Respondents were asked to provide a single photograph of a typical transit operator workstation, which they digitally uploaded to the questionnaire host site.

Summary: Prototyping Study (Focus Groups)

The prototyping study discussed systems' designs and tasks with bus operators during focus groups. Participants in the focus groups were asked to come up with ideas for technologies that could reduce pedestrian strikes. For each focus group, participants were shown a series of pedestrian strike scenarios. After each scenario, participants were given time to think about bus-operating tasks and note any ideas for technologies to reduce pedestrian strikes.

Participants were encouraged to draw or write down their ideas. The ideas were then discussed with the entire focus group. The discussion of their technology ideas often included descriptions of the tasks and behaviors that their ideas would support. Accordingly, this format uncovered many additional bus-operating tasks.

Summary: Cognitive Task Analysis (Observations & Interviews)

The data collection for the cognitive task analysis consisted of observing bus operators as they drove routes, followed by interviews to discuss the observation. The goal for the cognitive task analysis was to assess demands on an operator's attention, amounts of workload while driving, and the extent of interaction with any onboard technologies.

Researchers met bus operators at transit facilities and explained the purpose for the observations and interviews. The observations and interviews captured information on the operator's tasks, actions, and interactions with equipment and technology.

Summary: Validation Study (Focus Groups)

The validation study used a focus group method to gather information to confirm the accuracy of bus-operating tasks acquired from the cognitive task analysis and the prototyping study. The information acquired from the previous activities included comprehensive information about the demand of bus-operating tasks for picking up riders, driving through intersections, and general driving. However, the assumptions needed to be validated. To do this, bus operators were recruited to validate the task analyses. Participants of the validation study focus groups were not involved in the questionnaire, ride-alongs, interviews, or other focus groups.

Task diagrams were presented to four focus groups of bus operators, and they were asked to verify accuracy, fill in any missing tasks, and rate each task's mental, visual, and physical demands.

CHAPTER 2. TRANSIT TECHNOLOGY QUESTIONNAIRE

INTRODUCTION

The service life duration of a transit bus (12 years according to Laver, Schneck, Skorupski, Brady, & Cham, 2007), the rapid development of technology in ITS, and timing of transit funding cycles results in many retrofitted onboard transit bus systems. The inclusion of technology during the transit bus life cycle is not well documented, resulting in a lack of knowledge about the technologies present on transit buses.

The purpose of the transit technology questionnaire was to collect information about transit agencies' uses of ITS and to obtain information about their bus operators' interactions with onboard systems. Therefore, the questionnaire partially addressed the primary question, identified in earlier stages of this project (0): *Is there more we can learn about what bus drivers are doing behind the wheel that can support system designs and designs for displays and controls?*

The questionnaire results suggest that several onboard systems are present on existing fleets, many of the systems have been retrofitted, and a few systems require operator input of some kind. This section describes the questionnaire's methods, results, and conclusions.

METHOD

Participants

Solicitations for transit agency participation in the transit technology questionnaire were sent to 44 agencies across the United States (Chapter 6.Appendix D). Eighteen agencies responded, as shown in Table 4.

There were multiple rounds of sending solicitation e-mails to agencies. This was required due to the low number of initial responses. Initially, solicitation e-mails were sent to 17 metropolitan agencies, selected due to their large ridership numbers (e.g., daily ridership of 50,000). Six agencies responded. A second round was sent to several additional agencies identified with the assistance of the FTA. This second round of e-mails resulted in 4 additional responses. Subsequently, as a third attempt, solicitation e-mails were sent to 20 agencies across the state of Washington, resulting in 8 more responses. The Washington State agencies were targeted based on convenience. Contact information for the third round was found at www.wstip.org/Members.aspx.

Table 4. Responder Demographics by Agency ID, Count of Bus Type, Ridership, Routes, and Miles Served (n =18)

Agency ID	Articulated Buses/ Buses ≥ 40-ft Long	Motor Coaches	Demand Responsive/ Paratransit	Number of Permanent Transit Bus Routes	Approx. Area Served (mi^2)	Transit Bus Average Daily Ridership
Agency 1	390	155	*	139	2,348	343,650
Agency 2	230	*	258	75	2,500	105,682
Agency 3	343	*	*	78	507	88,000
Agency 4	151	0	0	78	497	86,000
Agency 5	300	300	*	62	41	51,000
Agency 6	201	*	54	55	292	49,586
Agency 7	75	41	52	31	141.5	15,109
Agency 8	0	71	38	18	97	14,841
Agency 9	16	*	*	15	26	11,000
Agency 10	0	19	5	11	12	8,500
Agency 11	11	34	15	13	263.6	2,850
Agency 12	14	12	15	8	1,909.8	2,620
Agency 13	0	16	14	8	2,660	700
Agency 14	755	*	*	*	*	610
Agency 15	*	6	3	3	10	250
Agency 16	765	50	465	*	*	*
Agency 17	460	0	154	*	*	*
Agency 18[1]	*	3,820	*	14	2,670	2,500

* Value not provided by agency.

[1] Did not complete technology portion of survey.

Materials

The website Jotform.com was used to make and distribute the questionnaire (Chapter 6.Appendix E). The questionnaire asked agencies for information on fleet characteristics (e.g., number of buses, bus routes, and average daily ridership) and included a checklist that asked agencies to indicate their use of the technologies listed in Table 5. Agencies were asked to select the technologies used in their fleet, if there is a display or control (i.e., DVI) that the transit operator must interact with, if the systems are integrated or stand-alone, and if any technology was retrofitted.

An open-ended section of the questionnaire allowed respondents to list additional technologies. In addition to the questionnaire, respondents were asked to provide a photograph of the transit operator's workstation. These images are provided below, although this report offers no further discussion about layout.

Table 5. List of Technologies in the Questionnaire

Technology	
Autonomous Cruise Control	
Automatic Fare Collection	
Automatic Head Signs	
Automatic In-Vehicle Announcements/Annunciators	
Automatic Passenger Counter	
Blind Spot Detection System	
Covert Alert	
Computer Aided Dispatch or Automatic Vehicle Location	
Connection Protection	
Forward Collision Warning	
Infotainment Onboard (in-vehicle traveler information system)	
Lane Departure Warning	
Mobile Data Terminal	
Pedestrian Collision Warning System (in-vehicle alert)	
Side Object Detection System	
Call Warning for Pedestrians (Talking Bus)	
Transit Signal Priority	
Vehicle Guidance and Control (Vehicle Assist & Automation)	
Vehicle Health Monitoring	
Video Monitoring System	
WiFi for Passengers	

Procedure

To achieve the final response rate, up to five reminder e-mails were sent after the initial solicitation. Each e-mail provided a link to the questionnaire. By following the link, potential respondents were provided an electronic briefing statement that described the project, the project goals, and what they could expect from participating in the research.

ANALYSIS AND RESULTS

This section reviews the responses to the technology list and shows the images of operator workstations that agencies sent.

Technology List

This section reviews responses to the technology list by the percentage of agencies indicating a specific technology under the following four uses.

1. Used in Fleet
2. Driver Interacts With Tech Using Displays and Controls
3. Tech Has a Stand-Alone Display
4. Retrofitted to the Existing Fleet

The two-way table below (Table 6) shows the percentage of agencies that use the technologies listed in the questionnaire. The technologies are listed in order of highest to lowest percentage under the column heading Used in Fleet.

The results show eight operational technologies that assist with mobility and that operators interact with using displays and controls. These are CAD/AVL, AIA, AHS, CA, AFC, MDT, APC, and VHM. There were no agencies indicating use of the following in-vehicle collision mitigation systems: SODS, LDW, FCW, or BSDS. For pedestrian-related systems, one agency (6% of the sample) indicated the use of a pedestrian collision warning device to warn drivers of pedestrians, and several agencies reported using TB to alert pedestrians of turning buses (29%).

Table 6. Percentage of Responses by Technology and Uses (*n*=17)*

Technology	Used in Fleet	Driver Interacts	Stand-Alone Display	Retrofitted
CAD/AVL	88%	41%	18%	24%
AIA	76%	24%	18%	29%
AHS	71%	59%	29%	18%
CA	59%	35%	6%	18%
VMS	59%	0%	0%	6%
AFC	53%	59%	18%	6%
MDT	53%	35%	29%	24%
APC	41%	12%	6%	12%
TB	29%	0%	6%	12%
VHM	24%	6%	6%	24%
TSP	12%	0%	0%	6%
ACC	6%	0%	0%	0%
Infotain	6%	0%	0%	0%
PCW	6%	0%	0%	0%
WiFi	6%	0%	0%	0%
VGC	0%	0%	0%	0%
CP	0%	0%	0%	0%
SODS	0%	0%	0%	0%
LDW	0%	0%	0%	0%
FCW	0%	0%	0%	0%
BSDS	0%	0%	0%	0%

* One agency did not complete the technology portion of the survey and was excluded from the results.

Table 7 shows a matrix of responses to illustrate the percentage of agencies using multiple technologies. Each cell represents the percentage of agencies using both technologies that intersect at the cell. The percentage is computed out of the total sample size. For instance, the table shows that 76 percent of the agencies have both CAD/AVL and AIA, 65 percent have CAD/AVL and AHS, etc.

Table 7. Percentage of Bus Agencies With Multiple Technologies (*n*=17)

	CAD/AVL	AIA	AHS	CA	VMS	AFC	MDT	APC	TB	VHM	TSP	ACC
AIA	76%											
AHS	65%	59%										
CA	53%	53%	41%									
VMS	53%	41%	41%	24%								
AFC	53%	53%	53%	41%	29%							
MDT	53%	47%	35%	29%	35%	29%						
APC	41%	41%	24%	35%	24%	24%	24%					
TB	29%	29%	29%	24%	12%	24%	18%	18%				
VHM	24%	24%	18%	18%	18%	18%	12%	24%	12%			
TSP	12%	12%	6%	12%	6%	6%	12%	12%	6%	-		
ACC	6%	6%	6%	6%	-	6%	-	-	6%	-	-	
Infotain	6%	6%	-	-	6%	-	6%	6%	-	6%		-
PCW	6%	6%	6%	6%	-	6%	-	-	6%	-	-	6%
WiFi	6%	6%	6%	-	6%	6%	6%	-	-	-	-	-

* One agency did not complete the technology portion of the survey and was excluded from the results.

Comparing Table 6 and Table 7 shows that the agencies using TB to warn pedestrians of turning buses (29% of the sample) tend not to have additional ITS. In other words, five agencies said they use TB and only one or two of these agencies are using TB and systems like CAD/AVL, AIA, AHS, and AFC. This indicates that some agencies are adopting systems to mitigate incidents involving pedestrians and the majority are doing so without additional ITS onboard. It is not clear how generalizable these findings are to the broader population of transit agencies. Additionally, a broader use of TB over other technologies would suggest agencies are currently prioritizing pedestrian incident mitigation technologies over technologies that provide operational solutions.

Images of Operator Workstations

Nine of the 17 responding agencies sent usable images of operator workstations. Figure 5 to Figure 13 show workstation images. In general, almost each image shows several systems that appear to be retrofitted. Most of the interaction displays are located to the right of the driver. Figure 6 shows a system interface on the left side of the driver. The workstation images in Figure 12 and Figure 13 do not appear to have any aftermarket or retrofitted displays and controls.

Figure 5. Bus Workstation 1

Figure 6. Bus Workstation 2

Figure 7. Bus Workstation 3

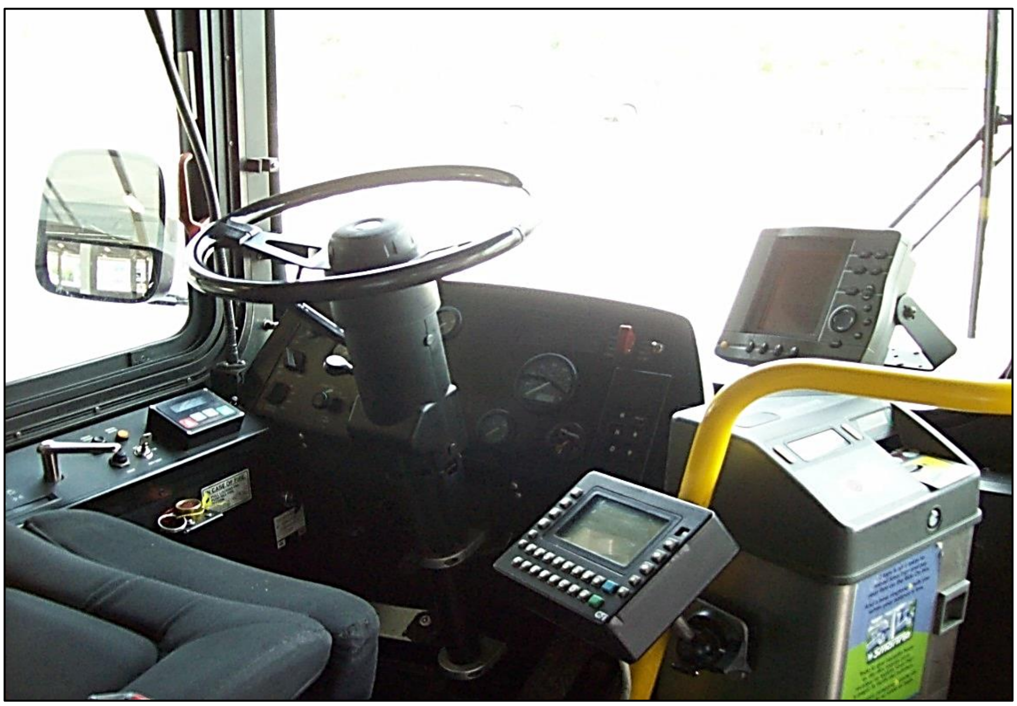


Figure 8. Bus Workstation 4

Figure 9. Bus Workstation 5

Figure 10. Bus Workstation 6

Figure 11. Bus Workstation 7

Figure 12. Bus Workstation 8

Figure 13. Bus Workstation 9

CONCLUSIONS

This section reviews the conclusions drawn from the questionnaire results.

The questionnaire results show that transit agencies commonly use technology systems for facilitating bus operator tasks. For instance, the systems used by most of the agencies automate announcements to passengers about bus stops (AIA); change the signage on the outside of the bus (AHS); collect fares (AFC); and count passengers (APC). Some of these systems require interaction with the bus operator, but the extent of the inputs on bus operator workload was not captured in the questionnaire. However, the workload associated with these systems was explored in the task analysis, prototyping, and validation studies.

The key conclusion from the questionnaire results is that there are agencies using technologies to mitigate buses striking pedestrians, as indicated by the use of TB to notify pedestrians of turning buses. Furthermore, media coverage shows that the use of TB is becoming more common. For instance, there was a recent pilot test of TB systems on 30 buses in Portland (Pecheux, Strathman, & Kennedy, 2015), and King County Transit at the time of this writing has TB on 10 buses running in the Seattle metro area (Lindblom, 2015).

The alternative to TB is the system that alerts bus operators of pedestrians (PCW). Such systems have very limited implementation, with only one instance in the literature (Pessaro, 2013). However, agencies are now starting to test out systems that provide collision warnings to drivers. The New York City Metro Transit Agency is planning to install a collision avoidance system in their fleet that provides FCW and PCW (Rivoli, 2015).

Ultimately, a key purpose for the questionnaire portion of this research was to provide topics to explore further during the task analysis and prototyping study. The pedestrian incident mitigation technologies, PCW and TB, were discussion topics during the research activities discussed in the chapters below. These research activities explored the relationship between display and control designs for in-vehicle warnings; also, bus-operating tasks were extensively discussed and reviewed with bus operators.

CHAPTER 3. PROTOTYPING STUDY

INTRODUCTION

This section describes the prototyping study's methods, results, and conclusions. The methods section reviews the focus group method and participants. The results are written as a narrative that describes bus-operating tasks and bus operators' ideas for technologies to solve bus-pedestrian crashes. As per the prioritized research questions identified in the research gap analysis (0), the prototyping study provides:

1. New information about what bus drivers are doing behind the wheel that can support designs of systems, displays, and controls.
2. New information on visual, manual, and cognitive demands imposed by the use of onboard systems interfaces.

Due to their expertise, bus operators are essential resources for determining how to optimize systems for operational tasks. To this end, the prototyping study revealed bus operators' preferences for technology and corresponding bus-operating tasks for reducing pedestrian incidents. The study also provides an extensive catalog of bus-operating tasks, which are the primary focus of the task analysis and validation study discussed in Chapters 4 and 5.

For the prototyping study, the focus groups were presented tabletop scenarios representative of real pedestrian incidents. Several scenarios replicated real incidents, while others were fabricated but based on known issues that contribute to incidents. They were also presented three pedestrian detection systems. The pedestrian detection system interfaces and system information presented to the groups were extracted from technical and marketing documentation. Using the information from these materials, the task for the focus group was to brainstorm ideas for mitigating pedestrian incidents, technological or otherwise, and to list bus-operating tasks relevant to the scenarios.

The focus of this work was not on examining how specific technologies operate, such as CV technology, machine vision, LIDAR, or ultrasonic sensor technology. Instead, the focus was on the following questions.

- When should information be provided to the transit operator?
- What is the optimal location for DVI components for both factory-installed and retrofitted technology?
- How should information be presented to ensure minimal additional loading?
- What would work for relative timing for alert on- and offset?

Additionally, as research by Vlassenroot et al. (2011) suggests, there are two constructs that influence acceptance of safety technologies; problem perception and responsibility awareness. Problem perception refers to the extent to which the user has awareness of the problem. Responsibility awareness refers to the extent to which the user accepts partial responsibility to solve the problem. These constructs were explored in the prototyping study. Operators' knowledge and understanding of the factors that contribute to pedestrian strikes can be useful in designing technologies that operators accept into their working environment. Information from the focus groups can inform the interaction design to improve bus operators' acceptance of systems that transit operators use (e.g., mobile data systems, or other ITS and CV systems).

METHODS

The methods section discusses the participants, materials, and procedures for the prototyping study. The study consisted of bus operator focus groups moderated by researchers at Battelle. Bus operators were selected because they are the end users of bus transit systems.

Participants

Eight bus operators (2 male, 6 female) 33 to 67 years old participated in the focus groups. Each focus group had four participants from two major metropolitan bus agencies (Agencies A and B). A recruitment flyer (Chapter 6.Appendix F) was posted at each transit agency. Participants enrolled by contacting the research team. They were compensated with $75 in cash for their time. The focus group demographics are listed in Table 8.

Table 8. Participant Table

ID	Focus Group	Agency	Age (yrs.)	Gender	Experience (yrs.)
P1	1	A	67	Male	12
P2	1	A	65	Male	13.5
P3	1	A	62	Female	3.5
P4	1	A	60	Male	36
P5	2	B	36	Female	14
P6	2	B	33	Male	0.75
P7*	2	B	~30	Male	N/A
P8	2	B	48	Male	2

* Participant 7 demographics are approximate, as this individual did not complete the demographic survey.

Materials

The materials section describes the response book and moderator guide, tabletop scenarios, the descriptions provided to participants of pedestrian detection systems, and the procedures for the focus group.

Moderator Guide and Response Book

A moderator guide was developed to read to the focus group at the start of the session. It introduced the topics and established the focus group ground rules (Chapter 6.Appendix H). Sessions were video recorded, and both the moderator and an assistant took notes during all sessions.

A response book was used to collect participant responses. It consisted of condensed summaries of the tabletop scenario descriptions and provided space for writing about pedestrian detection systems and listing bus-operating tasks (Chapter 6.Appendix I). Line drawings of buses were included for participants to illustrate their ideas on how systems should be designed (DVI placement, locations of sensors, etc.). There was also a basic demographic questionnaire, which collected information on gender, age, and bus-operating experience.

Tabletop Scenarios

The composition of the tabletop scenarios was based on real-world events, situations, and common pedestrian-bus collisions (Schneeberger, Torng, Hardesty, & Jacobi, 2013), collisions reported in the media, and a previous task analysis on bus left-turn crashes (Wei et al., 2014).

Aerial photographs from Google Earth were used make scenario images. There were two images for each scenario, the start and the end. Pedestrians and vehicles were depicted in scenarios using circles and boxes. The start and the end of each scenario were printed in the response book next to text that summarized the actions of the pedestrian and vehicles. Additionally, the start of the scenario was printed as a 17-by-22 inch poster and was used for the tabletop presentation. During the focus group, the moderator verbally described events and drew the paths of pedestrians and vehicles on the poster.

Other materials (blank paper, pens, markets, etc.) were used during the focus group for illustration of the scenarios and for participants to draw or write their ideas.

Scenario 1

The first scenario, titled *Straight Through Intersection*, starts with a bus (green and blue rectangle in Figure 14) driving toward an intersection on an urban two-way roadway. A group of pedestrians (black and yellow circles) stand at the intersection. Figure 15 depicts the end of the scenario, when a car (red and yellow rectangle) turns the corner, stops, and a pedestrian runs across the intersection to get into the car. The verbal portion of the scenario description indicated that the pedestrian "darted into the intersection to catch a ride with a friend."

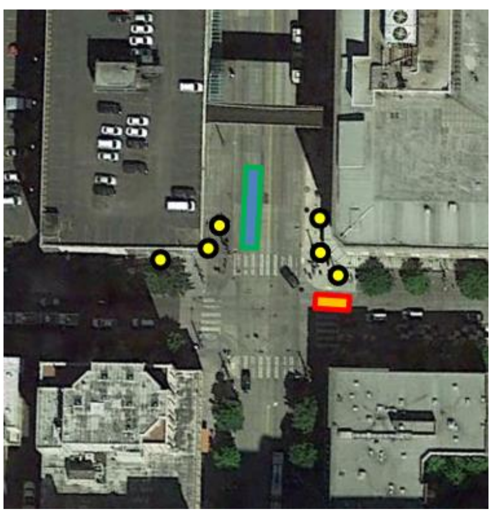


Figure 14. Start of Straight Through Intersection (Poster Image)

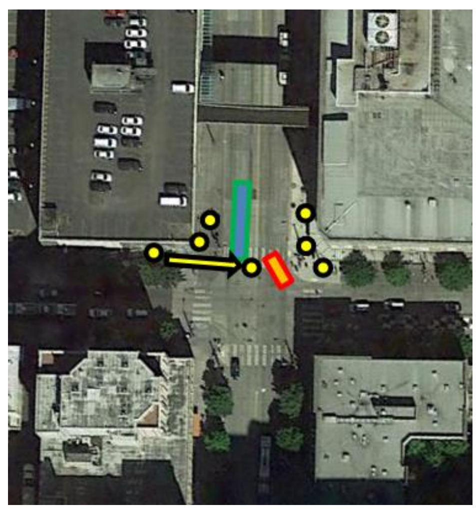


Figure 15. End of Straight Through Intersection (Response Book Image)

Scenario 2

The second scenario, titled *Bus Turning Right at Night,* starts with a bus at a T-intersection preparing to turn right onto a main road (Figure 16). It ends when a pedestrian standing at the corner enters the roadway and is struck by the front wheels of the bus (Figure 17). The focus group was told that the conditions were dark and the pedestrian was not visible to the bus operator.

The *Bus Turning Right at Night* scenario was based on a real incident, reported in the media to have occurred in Queens, New York, in 2015 (Bult & Stepansky, 2015). The verbal portion of the scenario description indicated that the bus operator had the right-of-way (i.e., the traffic signal was green for the bus) and the pedestrian entered the intersection when the crosswalk signal said, "Do not walk." This jaywalking feature of the scenario is a fabrication. It was added to remove culpability from the bus operator, which toned down the scenario, perhaps reducing the likelihood of defensive responses from the focus groups.

Figure 16. Start of Bus Turning Right at Night Scenario (Poster Image)

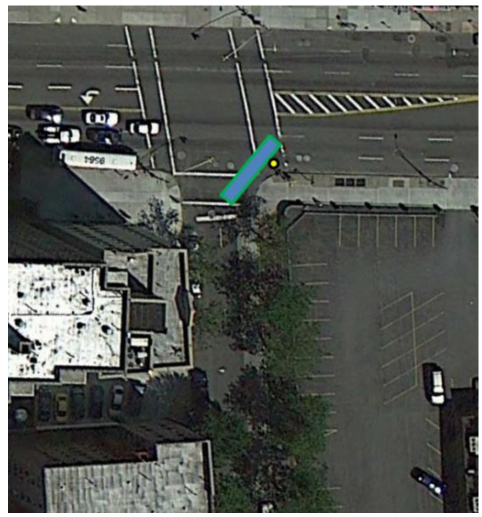


Figure 17. End of Bus Turning Right at Night Scenario (Response Book Image)

Scenario 3

The third scenario, titled *Mirror Clips Pedestrian*, starts with a bus approaching an intersection en route to the bus stop after the next cross street (Figure 18). A pedestrian is standing on the curb at a mid-block location and local shrubbery blocks the bus operator's view of the pedestrian. The bus merges into the lane next to the curb. The scenario ends after the bus merges and the bus mirror hits the head of the pedestrian (Figure 19). Although mirror strikes occur (e.g., Augustine, 2013), this scenario was fabricated. However, it was based on conversations with SMEs at the beginning of the project (0).

The intent of this scenario was to investigate general issues with partially occluded pedestrians at mid-block locations. Sight visibility problems from overgrown vegetation may conflict with safety; however, there are many other items that can block a bus operator's views of hazards (e.g., parked cars and newspaper racks; Macdonald, 2008).

Figure 18. Start Mirror Clips Ped. Scenario (Poster Image)

Figure 19. End of Mirror Clips Ped. Scenario (Response Book Image)

Scenario 4

The fourth scenario, titled *Left Turn in Heavy Traffic,* starts with the operator dropping off a passenger for a courtesy stop where traffic surrounds the bus (red rectangles) and five pedestrians are waiting on the corner for their right of way to cross the roadway (Figure 20). When the signal turns green, traffic proceeds through the intersection, the bus operator turns left, and pedestrians enter the crosswalk. The scenario ends when the bus strikes the group of pedestrians in the crosswalk (Figure 21).

The *Left Turn in Heavy Traffic* scenario was based on crash re-creation animations of an incident that occurred April 2010 in Portland, Oregon (Fat Pencil Studio, 2013).

Figure 20. Start of Left Turn in Heavy Traffic Scenario (Poster Image)

Figure 21. End of Left Turn in Heavy Traffic Scenario (Response Book Image)

Scenario 5

The fifth and final scenario, titled *Left Turn into a Transit Station*, starts with the striking bus (green) in the left turn lane, a pedestrian (yellow dot) standing at the corner, and a second bus (blue) heading the opposite direction as the other bus. (Figure 22).The second bus is preparing to turn right but yields to the pedestrian entering the crosswalk. The operator of the stationary bus honks the horn to warn the striking bus of the pedestrian in the crosswalk, which the operator of the striking bus may confused as a permissive signal allowing for the left turn. The scenario ends when the pedestrian is struck in the intersection (Figure 23).

This scenario was based on a real pedestrian incident used by Wei et al. (2014) for their bus operator interviews.

Figure 22. Start of Left Turn Into a Transit Station Scenario (Poster Image)

Figure 23. End Left Turn Into a Transit Station Scenario (Response Book Image)

Pedestrian Detection Systems

Sections of technical reports and marketing documentation of three pedestrian detection systems were shown to the focus groups. Additionally, the moderator described each system. The presentation order was different for each focus group. Participants were told to think about the system when generating their own ideas. They were not asked to provide their opinions on the designs of the systems.

The review of these systems provided the group an impression of feasibility for near-term use in transit buses.

Rosco Vision Systems Shield+

The product brochure for Rosco's Shield+ vehicle and pedestrian system was shown to the focus groups. The moderator described the system as written in the brochure and pointed out the depictions of the DVIs and the range of detection (Rosco, n.d.). The moderator also discussed the "market readiness" of the Rosco system by indicating that the system is already available for agencies to acquire.

Transit Safety Retrofit

Relevant images (Figure 24 & Figure 25) were extracted from a technical report that describes the development, testing, installation and maintenance of TRP systems on transit buses (Zimmer, Burt, Zink, Valentine, & Knox, 2014). The images were shown to participants and described as the pedestrian warning provided to the bus operator, and the location of the DVI that shows the warning.

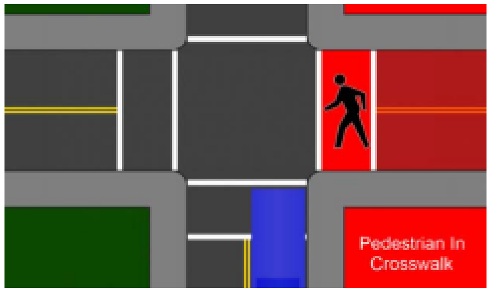


Figure 24. Pedestrian Warning (Battelle)

Figure 25. DVI Location (Battelle)

Cedar Avenue Driver Assist System

Figures Figure 26 and Figure 27 were extracted from a report on the evaluation of the Cedar Avenue Driver Assist System (Pessaro & Nostrand, 2011). The moderator showed the focus groups the images and explained the function of the system as follows.

> "The driver assist system was designed to support driving on the shoulder. It provides information about lane position to the bus operator. It also detects hazards and provides collision warnings for pedestrians and other road users like people driving passenger vehicles. Lane position information is provided in the heads-up display (HUD), and through the bus operator's seat and steering wheel. The HUD shows white lines that overlay the lane lines. When a lane departure occurs, the white lines change to red. Similarly, the seat vibrates on the side that corresponds with a lane departure, and the steering wheel rotates. Additionally, the hazard detection system shows hazards through the HUD as boxes that change from white to red if a pedestrian or car is too close to the bus."

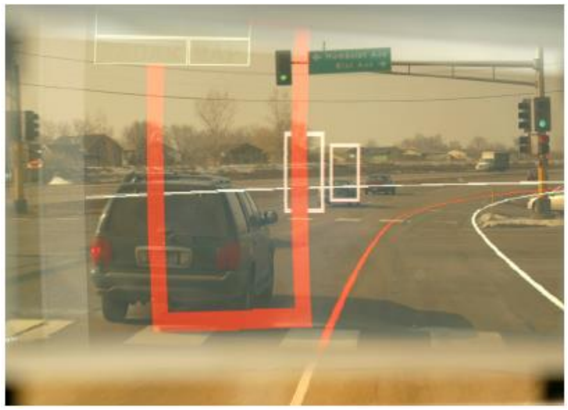


Figure 26. Hazard Detection Warnings (Pessaro & Nostrand, 2011)

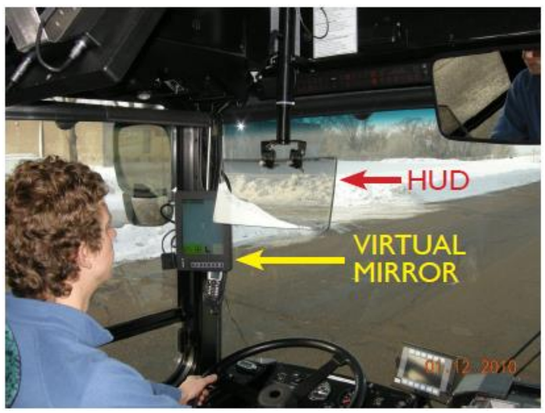


Figure 27. DVI Locations for HUD and Virtual Mirror (Pessaro & Nostrand, 2011)

Procedure

Participants were met and escorted to a meeting room where consent was obtained. When all participants arrived, a researcher read the moderator guide to review the purpose and intent of the session, set the ground rules, and inform participants of their options for providing responses (i.e., writing in the book and contributing to discussions).

The presentation of the scenarios and pedestrian detection technologies was the only scripted part of the focus group. The scenarios were shown one at a time, followed by 5 minutes of thinking time for participants to list tasks and write or sketch system ideas in a response booklet. The pedestrian detection systems were presented after the first scenario.

After the 5 minutes, or when most of the participants had generated at least one idea, the floor was opened for discussion. Participants were encouraged to edit their responses or add additional notes as needed during the discussion segment.

ANALYSIS

The focus group commentary was reduced to relevant discussion points, which were extracted from both moderator and assistant notes, as well as from the audio recordings. Relevant segments of lengthy discussion points were summarized for useful content (i.e., key points related to equipment DVI design, information formatting, and information display).

Much of the results are presented in a narrative format. Comments were interpreted to summarize bus-operating tasks and ideas for mitigating pedestrian strikes. Direct quotes are inserted as necessary. These quotes are edited for clarity. Terms added by the authors are enclosed in brackets. Quotes are validated when possible with results from online searches for bus agency policy, news headlines, or other literature sources. These searches were done using the TRID database or Google Scholar.

Focus group ideas for pedestrian intervention systems are illustrated and described in the text of the results report. The illustrations were made with CorelDRAW X5. Statements from operators about the rationale for their ideas are a focus of the descriptions. Their design rationale provides insight into operational problems, safety issues, and operator willingness to accept technology.

RESULTS

The results are organized by topic. Within each topic, there are subsections that describe tasks and systems. The results are divided into the eight topic sections listed below.

- Visually Demanding Tasks
- Visual Search Tasks
- Turning
- General Tasks
- Ideas for Alerting Bus operators
- Ideas for Alerting Pedestrians
- Ideas for Systems That Facilitate Tasks
- Existing Mitigation Strategies

The results of the focus group are provided below as a bullet-form narrative. Focus group comments are italicized and labeled with the participant's ID (e.g., P1, P2, P3, P4, P5, P6, P7, or P8).

Visually Demanding Tasks

This section discusses visually demanding tasks. The amount of time that a driver's eyes are on the road scene has been used to study the attentional and visual demands of driving (e.g., Senders et al., 1967; Tsimoni et al., 1999). The focus groups discussed where bus operators look and what they look at. Their discussion on visual attention and visual demand covered visual locations, objects of importance (the road scene, onboard displays, etc.), and whether or not visual demands are associated with the primary task of driving, service tasks, or secondary tasks.

Scanning for Clues of Hazards

Bus operators visually search their driving environment for clues of hazards. They look for sudden changes and evaluate traffic movement to estimate the hazardousness of pedestrians and vehicles. The following comments tell about the need to continuously search for movements or a sudden changes.

- *“The* [bus operator] *is always scanning* [the] *roadway,* [intersection] *and mirrors for pedestrians and obstacles.”* (P1, P2, P3, and P4)
- *“*[We] *scan the road ahead, that’s what we’re trained to do.* [We] *look all over* [for] *people* [and] *cars.* [We are] *scanning the corners for any movement* [or] *sudden changes.”* (P2)

Bus operators predict hazards by scanning traffic and paying attention to driver and pedestrian behavior. According to the following comments, searching for hazard clues is linked to intersection signal status and “body and car language,” as well as facial expressions.

- *“*[As a bus driver, I’m always] *scanning the intersection,* [checking the] *mirrors,* [and checking] *walk signs and the signal light* [status] *to be sure it’s safe to get through the intersection. I’m also looking for people who may dart across or that aren’t paying attention to traffic.”* (P6)
- *“*[As a bus driver, I’m always] *searching for people that could come in and hit me.* [I’m] *trying to read body and car language.* [I] *try to tell what people are going to do; to see if* [drivers of other vehicles] *look at me.”* (P2)
- “[As a bus driver, I’m always] *identifying intent on faces”* (P1) (i.e., predicting where pedestrians and drivers intend to go and when).

Additionally, visual searches can occur concurrently with motor tasks like responding to a radio call, as described below.

- “[The bus operator was probably] *checking signal, pedestrians, other vehicles,* [and maybe] *answering radio call from dispatch.”* (P8)

The extent that answering a radio call effects visual search is not known. However, bus operators have strategies for ensuring continuous visual search. These strategies may be self-regulated attempts to reduce risk.

Strategies for Visually Searching for Hazards

Bus operators are vigilant and use techniques to ensure uninterrupted visual search. For instance, they will twist and contort themselves to look around visual obstacles (e.g., bus features and riders) to ensure a full scan for clues of hazards. They also make wide turns to increase sight distance.

Glances at pedestrians, vehicles, and other visual elements can be blocked or occluded by anticipated and unanticipated “vision barriers” or obstructions. Bus operators act out a motor behavior they call “rock-and-roll” or “bob-and-weave” to look around these visual obstructions. This technique helps bus operators look around obstructions that are fixed (e.g., the A-pillar) or non-fixed (e.g., a rider). The comments below define “rock-and-roll” as a series of behaviors to help see around blind spots.

- “[Bus operators] *lean forward and twist in the chair to see around blind spots.”* (P1)
- *“You only use rock-and-roll when you’re turning; you don’t use it when you’re going straight.”* (P4)
- *“*[In Scenario 1, the bus operator] *could have looked to the left because it’s a couple busy streets, to see if cars are stopping …then the* [bus operator] *could have looked to the right and saw the*

pedestrians standing there, then assumed they were standing-put and not a problem. There could also have been a rider standing at the wheel-well and blocking the view...." (P7)

To detect far hazards, bus operators use visual scanning, and "eye-lead" time; both are characterized as

- "*Looking forward into traffic, scanning for obstacles."* (P3)
- "[maintaining a] *15-second* [visual/eye-lead time]." (P8)

Bus operators are trained on this 15-second eye-lead time. The instruction is to, "Aim high in steering and watch 15 seconds ahead of your vehicle, 30 seconds if possible" (Smith System Driver Improvement Institute, 2014). Additionally, the California Department of Motor Vehicles driver's manual and the New York DMV commercial driver's manual suggest that an appropriate visual lead is 15 seconds or one city block (California DMV, 2015; New York DMV, 2014). Bus operators say they use these techniques effectively. However, the efficacy of visual lead-time is not supported by research. A literature search in TRID only found two entries for a search on "visual lead" and "eye lead," which suggests limited empirical support.

To increase sight distance at an intersection, bus operators adjust their driving behavior. The comment below discusses making wide, slow turns to provide greater visibility of the roadway.

- "*If there isn't a stop located at that intersection, I'm taking advantage of the space and turning wider, doing a slow roll until I can see what's going on in the darkest space."* (P8)

Deciding if There Are Hazards (i.e., "Clearing")

At various points while driving, the bus operator must decide that there are no hazards before executing a lane change, turning, going straight, or entering an intersection. "Clearing" is the term used by bus operators for deciding that there are no environmental threats, for example:

- *"Clearing the intersection of the hazards."* (P8)

The term "clearing" was used repeatedly during the focus group to describe the process of deciding if hazards are present. Clearing roadways requires that operators visually inspect adjacent lanes, intersections, and crossroads for hazards. When operators are clearing, they are looking for hazards like red-light runners and adjacent traffic. For example:

- *"*[When] *clearing intersections*, [operators are] *making sure nobody is running red lights, coming from other lanes into intersection."* (P2)
- *"*[The bus operator in Scenario 3 was probably] *clearing the right lane in preparation of lane merge, scanning obstacles and threats in oncoming intersection…."* (P8)

When doing visual searches during clearing, the eyes follow a scan path that consists of glances that jump from one area of interest to the next. A bus operator may look at a location, see no hazards, and then devote visual and cognitive resources elsewhere. The following comments describe clearing scan paths:

- *"The* [Scenario 1 bus operator probably] *did the proper scan. However, once you see that* [the people at the corner are not moving], *your focus is on all the other points we need to attend to.*

[The bus operator] *could have already looked to the right, assumed the pedestrians were staying put, then continued scanning for other potential hazards in the intersections."* (P5)
- *"*[In Scenario 2, the bus operator] *may have been reading the traffic, and* [because] *there's* [an apparent] *lack of pedestrians, attention could have been focused elsewhere."* (P7)

Since it is impossible to assess the hazardousness of pedestrians that are not clearly visible, poor pedestrian visibility reduces the effectiveness of clearing a roadway. There is substantial literature indicating that pedestrians in dark clothing at night are not easily identified by drivers (see Langham & Moberly, 2003). Additionally, pedestrians are often unaware of their poor visibility (Tyrrell, Wood, Carberry, 2004), and unaware of the danger of being in a roadway that has bus traffic. However, infrastructure lighting can help. The following comments emphasize bus operators' viewpoint on pedestrian visibility, safety, and lighting.

- *"Everyone wears black at night, and it seems they think that it's the driver's responsibility to see them*. *People don't care, they think they can make it* [and they enter an intersection in front of a bus]." (P1)
- *"Good intersection lighting making pedestrians more visible."* (P3)

Education was mentioned by the focus group as a countermeasure. Research suggests this could be effective. Education has worked to get people to realize the limitations in drivers' ability to see low-visibility pedestrians (Tyrell, Patton, & Brooks, 2004). Coincidently, guidelines for transit agencies suggest informing the public about pedestrian safety through better enforcement of laws and committee involvement (Nabors, Schneider, Leven, Lieberman, & Mitchell, 2008). The focus group offered the following comments:

- "*Education seems to be the critical piece. You could have all the warnings you want...."* (P1)
- *"Our culture seems to be teaching people to become less and less responsible, which seems to be making the bus driver increasingly more responsible."* (P2)

Visual Search Tasks

This section discusses two visual search tasks: glances at mirrors and signals, and searching for bus stops. It is recognized that bus operator visual search activities in the real world are broader than the topics provided by the focus group. However, there is a latent construct present in the discussion. This construct presents a trade-off between automatically looking at specific areas and maintaining broad visual search for unanticipated hazards. In other words, compulsory visual inspection of areas of interest (e.g., mirrors, signals) could draw attention away from unanticipated hazards.

Nevertheless, searching for bus stops is a visual search task that can encourage broader visual search. This is due to the requirement that bus stops operators visually search the driving environment to find bus stop signs.

Glances at Mirrors and Signals

Bus operators are trained in techniques for glancing at mirrors and signals. The focus group suggested a certain degree of obligation and regularity, but said that mirror glances help to identify potential hazards. This is described below.

- "[Bus operators are] *checking mirrors every 5-7 seconds.*" (P2)
- "[Bus operators] *keep an eye on the traffic and walking signals.*" (P3)
- *"The operator* [in Scenario 1, was probably] *scanning both left and right sides of bus with his mirrors, but the* [operator's] *focus could have been taken away for that brief moment."* (P7)
- "[Operators should] *always be looking at the 'curb line'* [in the mirror or through the door] *for potential hazards while changing lanes."* (P1)

Searching for Bus Stops

Bus operators are also scanning for the location of their next stop. For example:

- "[The bus operator in Scenario 1 was probably] *looking for next* [bus] *stop zone."* (P3)
- "[The bus operator in Scenario 3 was probably] *clearing the right lane in preparation of lane merge, scanning obstacles and threats in oncoming intersection, and* [scanning] *to locate next stop* [or bus stop zone]*."* (P8)

In many cases, searching for the next bus stop can be visually demanding. However, it keeps the operators' eyes broadly searching the driving environment. Many bus stop signs are located where the local shrubbery is overgrown, blocking the bus stop sign or making the sign difficult to identify. For example:

- "*When you're driving near trees you can only see 15 percent of the bus stop signs* [due to vegetation growth blocking the line of sight]." (P8)

Turning

This section reviews two key aspects of turning a bus: turning speed, and squaring the turn. Bus operators are trained to turn at specific speeds. Similarly, agencies may decide to train drivers on "squaring turns."

Turning Speed

The focus group talked about bus operating speeds when turning, and stated that it is difficult to make turns at the suggested speed.

- *"We're trained to drive at a speed of 5 to 7 mph for turns."* (P7)
- *"Buses are supposed to go slow when turning, driving at 3 to 5 mph, but this is often difficult."* (P1 and P2)

Squaring the Turn

There are two steps to a square left turn: entering the intersection and "squaring the turn." "Squaring" is a 90-degree turn that occurs within the intersection after the bus fully enters. Turning like this gives the bus operator time to scan for hazards in the crosswalk and elsewhere before turning. The comment below discusses squaring the turn as a solution for the incident in Scenario 4:

- *"It doesn't seem like the* [bus operator in Scenario 4] *was squaring-off the turn properly. If the driver had done so, there may have been a better chance the pedestrians were seen. Looks like a corner cut to me.* [The bus operator] s*hould've been preparing for turn; should've been rocking and rolling, and squaring off the turn properly."* (P3)

Squaring a turn is depicted in Figure 28 as a dark dotted line, showing the starting point (A), mid-point where the square turn occurs (B), and final point of the turn (C). A sweeping turn is shown in red for comparison. In other words, the bus operator drives straight until their shoulder lines up with the cross-street's middle-lane marking before starting to turn.

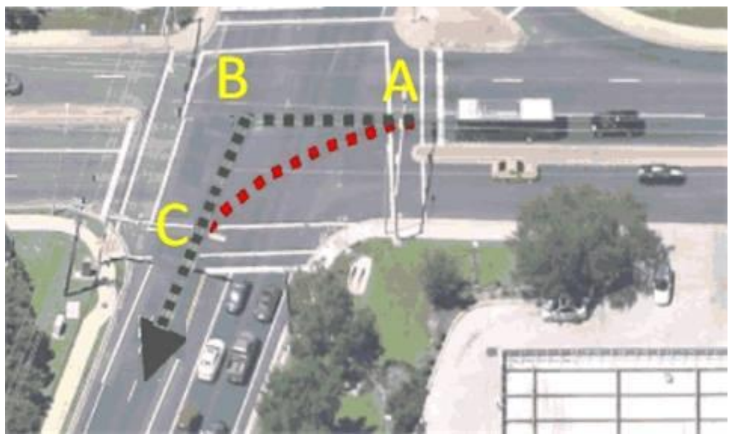


Figure 28. Squaring a Turn Compared to Rounding a Turn (from Mentzer, 2014)

General Tasks

There are several general tasks discussed in this section, which include finding courtesy stop locations, customer service, practices to enhance safety, taking breaks, and communicating with dispatch.

Finding Courtesy Stop Locations

A courtesy stop occurs when a rider requests to be dropped off at a location that is not a bus stop. The focus group talked about these drop-off locations as being a problem due to their inconsistency.

Courtesy stops can occur anywhere, including before or after an intersection. Although crossing the intersection puts the courtesy stop at the safest location, some operators drop passengers off before crossing the intersection. Inconsistency in locations for courtesy stops can lead to problems for bus operators when riders demand to be dropped off at locations that are in conflict with the operator's impression of safety.

- *"At night we can drop off passengers for courtesy stops, but we don't do it at the near side of an intersection. You'd clear the intersection then do it. There are a lot of* [bus operators] *dropping off* [riders] *at the near side of the intersection, so I have to deal with telling riders that I won't do that."* (P4)

For safety reasons, not all agencies allow courtesy stops without restrictions. The pedestrian incident in Scenario 4 was based on a real-world collision that lead to an agency moratorium on courtesy stops near left turns (Rose, 2010). Fortunately, many bus operators use visual cues to identify where passengers can be safely dropped off. The focus group talked about "bus zones" as such a place, as per the comment below.

- *"Do not drop passengers outside of zones."* (P1)

When the focus group talked about bus zones, they were likely referring to boarding and alighting stations that are signed to prevent other vehicles from entering areas where bus riders can stand. Figure 29 shows a bus zone sign. Signs for any bus zone, even those that are not part of the bus's route, could be used to identify safe locations for courtesy stops.

Figure 29. Bus Zone Sign (Seattle DOT)

Customer Service

Customer service tasks can occur with other tasks. Searching for hazards can occur at the same time as helping riders and monitoring for "stop requests." These tasks require motor, cognitive, and visual effort. The examples below were provided by the focus groups:

- "[Bus operators] *help riders on-board,* [for example, by] *giving directions."* (P5)
- "[Bus operators simultaneously] *clear intersections, keep an eye on signals,* [and] *maintain awareness of the stop request."* (P3)

Though not directly related to driving a bus, handling customer fares was discussed. When speaking about automated fare collection, the following comment was made:

- *"Automated fare pay would make life so much easier. We won't have to deal with that guy searching for fifty cents he needs to pay his fare."* (P6)

It is not easy to determine if a rider warrants a discounted rate. Some riders carry discount cards to show to the bus operator, as per the following statement:

- *"It's against the law to ask about a disability, you can ask to see the* [fare discount] *card but not about a disability."* (P7)

Practices to Enhance Safety

Bus operators take ownership of safe driving, do their best to avoid prevent the bus mirrors from hitting people and signs, and admit that attention waxes and wanes depending on the driving context. The focus group conceded the bus operator is always responsible for driving safely. The statement below suggests bus operators hold a level of responsibility awareness for driving safely.

- *"*[Scenario 5 is a] *very possible scenario but it is still the driver's responsibility to see a safe zone to turn."* (P1)

The following comments indicate that some bus operators find it effective to use the bus horn to alert pedestrians that the bus is approaching, but others may find it ineffective.

- *"Maybe a light horn honk if someone is close to the curb not looking at the bus.* [Additionally] *pedestrians used to stand back, now they stand right at the edge. The bus is within six inches of the curb,* [which is a problem] *if someone makes a sudden movement."* (P1)
- *"*[Now, the] *horn is less effective for warning pedestrians. In addition, riders apparently get upset about the horn honking. We are no longer supposed to use our horns. Not like we used to use them."* (P4)

Some city ordinances have rules against using horns for non-emergencies (e.g., Washington State Legislature Municipal Code RCW 46.37.380), which could lead to agency bans. However, other areas are more open to the idea of using horns. A "gentle bus horn" or "softer warning bell for non-emergency incidents" exists in Europe (Great Manchester News, 2014), but there is no information about its effectiveness. In any case, giving drivers an opportunity to notify pedestrians of buses may be beneficial for reducing pedestrian-bus incidents, especially in situations when riders may stand close to the bus waiting to be picked up.

Bus mirrors can strike riders waiting to board. Some bus stop loading zones are too high, causing bus mirrors to be closer to riders' heads. Because of the variation in bus stop heights, operators have to monitor the mirrors to avoid hitting riders. The following safety issue is related to mirrors nearly hitting riders and riders ducking and weaving to avoid being hit.

- *"Certain stops have road-curvature that makes the height of the curb cause the mirror to be closer to the heads of customers waiting to board. I have had customers duck-and-weave to not get hit by the mirror, but they do not move from where they're standing. Perhaps they stay put to avoid losing their place in line to get on the bus."* (P8)

Bus signs are also a problem. Presumably, bus operators try to avoid colliding with bus stop signs, but they still crash into them often. To increase visibility, bus agencies place bus stop signs close to the road and at eye level. Additional messages are sometimes mounted to existing signs. However, the locations and size of signs lead to problems with operators crashing into them.

- *"Ninety-percent of our mirror collisions are from us hitting our own bus stop signs. Signs are located close to the road so we can see them. We are always supposed to be looking up and forward to see the signs*. (P7)

- "*The 'FREQUENT STOP' add-on to the sign, that is just at the right height to hit your mirror.* (P6)
- *"Just put the signs 2-feet back instead of 4-inches from the curb."* (P8)

The focus group mentioned that their attention can wax and wane, but when approaching an intersection, awareness is especially high. This is because a bus operators' expectation for hazards is lower in sections of road (e.g., mid-block areas) where unusual and unanticipated hazards appear, but higher where anticipated hazards appear (e.g., intersections). For example:

- *"*[Referring to Scenario 3,] *if you're traveling maybe about 20 miles per hour and you have to stop this 40,000 pound vehicle, you're thinking, I'm in the middle of a block, everything is probably OK.* [Any suspicion of danger] *may start to kick in when I get closer to the intersection."* (P7)

Taking Breaks

The focus group commented about timetables and schedules causing conflicts with breaks for essential human needs (e.g., using the restroom) as a potential reason for the bus operator in Scenario 5 driving in a rushed manner:

- *"This could be the end of the line and perhaps* [the bus operator has not] *used a restroom, and any ten seconds that might have been on their mind."* (P7)
- *"The bus operator could need to use the restroom. That could be why he was in such a hurry. Now we are talking about scheduling. We are talking about real-life situations and so many things can happen. It is hard to protect against all these scenarios. That is why it is such a tough job."* (P4)

An additional comment about the limited time to complete driving activities indicates that frequency and quality of break periods may be problematic and may not lead to adequate recovery from job-related stresses. The statement below indicates that operators may be frustrated with computer-generated schedules that do not seem to capture the time requirements for breaks.

- *"We cannot drive in a normal fashion because our breaks are generated by a computer. Me, I have a feel for how to do the job, I have a feel for the speed I need to go, and I could drive* [at a speed that allowed] *for taking breaks."* (P1)

Communicating With Dispatch

Bus operators interact with computer devices to communicate with dispatch. These devices have a graphical user interface for controlling communications with dispatch. The controls for sending and receiving messages can be integrated in a multitiered menu structure. This menu design can make the controls difficult to use.

The comments below illustrates how interaction with communication tools contradicts policies that ban cell phone.

- *"I have to set up my* [device] *so I can read it at night and in the day. I get texts on the* [device] *about reroutes or opportunities for overtime. They also send broadcast messages. I have to know whether it pertains to me, so I read it right away. But it may be about missing children that are not anywhere near me. However, I have to read it to see what it says, then I see it is not something I can do anything about. I am supposed to read the texts on it, but I cannot text on my phone…."* (P1)
- *"If I get caught using my cell phone while driving, it is a two-day suspension. Think of that in terms of using this equipment… it is ok to do that, but not text."* (P4)

The concerns over suspension from duty are warranted. A Metropolitan Transportation Authority bus operator who was filmed in Washington, D.C., allegedly reading the bus-stop schedule "timetable," faced disciplinary charges and suspension (Harshbarger, 2015).

Ideas for Alerting Bus operators

The focus group discussed ideas for alerting bus operators. The discussion was about pedestrian alert systems and the components of acceptable systems. They discussed alert triggers, DVI locations, existing pedestrian system DVIs, and concerns about public scrutiny, and their own trust in safety systems.

Alert Triggers

Bus operators want alerts for sudden movements and atypical behavior. Sudden and atypical behaviors are thought to be difficult to detect but are said to be the key components of hazards, as per the following comments.

- *"Something that could instantaneously pick-up sudden movements, then provide a warning. Most of the danger comes from quick darting motions."* (P7)
- "*Sudden movement detection would be good.*" (P1)
- *"A warning system needs to pick-up the behaviors that are not typical. When someone does something out of the norm, we are not attuned to it. People do not realize that when they run* [at a crosswalk] *it is unusual. It's called a crosswalk, not a 'crossrun.'"* (P7)

The tabletop scenarios included pedestrians walking in a normal and predictable manner and those making sudden and atypical movements. As discussed in the introduction, many pedestrians are struck by buses when walking at a normal pace in protected areas (e.g., crosswalks). Accordingly, the comments above suggest low awareness of non-pedestrian-initiated factors that contribute to pedestrian incidents.

General awareness is higher when bus operators drive somewhere unusual (e.g., dropping off a passenger outside of a bus zone or while deadheading on an unapproved route). Repeated exposure to the same driving areas can reduce awareness, according to the statement below.

- *"Driving the same area, day in and day out, that is when* [warnings to the bus operator] *would be better. If I am supposed to be deadheading down the highway but it is jammed and I decide to take a different road, my attention is piqued and I pay attention to everything."* (P5)

Context dependent awareness, as described above, may have an effect on pedestrian strikes, or any type of incident, as mentioned below. However, this claim needs to be verified.

- "*There are less pedestrian crashes downtown. Less accidents because you are more aware downtown.*" (P3)

If true, operators could become less responsive to alerts in certain contexts. The comment below suggests that warnings could be a problem for using pedestrian detection systems in downtown areas that have lots of pedestrian traffic.

- "[While driving downtown] *you would either be on hyper-alert, or desensitized* [to alerts from a pedestrian detection system]." (P2)

Whether it is true or not that bus operators experience context-dependent awareness, a work-around of temporarily inactivating a warning system was discussed. It was found acceptable to allow operators to shut off the alerts temporarily, as stated below.

- *"If there is a chance for many false alerts, maybe we can hit a button that shuts off* [alerts to the bus operator] *for 30 seconds."* (P4)

DVI Locations

Bus operators prefer display locations that correspond with the need to scan the visual environment. The focus group participant that offered the comment below also provided a drawing to illustrate the idea:

- *"I would like to see some sort of blinking person at eye level going across my windshield."* (P3)

The participant drew the idea on the images provided in the workbook. As shown in Figure 30, a DVI could appear on the inside of a bus. The "blinking person at eye level" is shown as an orange icon. The participant suggested that the icon flash, which was illustrated by changes to color saturation and icon position.

There was an additional comment, not supported by a drawing, about the benefits of eye-level displays.

- *"What I ultimately see is something like a fighter cockpit with a heads-up display. Then the information you need is right in front of your face."* (P8)

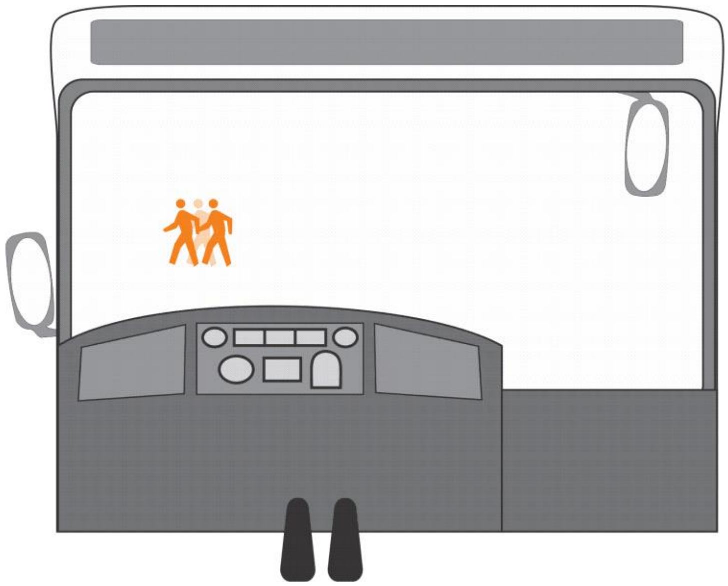


Figure 30. Focus Group Drawing: Blinking Pedestrian Alert on Bus Windscreen

An eye-level display location may be preferred, but the visual complexity of the display needs to be simple. According to a formal evaluations, users of the Cedar Avenue driver-assist found the system's HUD to be distracting (Pessaro & Nostarnd, 2011). The authors said the display was too cluttered and too complicated to set up.

Existing displays and bus infrastructure create visual barriers. However, an overhead display would not create a vision barrier. As depicted in Figure 31 and discussed below, the typical overhead location for large interior mirrors could be used for a DVI. The appreciation of this location depends on the bus operator's use of the existing mirror. Some operators may regularly use the mirror; however, the operator that came up with this idea does not.

- *"You know that big mirror for looking at the back of the inside of the bus; I do not use it unless there is a disturbance on the bus. That big mirror could be a good spot to put a display, up high. Will not block any vision there."* (P3)

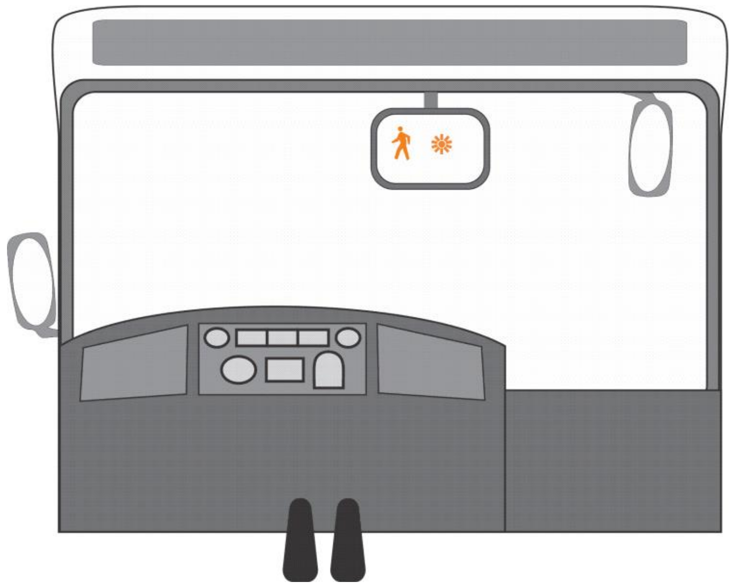


Figure 31. Focus Group Drawing: Internal Mirror as a Location for DVIs

A-pillar and center-console DVIs were discussed. A-pillars are visual obstructions that bus operators are trained to "rock-and-roll" or "bob-and-weave" around. The addition of DVIs to the A-pillar adds more visual obstruction. However, this may be acceptable if the information on the DVI increases awareness of the hazards that could be obstructed. When discussing the locations of the DVIs shown in Figure 32, a participant said the following.

- *"This could eliminate all the rock-and-roll stuff they train us about."* (P3)

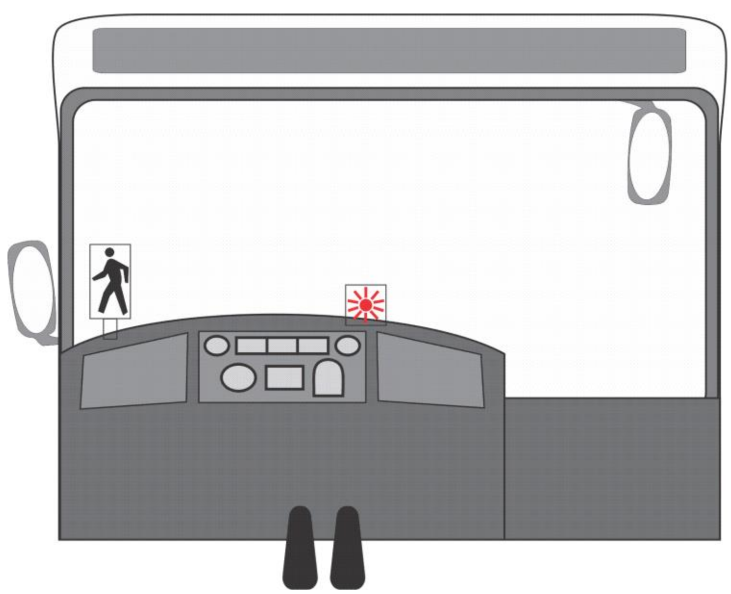


Figure 32. Focus Group Drawing: DVI Locations Near A-Pillar and Center Console

Existing Pedestrian Detection System DVIs

The focus group provided a few critical comments on existing pedestrian display sizes for detection systems, display location options, and interaction requirements.

The following comment about the size of the tablet interface of the TRP system could be addressed by using a smaller screen.

- "*The reason the larger touch screen was problematic was because it creates a blind spot*." (P5)

Given an appropriately sized DVI, the A-pillar may be an acceptable location for it:

- *"…the* [visual display on the A-pillar of the Cedar Avenue System] *is too busy, it is one more visual annoyance. The other unit,* [The TRP], *I would like that* [tablet DVI] *located on the A-pillar."* (P2)
- *"We got to have A-pillars and that is a good thing to do with it."* (P3)

Coincidently, the TRP was redesigned to reduce the size of the screen and change the location to increase driver acceptance (Zimmer, Burt, Zink, Valentine, & Knox, 2014). The display size was reduced and the display was relocated to the center console.

Concerns about Public Scrutiny

In addition to the size and location of the DVI, it matters if it looks like a tablet computer. Although bus operators are not interested in using applications while driving, they are concerned that the public may confuse the device with a domestic tablet computer. The following comments pertain to the TRP tablet computer display.

- *"This would not be a screen that we would need to touch like a CAD/AVL?"* (P5)
- *"Can* [bus operators] *use a different application while driving?"* (P8)
- "[It might look like you are] *reading your Kindle.*" (P7)

The concern for public confusion and backlash is warranted. Unfortunately, a wayward bus operator once used a Kindle during revenue service; riders filmed it and complained to the agency (Photorights, 2010). Riders also filmed a bus operator using printed timetables (Harshbarger, 2015). The use of paper timetables during service is very common, but perhaps not understood by the public.

Trust

There are concerns that agencies already use technology to discipline bus operators and will use assistive technology in the same way. The comment below suggests that there may be organizational trust issues that need to be overcome to persuade bus operators to adopt new technology.

- *"They already use technology against the* [bus operators]. *Surveillance cameras, put on the bus to protect us, were used against me when someone complained about using the bike rack on my bus. So, this shoulder-support system, I could see someone saying to me, 'oh, you went over the fog-line 9 times, keep that up and you're fired.'"* (P1)

Ideas for Alerting Pedestrians

Many ideas relied on the pedestrian's position to activate the alert. The activation parameters for alerts address "danger zones" around the bus. These ideas included auditory alerts from the bus, visual alerts from the bus, alerts from infrastructure, increases in ambient illumination, and minimal harm countermeasure.

Auditory Alerts From the Bus

Bus operators recognize the usefulness of auditory alerts towards pedestrians. The need for concise announcements from equipment on the bus that activates when pedestrians are located in dangerous areas is expressed in the following comments.

- *"Sensors near the tires could read if a person is within a foot of a tire. The alert could say, 'Back Away.'"* (P5)
- *"A warning about a bus should be concise, like 'Bus turning.'"* (P3)
- *"…or, like 'Bus approaching.'"* (P1)

Announcements to pedestrians would be received well by operators and communities if false alerts were low, meaning that announcements occur only when a pedestrian incident is likely, which could be accomplished by linking the alert to steering wheel turns and the speed of the bus. This assumes that there is a bus speed that corresponds well with the presence of pedestrians, as implied below.

- *"The talking-bus alerts should be in conjunction with speed and angle of wheel turn."* (P8)
- *"If you are going to do auditory it has to be below 10 mph."* (P7)

Visual Alerts From the Bus

A sketch for a system that emits a visual warning from the bus onto the ground is shown in Figure 33. The warning projects onto roadway areas where bus tires will be driven. This idea addresses danger areas and getting the attention of pedestrians:

- *"What I came up with, you know how cars have rotating headlights, the bus would have those, and a third light that is like a laser drawn image. It would look like a stop sign shooting from the bus."* (P8)
- *"The stop sign could project on the ground. You could even do tracking, like what you see in cars with the back-up guidance. This would be most useful for the rear-duals because that is where people get killed."* (P7)
- *"Right, if it is on the ground. Most people have their attention forward and down."* (P6)

It is not known if the rear-duals are as dangerous as these operators imply. Unfortunately, analyses of pedestrian incidents in the United States have not included the impact location (e.g., Schneeberger et al., 2013). However, an analysis of data from the Ontario Ministry of Transportation found the impact zone for most (25%) pedestrian incidents was the front, left corner. The rear left and right areas, where the duals are located, were associated with fewer pedestrian strikes, at 1 to 2 percent respectively (Shaw, 2008). Perhaps the duals are more frequently monitored and thus associated with fewer pedestrian collisions.

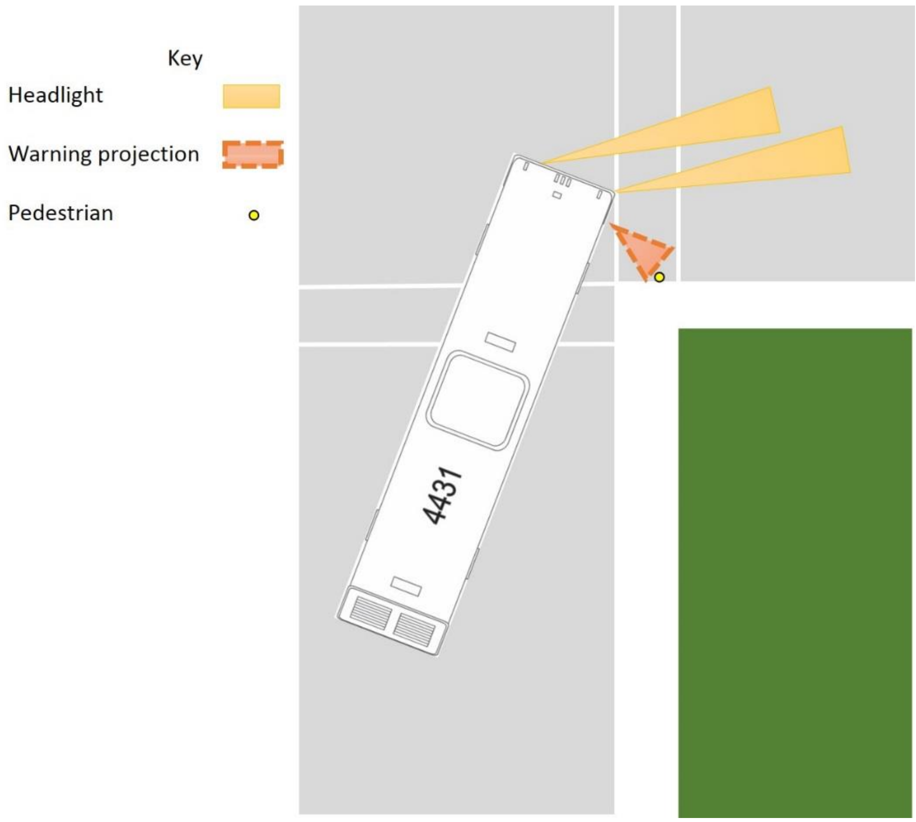


Figure 33. Focus Group Drawing: Warning Projection

Because pedestrians are often looking down and at a phone, an alternative idea is to send warnings to cell phones.

- *"For people with ear buds in and a cell phone in front of their face... I envision [a system that], blocks out music, sends a message saying 'DON'T CROSS,' and the phone's screen turns red."* (P5)

The visibility of the bus could be enhanced to increase the likelihood that a pedestrian or rider would notice it. The illustration in Figure 34 was accompanied by the comment below.

- *"Lights could be added around the bus …sensors near the tires could read if person is close to the tire, and then light-up to make the bus very visible." (P5)*

The drawing shows the illumination enhancements and the sensor positions. Similar to the projected warning idea discussed earlier, the sensor positioning addresses areas around the bus that bus operators believe to be the most problematic.

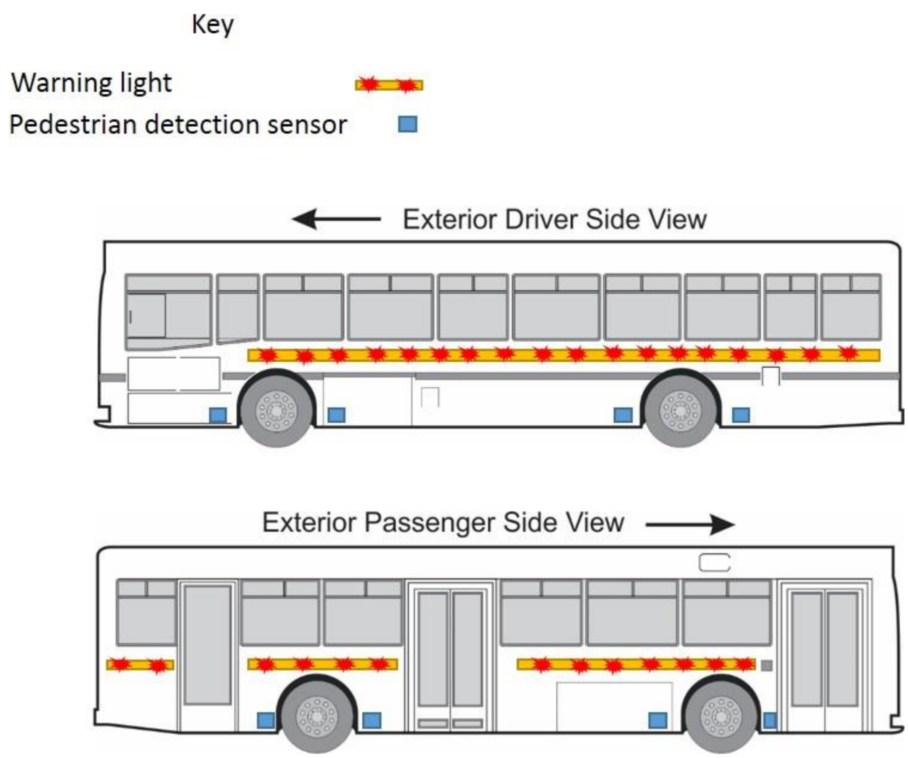


Figure 34. Focus Group Drawing: Dynamic Exterior Lighting

The bus turn status could be used if sensors are incapable of detecting pedestrians, as stated below.

- *"Turn-on a bright flashing light on the side of the bus when it is turning." (P7)*

Coincidently, in March 2015 the Southeastern Pennsylvania Transportation Authority started pilot testing a "Safe Turn System" that has a small strobe light that activates when buses turn (SEPTA, 2015). The strobe light, located next to the front passenger door, is accompanied by an auditory announcement from a speaker mounted on the exterior of the bus. The announcement says, "CAUTION BUS TURNING."

Alerts from Infrastructure

Some focus group ideas also were integrated with infrastructure. For instance, communication between the bus and infrastructure could be used to create pedestrian alerts similar in feel and appearance to existing alerts at parking ramps. The idea is described below.

- *"I was thinking about a system that would pick up the signal from the bus and provide a warning to the pedestrians, like when you are pulling out of a parking garage with the lights overhead that say 'Car Approaching.'"* (P6)
- *"Audible outside, like a horn type, or* [a message] *similar to crosswalks and parking garages indicating 'Warning' or 'Caution.'"* (P1)

Increases in Ambient Illumination

Increases to ambient illumination based on the presence of pedestrians could inform approaching bus operators of the potential presence of pedestrians, as per the comments below.

- *"A blinking street light could help the* [bus operator] *see, or notice that there is a chance that a pedestrian is located there."* (P4)
- *"…this could be triggered by someone standing there."* (P3)

Some bus zones already have illuminators. However, these illuminators can be broken:

- *"Bus stops already have push button LEDs* [for use by riders]*, but sometimes those lights are broken."* (P1)

Minimal Harm Countermeasure

At a minimum, a life-saving strategy could be implemented. For instance, deflecting pedestrians away from the bus. The goal of the idea below is to reduce the likelihood of fatality; however, the system may leave the person injured:

- *"*[Buses] *have these air tanks that have a huge amount of air ...here is a more dramatic idea, use the air to blow the person back* [and] *away from the bus. If sensors detect that you are in the death zone for too long… you'll get a blast of air."* (P7)

The idea of deflecting pedestrians is not new. Although there is no indication of its efficacy, some buses are equipped with a flexible plastic shield used to deflect a fallen pedestrian away from the path of the rear wheels (Pecheux et al., 2008). A demonstration of a deflection product called the S-1 Gard is found on the company's website (www.s1gard.com/home.html).

Ideas for Systems That Facilitate Tasks

A unique idea was to show the speedometer in a HUD to help operators keep their eyes on the road and still know the travel speed.

- *"There are other things you are supposed to be doing, checking mirrors, looking ahead, making sure you are clearing the curb. The speedometer could be in a heads-up display." (P3)*

Another idea was to limit the driving speed to assist with turning at a safe speed.

- *"….something like a speed retarder on the bus. Like, when the bus is turning it would be forced to take the turn at a specific slow speed, the speed they suggest. It may not take pedestrian incidents off the table, but it could reduce or minimize injuries…. We already have retarders on the buses, for going downhill so you don't have to do a lot of braking…."* (P3)
- *"That is interesting, so when you turn the wheel the transmission engages differently, then it slows you down."* (P4)

Existing Mitigation Strategies

The focus group discussed only two existing pedestrian incident mitigation strategies: safety campaigns and the talking bus.

Safety Campaigns

Agency outreach efforts to reduce pedestrian incidents include the use of stickers (banners, tape, etc.) with sayings that serve as reminders to scan for pedestrians:

- *"We have warning notices that are tape that says 'caution pedestrians.'"* (P1)

Stakeholders rate these stickers as effective for reducing pedestrian incidents (Pecheux, et al., 2008). However, there are no published crash data to support their effectiveness.

The Talking Bus

The focus group had knowledge and experience with bus annunciators (e.g., "the talking bus"). However, their opinions were mostly negative. Issues included bilingual messages confusing riders and negative community feedback. For instance:

- *"*[There was a] *bus that broadcasted turn warnings in English and Spanish. I drove this bus once. People could not figure out that there was a Spanish part. People told me they thought it was English."* (P4)
- *"The alert to pedestrians was tested last summer. It said, 'Please stand back, bus is approaching.' Community feedback was like, 'You have got to shut that up.'"* (P8)

Road curves cause the bus-turning message to activate too often for community members. For instance:

- *"We are driving through some of the nicest areas. Moreover, the roads are S-curves there. When I drive through these neighborhoods it keeps talking."* (P7)

DISCUSSION

As identified in earlier efforts within this project, very little attention is given to the DVI designs of different technologies intended for use in transit vehicles. While these devices are often developed with the intention of improving transit operator performance, the manner in which many of these systems provide information to the operator is not optimal. Furthermore, there is a paucity of information in the literature regarding the DVI of transit bus systems.

This research gathered information critical for the design of pedestrian safety transit ITS. The value is timely considering that CV technology enables many lower-cost applications for transit operations. Importantly, the information gained from these studies will be used to support the Human Factors Design Guidance for Driver-Vehicle Interfaces.

Summary of Bus operator Tasks

The focus group was asked to discuss tasks that the bus operators in the scenarios may have been doing preceding the pedestrian incident. Additionally, while describing their ideas for pedestrian detection systems, focus group participants often described tasks.

Table 9 provides three lists of tasks: tasks that occur at intersections, general tasks that occur anywhere, and tasks that occur when passengers are boarding or alighting. Several of the intersection tasks were poorly defined. For instance, the 15-second/1-block visual lead-time tasks lacked a definition, and lacked evidence of their use, but bus operators and driver manuals indicate a requirement for it. Accordingly, this and other topics that were fuzzy were brought into the verification study discussed in Chapter 5.

List of Safety Issues

Safety issues discussed during the focus group are listed below.

- Riders can be visual barriers that occlude hazards.
- Bus operators use their horn to notify riders when approaching a bus stop, but doing so may be a violation of local law or agency policy.
- Deflection devices could save lives (e.g., S-Gard deflector).
- Use of paper timetables creates concern for riders (e.g., MTA driver suspension) and tablet displays could cause a similar concern (e.g., TriMet driver reading a Kindle).
- Route familiarity can be low, requiring operators to use scheduling sheets or assistance from CAD/AVL.

Table 9. Bus Operator Tasks From Focus Group

Intersection Tasks	General Tasks that Occur Anywhere	Boarding/Alighting Passengers
Checking the traffic signal Checking the walk sign status Checking mirrors every 5 to 7 seconds Clearing intersections Clearing lanes as needed Looking forward/Using a 15-second visual lead-time Scanning for: • Pedestrians • Red-light violators • Lane mergers Predicting traffic and pedestrian behavior Turning: • Turning slow (turn speed of 5 to 7 mph) • Rock-and-roll around vision barriers • Squaring off the turn or sweeping the turn	Clearing lanes Giving riders directions Interacting with the CAD/AVL or Driver Display Unit Looking for next bus stop Maintaining awareness of the stop request	Approaching bus stop (same tasks as intersection) Assessing fare discount Taking fares

CHAPTER 4. TASK ANALYSIS

INTRODUCTION

This section describes a task analysis that examined how transit bus operators do their job. The purpose of the task analysis was to address the two prioritized research questions identified in earlier stages of this project.0 and Chapter 6.Appendix B describe the research gap evaluation that led to identifying and prioritizing the issues raised by the questions below.

1. Is there more we can learn about what bus drivers are doing behind the wheel that can support system designs and designs for displays and controls?
    a. The task analysis will address the operational aspects regarding what bus drivers are doing. The design aspects will be investigated in greater detail in the prototyping study.
2. What visual, manual, and cognitive demands are imposed by the use of MDTs or systems with a similar driver interface?
    a. The task analysis will address the imposed cognitive demands associated with existing systems in the bus operator's workspace. This will be accomplished by having operators discuss the mental effort required to carry out tasks while in the operator workspace.

A combination of task and cognitive task analysis methods were used to collect information about transit bus operators and bus-operating tasks (for a review of CTA for transit see Roth, Rosenhand, & Multer, 2013). Data collection methods included workplace observations and interviews. The goal was to capture authentic bus operator behavior in revenue-generating runs (i.e., while driving passenger routes) and use it to determine the visual, physical, and mental demands of the job.

Chapter 3 discussed many bus-operating tasks. Accordingly, those results were integrated with the findings.

METHOD

This section describes ride-along and interview methods used for the task analysis.

Participants

With the consent of the agency, five participants (Table 8) were recruited using the flyer shown in Chapter 6.Appendix J from three metro transit agencies. Participants were compensated $75 for their time, unless not allowed by agency or union policy.

Table 8. Task Analysis Participant Table

ID	Agency	Age	Gender	Experience
I1	B	53	Female	9 weeks
I2	B	52	Male	3 months
I3	A	65	Male	13.5 years
I4	A	50	Male	11.5 years
I5*	C	54	Male	9.5 years

* Demographic values are estimates as the participant missed filling in the information.

Materials

A checklist was created to assist researchers during the observation task, as shown in Chapter 6.Appendix M. The checklist contained information to record periods of interaction with different technologies, as well different actions that the transit operator engaged in at different points in time during the run. A photographic camera was used to document the bus workspace, and a recording device was used during interviews to capture bus operator comments.

Procedure

Four ride-alongs were conducted, one at a time, and were followed by a one-on-one interview. For each session, a researcher met an operator at the transit agency, explained the goal of the ride-along and follow-up interview, and obtained consent using the form in Chapter 6.Appendix K or Chapter 6.Appendix L depending on if the participant could receive compensation or not. After obtaining consent, the researcher sat towards the front of the bus near the operator, but in a passenger seat. The location of the researcher was compliant with agency safety requirements.

The researcher observed the transit operator for a minimum of 2 hours during a route. The observation began at the agency when the bus operator prepared the bus for the route. A full working day was not captured, as the potential length of a workday is 10 hours, which makes it infeasible to observe in a practical manner. However, the ride-along and interview provided adequate information to build an initial understanding of transit operator tasks.

The transit operator’s workspace (i.e., the driver’s area) was photographed. Photographs consisted of the driver’s area at multiple levels of detail, including views of the vehicle controls and displays, as well as the controls and displays of other equipment present.

The interviews were conducted either over the phone or in a quiet room at the agency. The researcher/interviewer questioned the transit operator about the observations made during the ride-along, beginning with leaving the transit agency. The questions were generated ad hoc, but could include any of the following probe questions.

1. What information are you looking for, both inside and outside of the bus, during this time?
2. Are there any specific sequences of events that you must follow?
3. How do you make sure that you are following them?
4. What is the action sequence?
5. What cognitive activities are involved (e.g., mental computations to complete tasks)?

6. What makes this task difficult or easy?
    a. What about the support or information depiction makes the action sequence difficult?
7. What technology or aids are present, and how do they help?
    a. What is good or useful about it?
    b. Are there confusable displays?
8. Are there any aspects of this where the procedure doesn't work?
    a. If so, how do you handle it?
9. Are there any local work-arounds that are used?
10. What kinds of errors can be made?
    a. What are the contributing factors to those errors?
11. What kinds of additional aids might be useful?
12. Do you have any questions or additional information you would like to share?

ANALYSIS

The task analysis identified the types of load associated with bus-operating tasks and mapped out where the load occurs. Observations from ride-alongs and comments from interviews were used to generate the task analysis results. There were two steps to the analysis. The first step was to sort all tasks according to where the tasks occurred along the route within the following activities: boarding and alighting passengers at bus stops, navigating intersections, and driving on the highway and other roadways.

The second step was to match tasks to types of demand using expert judgement. To accomplish this, a series of evaluation tables were made that contained the following six categories of load: broad visual inspection, focused visual search, working memory, executive function), motor demand, and non-typical. The categories are defined in Table 9. Tasks and task locations were inserted into the evaluation tables. Then tasks were marked with an X for each category of load associated with the task.

Table 9 lists the types of load used for the task analysis.

Table 9. Task Analysis Scoring Criteria and Definitions

Load Category	Definition
Broad Visual Inspection	General scanning of the environment to identify tasks (e.g., looking for bus stop signs) and hazards (e.g., bikers in the bike lane)
Focused Visual Search	Tasks such as pre-planned visual search or inspection of the known areas of interest (e.g., checking traffic lights, mirrors, passenger tickets, etc.)
Working Memory	Tasks that require temporarily holding information in memory that will be recalled within a short period of time. These include tasks such as monitoring vehicles that may disappear/reappear from a visual field (e.g., in the side mirrors).
Executive Function	Tasks that require bus operators to make evaluations, determinations, or a decision. Typical executive tasks include evaluating the gaps in the oncoming traffic, determining the state of the traffic signal/light (e.g., if a green cycle has just started or is nearing its end), judging the distance from a curb and/or determining the number of turn lanes, and deciding to turn.
Motor Demand	Tasks that require the bus operator to make physical responses. Some of these tasks are continuous, such as minor corrections of the steering wheel, while others occur at specific locations, such as departing from a previous stop or turning at an intersection.
Non-typical	Tasks that are well known by bus operators, but are unusual or not typical. Transit bus operators are frequently required to cope with unplanned events, which may include passengers asking for directions, noise in the back of the bus, or other unexpected events that may require the attention of the bus operator.

RESULTS

The results are discussed in three sections that correspond to the following activities*:* boarding and alighting passengers at bus stops, navigating intersections, and driving on the highway and other roadways. Each section contains an overview task analysis table and subsections to explain the tasks and ratings.

Boarding/Alighting Passengers at Bus Stops

There are 24 tasks for boarding and alighting passengers at bus stops, which are divided into four primary tasks called approach, prepare for stop, boarding/alighting passengers, and departure. Table 10 shows all tasks across the four primary tasks, and shows the demand categories per task. The tasks are explained in the remainder of this section.

Table 10. Boarding and Alighting Passengers Task Analysis Table

Primary Tasks	No.	Subtasks	BV	FV	WM	Ex	MD	NT
1. Approach	1	Checking the schedule: check timetable for scheduled stop time, and schedule adherence		X		X		
	2	Identify the location of the bus stop	X	X*				
	3	Decide to stop at bus stop: riders at bus stop/stop-request		X	X	X		
	4	Assess space at bus stop for parking the bus for boarding/alighting		X		X		X
2. Prepare for stop	1	Visual scan by alternating glances toward areas of interest: forward, left and right mirrors, and through the door	X	X			X	
	2	Track forward closing-distance to the bus stop			X	X		
	3	Check for traffic approaching from the rear (using left mirror)		X	X			
	4	Monitor current lane position (right mirror)		X	X			
	5	Check distance from the curb (right mirror and door window)		X			X	
	6	Determine if lift/ramp deployment is required.		X		X		
	7	Alert waiting riders at bus stop, if needed					X	
	8	Pull into bus stop				X	X	
3. Board/alight passengers	1	Notify riders at bus stops–inside and outside, using microphone or auto announcement			X	X		X
	2	Board wheeled mobility device passenger, if needed (see breakout of subtasks above)			X	X	X	X
	3	Board other passengers				X		
	4	Monitor fare payments for correct amount, and provide transfers if needed		X			X	
	5	Apply fare discounts		X	X	X	X	X
	6	Assist bikers boarding/alighting				X	X	X
	7	Message dispatch if needed		X		X	X	X
	8	Message onboard riders if needed		X		X	X	X
4. Departure	1	Visual scan by alternating glances toward areas of interest: forward, left and right mirrors, through the door, and through window behind door pillar	X	X			X	
	2	Check for traffic approaching from the rear (using left mirror)		X	X			
	3	If bike lane is present, look in mirror to see if a biker is approaching		X	X			X
	4	Depart by accelerating bus					X	

* If bus system indicates distance to stop in DVI, or if driver is experienced and knows the approximate location.

Primary Task 1: Bus Stop Approach

The bus stop approach has four tasks: check the route schedule, identify the location of the bus stop, decide to stop, and decide where to stop. The approach task consists of broad and focused visual search, executive function, and contains some irregularity (Table 11).

Table 11. Bus Stop Approach Demand Ratings

No.	Subtask	BV	FV	WM	Ex	MD	NT
1	Check the route schedule		X		X		
2	Identify the location of the bus stop	X	X*				
3	Decide to stop at bus stop		X		X		
4	Decide where to stop				X		X

* If bus system indicates distance to stop in DVI, or if driver is experienced and knows the approximate location.

Details on these tasks are discussed below. Comments from participants are identified in parentheses by their ID numbers.

Task 1. Check the route schedule

Checking the route schedule consists of looking at the scheduled times for arriving at stops along the route, and mentally computing schedule adherence based on the current time and schedule. This also requires deciding if the driving speed is adequate to arrive on time.

Checking the schedule requires FV to look at the schedule and Ex to decide if the current driving speed adheres to schedule. The speed may need to increase or decrease to arrive on time. Early arrivals are avoided. The following comment indicates the importance of not arriving early to a bus stop, "*You cannot be early but you can be late. Customers will wait. This helps with prioritizing safe driving*." (I2)

Task 2. Identify the location of the bus stop

Identifying the location of the bus stop consists of visually scanning for bus stop features (bus zone markings, a bus-stop sign, boarding and alighting platforms, etc.). In some areas, vegetation overgrowth occludes identifiable features of the bus stop.

This task requires BV processes because of the visual scanning. Vegetation overgrowth likely increases BV demand.

Task 3. Decide to stop at bus stop

Deciding to stop at a bus stop consists of visually scanning for waiting riders and checking if the onboard "stop request" is active.

This decision task requires FV because of the focused visual scan toward the bus stop and the stop request. In addition, there is a go/no-go decision that requires Ex.

Task 4. Decide where to stop

Deciding where to stop at a bus stop consists of evaluating the available space and deciding where to park the bus. The presence of other buses makes this task more difficult.

Because of the decision-making aspect, this task requires Ex processing. When other buses are not present, Ex demand may be low.

Additionally, bus stops located on the far side of an intersection pose a safety problem when dropping off passengers if a lead bus is already there. A lead bus can cause any following buses planning to stop at the same stop to park behind it, extending into the crossing roadway. In these situations, riders may choose to exit the rear door of the following bus into the roadway; this is what compromises safety. However, the operator may choose to wait for the lead bus to depart to give space for the entire bus before letting passengers off.

If there are no riders needing to board or exit, the bus does not need to stop, and the demand of deciding where to stop is zero (e.g., non-typical).

Primary Task 2: Prepare for stopping at the bus stop

Prepare for the bus stop has eight tasks as shown in Table 12 and consists of BV, FV, WM, Ex, and MD. The subtasks are thought to occur regularly.

Table 12. Prepare for the Bus Stop Demand Ratings.

No.	Subtask	BV	FV	WM	Ex	MD	NT
1	Visual scanning	X	X			X	
2	Track closing distance to the bus stop		X	X			
3	Check for traffic approaching from the rear		X	X			
4	Track current lane position		X	X			
5	Track lateral space between the bus and curb (using information from the right mirror and door window)		X	X			
6	Visually inspect the bus stop for lift/ramp deployment needs		X		X		
7	Alert waiting riders at bus stop, if needed					X	
8	Pulling into the bus stop				X	X	

Details on these tasks are discussed below.

Task 1. Visual Scanning

Visual scanning picks up information necessary for tasks 2 to 5. It consists of searching for hazards by glancing at mirrors and through the front passenger door. The head and torso are often rotated to obtain the proper vantage point. These rotations are for glancing at the door, the mirrors, and through the front window.

Visual scanning requires BV for searching for hazards, FV for glances at mirrors and through the front passenger door, and MD because of the rotating movements of the head and torso. Rotations and glances are repeated until the bus is parked for boarding or alighting.

Task 2. Track Closing Distance to the Bus Stop

In addition, monitoring closing distance (task 2) requires WM processes. General demand can be lower if the bus has such a system, like a CAD/AVL, that shows closing distance in feet or meters. This information is useful on routes with greater distance between stops, as per the following comment from a bus operator: "*I did not watch the CAD/AVL in the inner city because I stop so often, but when there is like 5 miles between stops, I need the reminder from the CAD/AVL."* (I1)

Task 3. Check for traffic approaching from the rear

Checking for traffic approaching from the rear consists of visually inspecting the left mirror for approaching vehicles; the status of traffic is kept in working memory while other tasks are carried out.

In addition to the FV required for inspecting the mirror, this monitoring task requires WM for mentally keeping track of traffic.

Task 4. Track current lane position

Tracking the current lane positon requires WM processes, as it is a monitoring task. Bus operators check the location of the bus relative to the lane line (i.e., fog line) by looking at it in the right mirror and gauging how far the bus is from it by looking at the rear-dual tires.

Task 5. Track lateral space between the bus and curb

Tracking the lateral space between the bus and curb requires WM processes, as it is a monitoring task. This space is tracked by making glances through the windows in the front door.

Task 6. Visually inspect the bus stop for lift/ramp deployment needs

Visually inspecting the bus stop for lift/ramp deployment requires FV for visually scanning the bus stop for mobility devices and Ex processes for deciding if the ramp needs to be deployed.

If a person with a mobility device is at a bus stop, the type of device may need to be identified. A wheeled mobility device, like a wheel chair or a non-wheeled device, may require the lift/ramp. A non-wheeled mobility device, like a walker, may not require the lift/ramp. The following comment describes picking up a rider that used a walker: *"I did not lower the bus or deploy the lift. If it would have been a normal bus without a lift she would have had to lift her walker."* (I1)

If a WhMD rider is present, preparation for boarding and alighting passengers may change slightly because adequate distance is needed to create clearance for lift/ramp deployment mechanisms. Because of this, the bus may have to park farther away (6 to 12 inches) from the curb.

Task 7. Alert waiting riders at bus stop

Some bus operators honk their horn to alert passengers of their arrival, which requires MD processes.

Task 8. Pulling Into the bus stop

Pulling into the bus stop requires MD processes to rotate the steering wheel and apply the brakes. Ex processes are required for deciding how to position the bus. The type of bus stop matters, as pulling into roadside bus stops (i.e., inline stops) is different compared to other bus stops.

At an online stop, the bus operator may decide to approach at a slight angle and park most of the bus in the road while riders board and alight (Transit Authority of River City (TARC), 2013). The angle gets the bus close to the stop, and keeps the rear tires on the road. Keeping the rear tires on the road creates the traction needed to accelerate later during departure.

For bus stops in areas with parked cars, a bus operator has to make sure there is adequate space between the bus and parked cars for merging back into the road after boarding and alighting.

Primary Task 3: Passenger Board and Alight

Passenger boarding and alighting has eight tasks requiring all types of demand except BV (Table 13). Additionally, many subtasks are NT. Therefore, demand may be higher or lower depending on subtasks required of the situation.

Table 13. Passenger Board/Alight Demand Ratings

No.	Subtask	BV	FV	WM	Ex	MD	NT
1	Announcing bus stops to riders			X	X		X
2	Boarding WhMD passenger, if needed (see breakout of subtasks above)			X	X	X	X
3	Boarding other passengers				X		
4	Monitoring fare payments for correct amount, and provide transfers if needed		X			X	
5	Applying fare discounts		X	X	X	X	X
6	Assisting cyclists				X	X	X
7	Messaging dispatch if needed		X	X	X	X	X
8	Messaging onboard riders if needed		X	X	X	X	X

Details on these tasks are discussed below.

Task 1. Announcing bus stops to riders

The announcing bus stops to riders task requires Ex processes for deciding to announce the stop's name, and WM for recalling the name from memory. However, the bus operator may not need to announce the bus stop if the bus has an auto-announce system. Yet, auto-announcers sometimes announce the wrong bus stop because of GPS errors, which requires the bus operator to take over the task.

Task 2. Boarding WhMD passenger

Boarding WhMD riders is NT; it is rare relative to boarding non-WhMD passengers. When it happens, it requires MD for the steps discussed below and Ex for verbal instruction or questioning of these riders.

Subtasks for boarding WhMD passengers include the following (demand type required):

1. Prepare the bus:
    a. Set parking brake. (MD)
    b. Activate four-way flashers. (MD)
    c. Set transmission to neutral. (MD)
    d. Kneel the bus. Note that kneeling is an automatic feature on newer buses. (MD)
2. Verbally indicate to other riders that WhMD rider(s) board first. (Ex)
3. Ask if WhMD rider prefers securement. (Ex)
4. Ask WhMD rider for final destination. (Ex)
5. Secure/do not secure WhMD rider. (MD)
6. Message dispatch about WhMD securement status using integrated fare and dispatch messaging system. (MD, Ex)

Research literature on the topic of WhMD riders indicates that the majority of WhMD riders decline securement. An observational study of 295 video recordings of transit service found that 76 percent of WhMD riders were not secured during their rides, and operator misuse occurred for 44 percent of all attempted securements (Frost, Bertocci, & Salipur, 2013).

Task 3. Boarding other passengers

The decision to allow waiting riders to board requires Ex function.

Task 4. Monitoring fare payments for correct amount and provide transfers

Monitoring fare payments requires FV due to searching for an indication that the rider's fare is correct. The task also requires MD for handing transfers to riders.

Task 5. Applying fare discounts

The applying fare discounts task requires FV for searching for correct buttons on the fare system. It also requires WM for remembering what buttons to press, MD for reaching out to touch the system, and Ex for deciding if a discount is appropriate for the rider. Fare discounts are not as common as regular fares.

Bus operators adjust fares for appropriate riders. They take account of discounts and other fare issues as well as use an integrated fare and dispatch messaging system (Figure 35 and Figure 36). If the fare provided turns out to be incorrect, and the correct amount irretrievable, the bus operator manually inputs the gain or loss amount into the system. Some fare issues may not be accounted for properly due to complicated system interfaces preventing easy access.

Task 6. Assisting cyclists if needed

The assisting cyclists task requires Ex to decide to help cyclists and MD to set up the bus to do so. However, this task does not occur at every stop. In addition, it should be of low general demand because cyclists are responsible for their use of the bike rack. However, there are several tasks for ensuring safety. These tasks are listed below (demand type required):

1. Engage parking brake/keep foot on brake (MD).
2. Kneel bus to help biker use rack, if needed (MD).

3. Alert biker to reset bike rack by honking horn, if needed, after the bike is taken off the rack (Ex, MD).

Figure 35. Integrated Fare and Dispatch Messaging System (Example 1)

Figure 36. Integrated Fare and Dispatch messaging System (Example 2)

Task 7. Messaging Dispatch (if needed)

The messaging dispatch task requires Ex to decide to send a message, WM to remember if the message is available, MD to reach out and press the messaging system's buttons, and FV to visually verify the message on the system screen.

Sending a message may occur the moment before departure. Messages are selected using the dispatch messaging system (Figure 35 and Figure 36). Depending on the design of the system, there may be dozens of preprogrammed message options. Operators may only use a few of these messages. For example, two common messages are "Running a few minutes late" and "Beyond recovery."

Task 8. Message onboard riders (if needed)

Messaging onboard riders requires the same processes as fare discounts, and messaging dispatch. All these tasks use the integrated fare and dispatch messaging system (Figure 35 and Figure 36). Example messages to riders are "Please step back to the rear to make room for more passengers" or "This is the last stop, please de-board."

Primary Task 4: Departure

The final task, departing from the bus stop, consists of four tasks, as shown in Table 14. Notably, BV returns for this task. BV is absent and unnessesary when picking up and dropping off passengers. Accordingly, bus operators restart BV, which may incraese demand substantially. The validation study chapter reviews this topic and confirms the changes in visual demand throughout the primary tasks when approaching bus stops.

Table 14. Bus Departure Demand Ratings

No.	Subtask	BV	FV	WM	Ex	MD	NT
1	Visual scan by alternating glances toward areas of interest: forward, left and right mirrors, through the door, and through window behind door pillar	X	X			X	
2	Check for traffic approaching from the rear (using left mirror)		X	X			
3	If bike lane is present, look in mirror to see if a biker is approaching		X	X			X
4	Depart by accelerating bus					X	

Details on these tasks are discussed below. Comments from participants are identified in parentheses by their ID numbers.

Task 1. Visual Scanning

Bus operators conduct visual scans similar to those in primary task 2. However, there is additional effort added by the rock-and-roll technique and glances through the windows near the front passenger-entry door. Furthermore, patrons are more likely to block the driver's view of the critical areas after boarding, which makes visual scanning difficult.

The following comment discusses riders as visual obstructions: *"… the most important scan looks to the far right [100 degrees turn from center]. I do this before I take off from a stop. I turn to look into the mirror, then continue turning to look through the door and behind the pillar of the door. However, sometimes there is a vision barrier. Sometimes I'm looking through customers' heads"* (I1). As with other visual obstructions, bus operators rock-and-roll around passengers to obtain the proper vantage point to check for hazards. However, passengers can be of various sizes and are thus not easy to rock-and-roll around.

Task 2. Check for rear traffic

Before departure, a glance is made toward the left mirror to check for traffic coming from behind the bus; this task happens in primary task 2.

Task 3. Check for bikers

Bus operators monitor for bike riders by checking mirrors. This requires FV and WM processes for glances and mentally tracking approaching bikers. Bike lanes and bike traffic have intermittent presence.

Task 4. Depart by accelerating bus

Departing from the bus stop is the final task and occurs once all hazards have been cleared. It requires MD to depress the accelerator.

Navigating Intersections

The intersection task analysis was created using comments from the ride-along interviews and the focus groups from the prototyping study. Discussion topics are labeled to indicate if they came from the focus group, interviews, both, or the literature.

Navigating intersections has three primary tasks: approach, intersection entry, and preparing the maneuver. The validation study in Chapter 5 includes a fourth primary task called "Monitor Safety" that continues throughout all tasks. Primary tasks are explained in detail in this section.

Table 15. Boarding and Alighting Passengers Task Analysis Table

Primary Tasks	No.	Subtask	BV	FV	WM	Ex	MD	NT
1. Approach	1	Visual scan by alternating glances toward areas of interest: forward, left and right mirrors, through the door, and through window behind door pillar	X	X			X	
	2	"Clearing"				X		
	3	Choose approach lane		X		X		
	4	Maintain visual lead time	X		X			
	5	Scheduled mirror checks		X			X	
	6	Check traffic signals		X				
	7	Accelerate/coast/decelerate				X		
2. Intersection entry	1	Continue visual scan and "clearing"	X	X		X	X	
	2	Predicting traffic and pedestrian behavior			X	X		
3. Prepare/ execute maneuver	1	Visual scan and "clearing"	X	X		X	X	
	2	Execute maneuver, turn or go straight					X	
	3	Calibrate speed		X		X	X	
	4	Squaring off the turn/or sweeping the turn		X	X		X	X

Primary Task 1: Intersection Approach

Approaching an intersection consists of seven tasks that occur regularly, and occupy BV and FV, WM, Ex, and MD (Table 16). The details on tasks like "clearing," which are not described in the literature or alternate sources (i.e., Internet blogs), are described using the vernacular of the bus operators who participated in the focus groups, ride-alongs, and interviews.

Table 16. Intersection Approach Demand Ratings

No.	Subtask	BV	FV	WM	Ex	MD	NT
1	Visual scanning	X	X			X	

No.	Subtask	BV	FV	WM	Ex	MD	NT
2	“Clearing”				X		
3	Choose approach lane		X		X		
4	Maintain visual lead time	X		X			
5	Scheduled mirror checks		X			X	
6	Check traffic signals		X				
7	Accelerate/coast/decelerate				X		

Details on these tasks are discussed below. Comments from participants are identified in parentheses by their ID numbers.

Task 1. Visual scanning

Visual scanning is a continuous task that occurs while the bus is in motion. It requires BV, FV, and MD due to the glances toward areas of interest: forward, left and right mirrors, through the door, and through window behind door pillar, and the body motions required to achieve the proper vantage point.

Task 2. “Clearing” (FG)

Clearing lanes and intersections starts during the approach but continues throughout the intersection. “Clearing” is a judgement that the bus operator makes and requires Ex. An intersection or lane is clear when a visual scan completes and no hazards are present, including pedestrian and vehicle traffic. An operator offered the following insight on judging if an intersection is clear of pedestrian hazards: “*To be sure it is safe to get through the intersection, that the intersection is clear, I look for people who may dart across or that aren’t paying attention to traffic.”* (P6)

Task 3. Choosing approach lane

Bus operators must choose the correct driving lane for going straight, turning right, or turning left. For example, the right lane occasionally becomes a turn lane, and the bus operator must merge into the mainline to go straight. However, there are intersections where the right turn lane permits bus traffic to travel straight, which is mentioned in the following comment: “*There was a double lane and a turn lane, you cannot always be in the right lane because there are turning lanes, but at that spot, buses were permitted to go straight.*” (I1)

Occasionally, at intersections where buses are permitted to continue straight, there may be a sign that says, “RIGHT LANE MUST EXIT – EXCEPT TRANSIT BUSES” (Martin & Levinson, 2012). There may also be bus-only shoulder lanes running continuously through intersections, which may be only legally usable during peak traffic times when congestion is present.

Because of the need to identify traffic guide signs and decide the appropriate travel lane, bus operators use BV and Ex when deciding the proper travel lane.

Task 4. Maintain visual lead time (FG and interviews)

Bus operators are always glancing forward, and using a 15-second, or one-city block, visual lead time. The focus group and interviews discussed visual lead time. Other than stating that bus operators look forward and mentally track time, a conclusive definition was not offered. Additionally, a sufficient definition of driver visual lead time is absent in the literature, although the notion of visual lead time is discussed in driver training manuals (e.g., California DMV driver's manual, the New York DMV commercial driver manual, the *Trucking: Tractor-trailer Driver Handbook/Workbook*).

The following quote indicates that bus operators are trained to maintain visual lead time: *"We are trained to do a quarter mile or 15 second eye-lead time. For eye lead time, we pick a specific point and count one-one-thousand, two-one."* (I1) The quote offers insight on mental tracking, but is insufficient in detail for fully understanding the visual lead time, practice, and usefulness of visual lead time.

Additionally, some bus operators may limit their visual lead time to reduce its cognitive load, as per the following comment: "*I do not anticipate anything, because if you start anticipating then your mind is working too much and it's not working on the things that it should, like mirrors, mirrors, where are my duals. Thinking too far ahead can get you into trouble."* (I2)

Accordingly, due to the cognitive load and scanning requirements, the visual lead time task was rated as requiring BV and WM resources.

Task 5. Scheduled mirror checks (FG and interviews)

In addition to scanning, there are scheduled glances toward mirrors. Bus operators are trained to check their mirrors every 5, 7, or 8 seconds. Additionally, they are trained to visually dwell on the mirror for a prescribed duration of 2 seconds. A visual dwell time of greater than 2 seconds is called a "fixed stare," described as follows: *"We are trained to look at the mirror every 5 to 8 seconds. If you look for more than 2 seconds, they call it a fixed stare. I try to do the best I can to turn my head all the time so I do not get in that fixed stares."* (I1)

Mirror checks require the operator to move their head or torso to view the mirror, which leads to eyes-off-road time. Bus operators recognize these risks and the benefits of proper mirror usage, and believed mirrors could be improved to aid mirror checks. For instance, the focus group thought the mirrors should be brought closer to the forward view.

Regarding the demand ratings, because of the intent to glance at the mirrors, and the requirement for bus operators to move their head or torso to view mirrors, the scheduled check mirror task in Table 16 notes FV and MD resources.

Task 6. Check traffic signals (FG)

Bus operators check the status of the walk signs and traffic signals, which is a task requiring FV resources. The focus group discussed checking traffic signals, as follows: *"…scanning the intersection* [and checking] *walk signs and signal light* [status]." (P6)

Task 7. Accelerate/coast/decelerate (literature)

Previous literature indicates that bus operators use the traffic signal status to determine if they should accelerate, coast, or decelerate (Wei et al., 2014). The bus operator may slow or stop the bus if the signal is a "stale" yellow (i.e., the signal has been yellow for several seconds during the approach).

Primary Task 2: Intersection Entry

Entering the intersection has two tasks: visual scanning and predicting traffic and pedestrian behavior. These tasks require BV and FV, WM, Ex, and MD (Table 17).

Table 17. Intersection Entry Demand Ratings

No.	Subtask	BV	FV	WM	Ex	MD	NT
1	Continue visual scan and “clearing”	X	X		X	X	
2	Predicting traffic and pedestrian behavior			X	X		

Details on these tasks are discussed below. Comments from participants are identified in parentheses by their ID numbers.

Task 1. Continue visual scan and “clearing” (FG)

As the bus begins to enter the intersection, in preparation for the turn, the operator will be scanning for pedestrians, cyclists, and traffic for red-light violators and lane mergers. If cyclists are present, bus operators will wait for them to traverse the intersection before proceeding, which may require slow driving or that the bus be stopped, according to the following comment: “*…At an intersection with 40 bikers ahead of me, my strategy was to let the bikers all go before me. When it comes to other traffic, I’ll bully cars by putting my hand out to let them know that I’m merging*.” (I1)

Additionally, the bus operator tries to initiate eye contact with cyclists to communicate the operator is aware of the biker, as per the following comment: *“Eye contact is good for drivers, and it’s easy for bicyclists because they don’t have anything blocking them, no windows. But, we need to let them know we see them.”* (I1)

Task 2. Predicting traffic and pedestrian behavior (FG and interview)

Bus operators try to predict the behaviors of surrounding auto, cyclist, and pedestrian traffic. A cyclist’s movement may provide a strong cue to imminent behavior or intention to enter an intersection, as per the following comment: *“*[Bicyclists,] *if they are not stopped, then they’re going for it, so I stop, and stay stopped until they go by….”* (I1)

However, the imminent behavior of auto and pedestrian traffic is predicted by looking for facial expressions and body or car language, as per the following comments:

“Identifying intent on faces helps predict what people are going to do.” (P1)

“Trying to read body and car language… I try to tell what people are going to do. See if [drivers of other vehicles] *look at me.”* (P2)

It is common to take mental note of the status of surrounding traffic during visual search. If there appear to be no hazards, the operator continues scanning. Regarding the ratings, predicting traffic requires WM and Ex resources for remembering and reassessing traffic, and deciding if a pedestrian, car, or bicyclist has become a hazard.

Primary Task 3: Prepare and Execute Maneuver

Preparing and executing a maneuver requires all mental resources. Additionally, some of the techniques (e.g., squaring a turn) are used situationally by some, but not all bus operators.

Table 18. Prepare and Execute Maneuver Demand Ratings

No.	Subtask	BV	FV	WM	Ex	MD	NT
1	Visual scan and "clearing"	X	X		X	X	
2	Execute maneuver, turn, or go straight					X	
3	Calibrate speed		X		X	X	
4	Squaring off the turn or sweeping the turn		X	X		X	X

Details on tasks are discussed below. Comments from participants are identified in parentheses by their ID numbers.

Task 1. Visual scan and "clearing"

The importance of rock-and-roll was further emphasized as a key safety technique when turning at intersections. Bus operators are trained to rock-and-roll (i.e., pivot their body and head to peer around fixed visual obstructions), and are told that rock-and-roll should happen when the bus is turning. The ratings reflect the visual scanning demands and motor demands, as well as the executive function demands for deciding if the intersection is clear.

Task 2. Execute maneuver, turn, or go straight

Executing the maneuver at the intersection is purely a motor task. Thus, it requires only MD. Other processing demands co-occur, as shown in the ratings in Table 18. Some bus operators do additional tasks to enhance the safety of those outside the bus. For instance, an interviewee activates the horn when turning to alert anyone that may be near, for example, "*When I am turning corners I toot my horn twice*." (I4)

Task 3. Calibrate speed (FG)

Bus operators may adjust their driving speed when traversing intersections. For left and right turns, bus operators are supposed to drive at slow speeds. Some operators mention that their agencies want them to turn at speeds of between 3 and 7 mph, and that driving a specific speed while making a turn is difficult due to the overall demand of executing a turn (see focus group discussion).

Calibrating speed requires glancing at the speedometer, evaluating if the current speed is appropriate, and adjusting the throttle if needed. Respectively, calibrating speed requires FC, Ex, and MD processing.

Task 4. Squaring off the turn or sweeping the turn (FG)

The focus group talked about two types of turn maneuvers: squaring or sweeping the turn (see focus group discussion). The squaring maneuver is characteristic of left turns and sweeping is characteristic of right turns. On occasion, bus operators may sweep their left turns.

There may be WM requirements for acting out the phases of a square turn. Squaring the turn has two phases, entering the intersection and then turning. The two phases allow the operator to visually scan and clear the intersection before rotating the wheel and executing the turn. The sweeping turn has one phase. In addition, it is usually executed at a faster speed to carry bus momentum through the turn (Mentzer, 2014).

Bus operators look through the right mirror when executing right turns to confirm the bus wheels do not strike the curb, which requires FV processes. An interview described the right turns as follows: *"The view of the wheel* [through the right mirror] *is necessary for right turns so you can see when you pass the turning point and that you are gonna clear that curb."* (I1)

Driving on the Highway and Other Roadways

There was substantial discussion about driving on highways and other roads. However, it was less informative for creating a task analysis. Accordingly, the topics listed below provide a summary of insights about general driving.

Visual Lead Time

Bus operators maintain awareness of their surroundings by continuing to use the visual lead time method, as discussed within the Intersection cognitive task analysis. The following comment suggests that visual lead time is executed the same on highways: "*We are trained to quarter mile, or 15-second eye-lead time. For eye lead time, we pick a specific point* [on the highway] *and count one-one-thousand, two-one-thousand....."* (I1)

Monitor Traffic

Bus operators monitor traffic that is both near and far, and behind the bus as per the following comments:

> *"When I see brake lights a quarter mile out, I begin planning to decelerate." (I1)*
>
> *"When I pull out [onto the highway, entering from an on-ramp], I check the blinkers of the cars that are coming up behind me, and I look at their eyes, to see where they are looking, and to make sure they do not merge in front of me." (I4)*

Clearing Lanes

Bus operators also monitor available space in adjacent lanes and adjust their driving speed to make sure there is space for emergency lane mergers. The following comment discusses "leaving an out," which is part of a standard training program called the Smith System: *"The space next to you is also important. You need an out. Need to back up or speed-up, so you have an out. This is part of the Smith System."* (I1)

Lane Positioning

Bus operators drive off-center of driving lanes and they select the fastest driving lane when possible. Driving off-center of the lane puts the bus in a position that ensures the bus will not collide with infrastructure on narrower roadways and driving in the fastest lane allows for better schedule adherence but requires lane merging. This was discussed as follows:

> "*When you go into* [a narrow roadway or lane], *you hug the lane-line that is the farthest away to give 3- to 4-feet on the other side. I ride right on the yellow line. I envision my knee is on the yellow line because then I know the tire is on the yellow line. I double check in the mirrors, because when you* [drive through a curve] *you don't steer like a car, because the rear can go over the yellow line so you steer out, you're aiming out. This is so your duals don't go over the line."* (I2)

> *"… I picked to drive the fastest lane. Then merged over when getting closer to the exit."* (I4)

Depending on the road and presence of traffic, the bus may be driven near the fog line rather than in the middle of the lane.

Traffic Control

Bus operators attempt to prevent traffic from the rear cutting off or colliding with the bus.

> "[When entering the highway from an entrance ramp] *I will turn on the left signal to get the on-coming traffic's attention.* [Activating the blinker as if merging into the lane] *was to try to prevent traffic from trying to merge into me at the last second.*" (I4)

Additionally, at crosswalks, as a safety measure for crossing pedestrians, they may position the bus in the middle of the road to block both lanes.

> *"If I stop in front of a crosswalk, I block both lanes to reduce the likelihood of them getting hit in the crosswalk."* (I4)

DISCUSSION

The task analysis discussed the demands of boarding and alighting passengers, navigating intersections, and driving on roadways. The results suggest that operating a bus is a demanding task, but the demands are not always the same. Sometimes multiple demands co-occur; mental, visual, motor, and executive demands happening at the same time may overwhelm the bus operator. Therefore, it is important to identify tasks that lead to overwhelming amounts of demand. The task analysis accomplished this by use of heuristics and expert assessment. The results of the analysis regarding bus stops and intersection tasks were explored further in the validation study discussed in Chapter 5. Regular driving tasks are left for other researchers to explore in detail.

A key take-away from the analysis of bus-stop tasks was that broad visual demand disappears when riders board, then reappears at departure. The amount of demand during this high-low-high transitional phase is explored in Chapter 5. Intersection tasks did not appear to wax and wane like bus stop tasks. These tasks had a lot of overlap with types of demand. Broad and focused visual search occurred during most of the primary task segments; like bus stops, the amount of visual demand is explored in Chapter 5.

CHAPTER 5. TASK ANALYSIS VALIDATION STUDY

INTRODUCTION

This section discusses a validation study of the bus-operating tasks identified from the prototyping study and task analysis discussed in Chapters 3 and 4. Those chapters discussed over 90 bus-operating tasks that occur while buses are driven on service routes. The validation study presented those tasks in several focus groups with bus operators and asked them to affirm their correctness and to estimate the mental, physical, and visual demands of each task.

This report structures bus-operating tasks in two ways: the task analysis followed in Chapter 4, and the hierarchical task analysis used in this chapter. Chapter 4 estimated the cognitive and motor demands using researcher judgment. The HTA in this chapter illustrates a structure of the tasks and subtasks (see Figure 37 and Figure 38). These HTA versions were used for the validation study and were presented to groups of bus operators who were asked to verify accuracy, insert additional relevant tasks, and provide demand estimates.

Designers of transit technology systems will benefit greatly from accurate information about when and how bus-operating tasks occur. A task analysis provides information about context of use, which is useful for matching systems' designs with tasks and goals and is essential in human systems integration (see Pew & Mavor, 2007). Furthermore, task analysis identifies opportunities for effective aids or support systems by identifying how, when, and what to information to present. The goal of this research is to identify a complete and accurate understanding of bus-operating tasks that can lead to better user-centered design decisions.

METHOD

Participants

Four focus groups were conducted with 16 bus operators (10 male, 6 female; *M* = 54 years, *SD* = 11 years) from two major metropolitan bus agencies in the United States. Eight of the participants had more than 10 years of experience, and eight had between less than one year and 10 years of experience. Operators enrolled in the study by responding to recruitment flyers posted on bulletin boards or in newsletters. Prior to beginning, consent was obtained using the form in Chapter 6.Appendix N or Chapter 6.Appendix O depending on if the participant could receive compensation or not. In return for their participation, they were compensated with $75 cash unless not allowed by agency or union policy. Additional information on the focus groups is in Table 19.

Table 19. Focus Group Demographics

ID	Focus Group	Topic	Agency	Age (yrs.)	Gender	Experience (yrs.)
P1	1	Approaching Bus Stops	A	57	M	36
P2	1	Approaching Bus Stops	A	53	F	< 1
P3	1	Approaching Bus Stops	A	34	M	12
P4	1	Approaching Bus Stops	A	52	M	5
P5	2	Navigating Intersections	A	48	M	2.5
P6	2	Navigating Intersections	A	61	F	< 1
P7	2	Navigating Intersections	A	58	M	1
P8	2	Navigating Intersections	A	59	F	10
P9	2	Navigating Intersections	A	46	M	14.5
P10	3	Approaching Bus Stops	C	25	F	< 1
P11	3	Approaching Bus Stops	C	54	F	22
P12	3	Approaching Bus Stops	C	59	F	34
P13	4	Navigating Intersections	C	65	M	18.5
P14	4	Navigating Intersections	C	59	M	5
P15	4	Navigating Intersections	C	62	M	11
P16	4	Navigating Intersections	C	43	M	4

Materials

Focus group materials included a moderator guide, task cards, task diagram posters, and a workbook with instructions and a survey.

Moderator Guide

The moderator guide is reprinted in Chapter 6.Appendix P. It was read at the beginning of each focus group.

Workbook

The participant workbook is reprinted in Chapter 6.Appendix Q and included focus group instructions, a demographic survey, surveys for each set of subtasks.

Task Cards and Task Diagrams Posters

Task cards were constructed out of 2-inch by 4-inch paper cards. Task names, numbers, and definitions were printed on the cards. The task cards were adhered to two 2-foot by 6-foot posters, one for each main task: arriving at bus stops and navigating intersections. Task cards were adhered to the posters with removable adhesive to allow for removal or adjustment during the focus groups. This was the main visual stimulus for the key focus group activity. The posters portrayed a hierarchical diagram of bus operating tasks for the two main tasks (Figure 37 and Figure 38).

A series of task cards is shown in Table 20. The full collection of task cards used during the focus groups are provided in Chapter 6.Appendix R and Chapter 6.Appendix S. Tasks came from the task analysis and prototyping study (Chapters 3 and 4). Blank task cards were available for participants to write additional tasks that were not already on the posters.

Table 20. Example Task Cards

Task Number: 1 **Task Name:** Approach the bus stop. **Task Definition:** This task consists of driving towards or approaching the bus stop.	**Task Number:** 1.1 **Task Name:** Check the route schedule. **Task Definition:** Checking the schedule consists of looking at the schedule/timetable. It may require deciding if the driving speed is adequate to arrive on time. "*Make sure you're not running hot if this is a time spot*."
Task number: 1.1.1 **Task Name:** If early, decide if it's OK to wait **Task Definition:** This task consists of evaluating the bus-zone for room to "sit-and-hold" to get back on schedule without block incoming buses.	**Task number:** 1.1.2 **Task Name:** If late, approach stop as normal. **Task Definition:** This task consists of proceeding to the bus-zone to exit/board passengers and proceed to the location of the next bus stop.
Task Number: 1.2 **Task Name:** Find location of the bus stop. **Task Definition:** This task consists of visually scanning for bus stop features (e.g., bus zone markings, a bus stop sign, boarding and alighting platforms, etc.). In some areas, overgrown vegetation may block from seeing identifiable features of the bus stop.	**Task Number:** 1.3 **Task Name:** Decide if stop is needed. **Task Definition:** Deciding to stop at the bus stop consists of visually scanning for people waiting at the bus stop, and checking if the on-board "stop-request" is active.

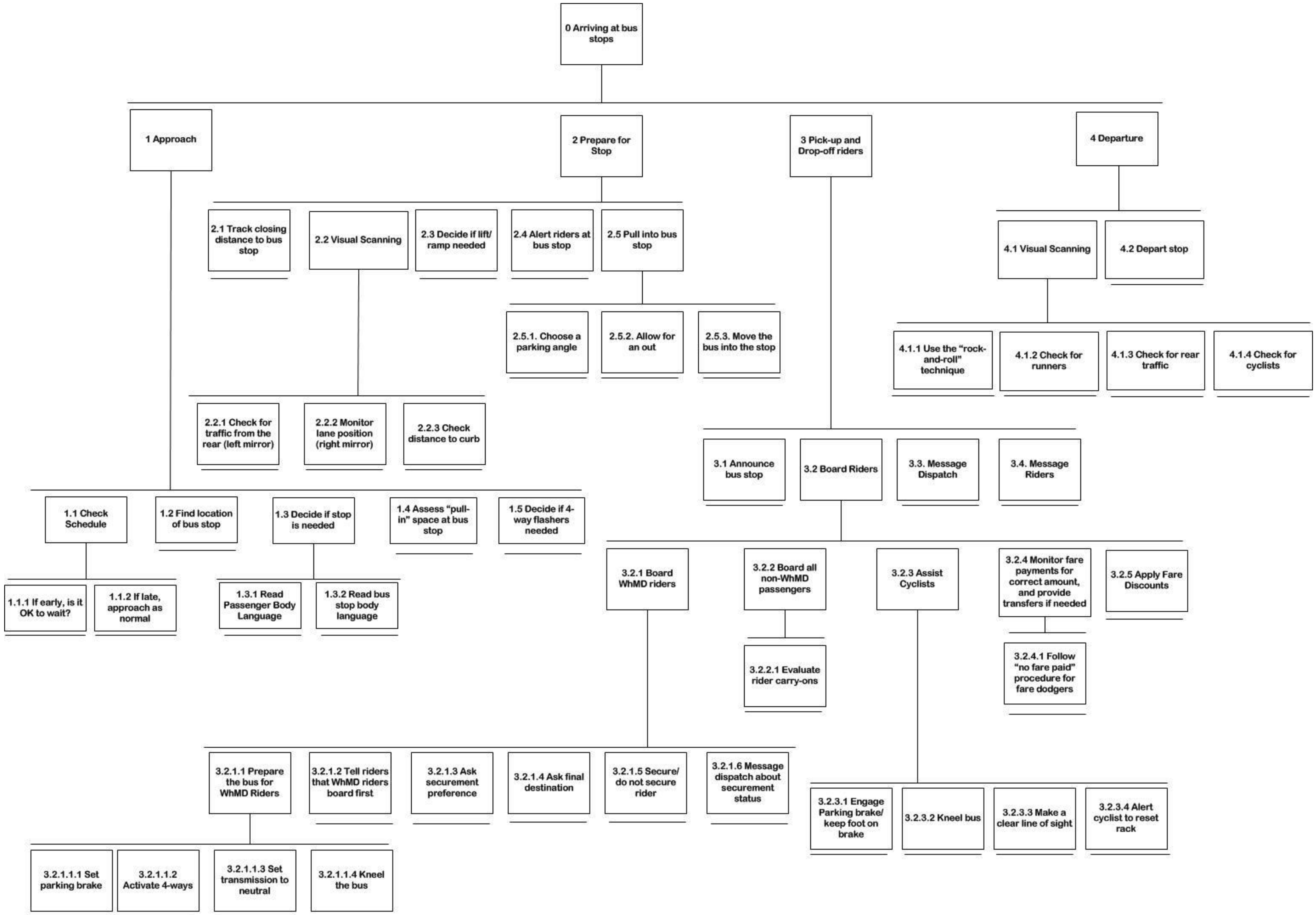


Figure 37. Arriving at Bus Stops Task Diagram

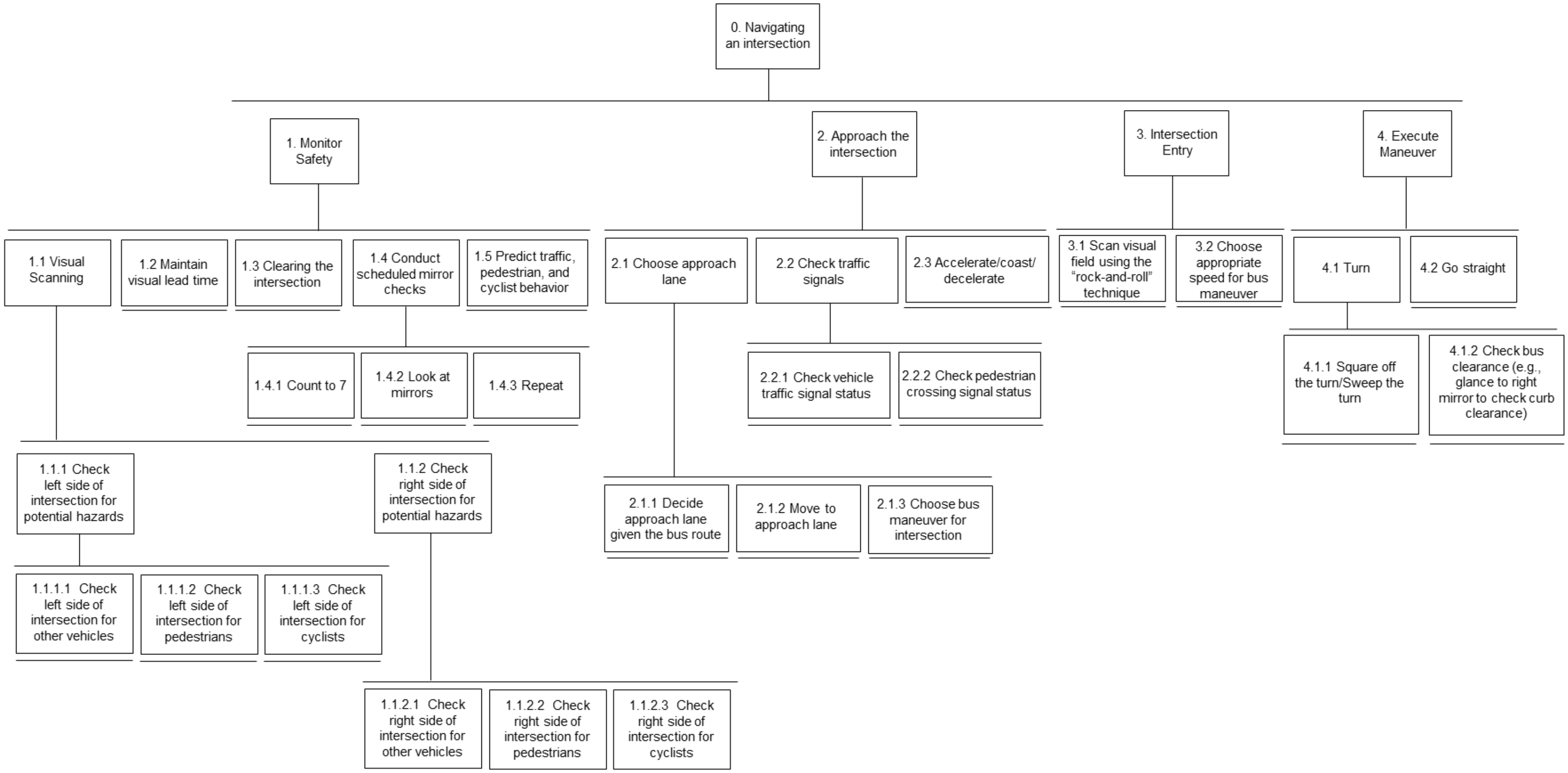


Figure 38. Navigating an Intersection Task Diagram

Participant Workbook

The workbook provided instructions about the focus group activities and contained the demographic and demand survey. The demand survey asked operators to estimate the physical, mental, and visual demand of each task, the frequency at which each task occurs, and how understandable the tasks were as written and discussed in the focus group.

The focus group activity instructions are printed below. An example of the workbook is reprinted in Chapter 6.Appendix I.

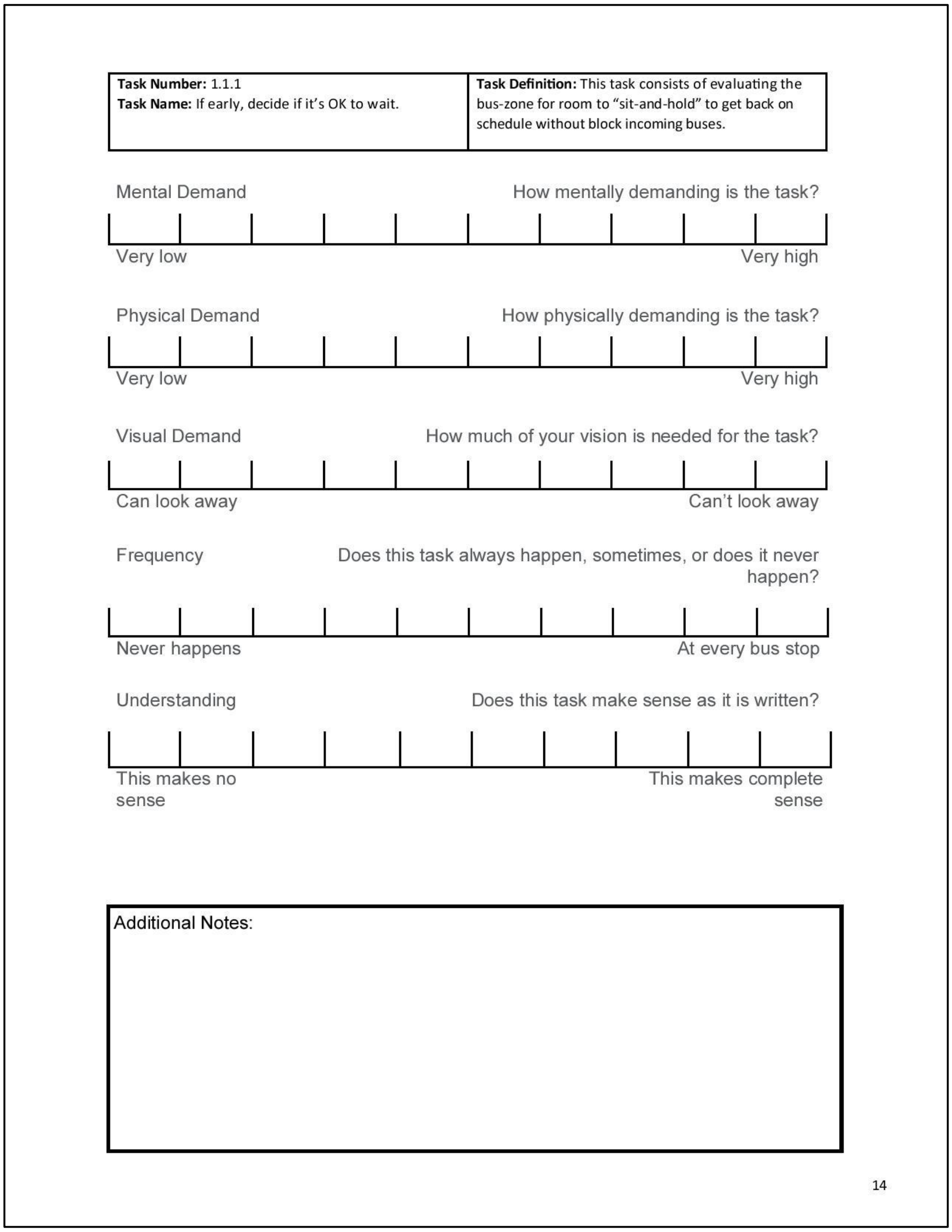
> ***Purpose of the Focus Group:*** *The purpose of today's focus group is to verify our recent work on bus operating tasks. We'll be looking at diagrams of bus operating tasks that my team recently developed. These diagrams were made using information from our previous focus groups, and our observations of bus-operators during revenue routes, and interviews with those operators. The job for the focus group is to verify the accuracy of the tasks that we've identified so far. As part of this job, please tell us about additional tasks or subtasks that are not in the diagram but should be. We'll be working as a group for most of today. Groups sometimes have disagreement. There may be instances when we do not reach consensus agreement about a task. To aid in a timely focus group, the moderator reserves the right to make the final decision for including or excluding any task or tasks. However, we need to record these disagreements. Accordingly, there is a survey that we'll do later that serves this purpose.*
>
> ***Making Task Diagrams:*** *The best way to learn how to make a task diagram is by looking at an example. There is an example diagram on the next page. It diagrams how a cup of tea can be made. The diagram shows five tasks (boil water, empty pot, make pot, wait, pour tea). Many of the tasks have subtasks. For instance, boil water has five subtasks (fill kettle, put kettle on stove, turn on stove, wait, turn off stove). These sub-tasks can have further sub tasks. We'll diagram bus operating tasks in the same way. We drafted bus-task diagrams already. These are shown on the pages after the tea example. Additionally, we prepared a much larger version that's taped to the wall. The larger version is what we'll edit or make changes to during the focus group to verify accuracy and add tasks. While we work on the diagram, think about tasks at a high level that generalizes across city-transit bus style, and route. These tasks should happen on low-floor 42 footers, articulating buses, trolley, or other. Paratransit and coach are excluded.*
>
> ***Diagramming Task Cards:*** *The larger diagram consists of task cards that describe many bus operating tasks. Blank cards are available for us to add tasks that are not included so far.*
>
> ***Survey:*** *Again, there is a survey later. We ask that you complete the survey after we complete our task with the large diagram. The survey will help us understand how often the tasks occur, and the mental and physical demands of the tasks. Survey instructions*

and an example are shown on pages 10 and 11. Please read over these instructions during any breaks.

The following instructions were provided before the survey began.

> ***Instructions:*** *This is a five-question survey that is repeated for each task in the large diagram. There is one survey on each of the remaining pages in this book. Please use as many surveys as are necessary to provide your responses to all tasks on the larger diagram. There is blank space on each page for providing any additional information that you think is important. The majority of the pages will already have the task number and name written at the top of the page. If task names or numbers are missing, please write the task number or name at the top of the page. The five survey questions ask for estimations of mental demand, physical demand, visual demand, frequency, and your understanding of the task. These terms are defined below.*
>
> ***Definitions:***
>
> > ***Mental Demand:*** *How much mental and perceptual activity is required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Is the task easy or demanding, simple or complex, exacting or forgiving?*
> >
> > ***Physical Demand****: How much physical activity was required (e.g.. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?*
> >
> > ***Visual Demand:*** *How much eyes-on effort is needed? How much of your vision is necessary for the task? Can you look away from the task? Does this task case fixed stares? This should be considered as the proportion of time that a bus-operator's eyes are directed toward a task, either the primary task of driving or secondary tasks.*
> >
> > ***Frequency:*** *How often does the task occur on any given workday? On a regular route? Does this task always happen, sometimes, or does it never happen.*
> >
> > ***Understanding:*** *To what degree do you understand the task-card you're evaluating? Does the task make sense or not.*
>
> *Tear out this page if it helps to keep track of the survey definitions.*
>
> *There is an example of how to respond to the survey on the next page.*
>
> *In most instances, the order of the tasks in the survey is different than the order in which they were presented. Please make note the task name and number at the top of the page when filling out the survey.*

Figure 39 shows an example of a survey for one task. The format and questions were the same for each task. Only tasks that were secondary, tertiary, quaternary or lower in the hierarchy were included in the survey. Primary tasks were excluded to reduce the likelihood of participant fatigue. The demand of a primary task is an aggregate of the demand of all tasks under it. The survey combined questions from the NASA Task Load Index (Hart & Staveland, 1988) and the Driver Activity Load Index (Pauzie, 2008). This was the first use of this unique combination of questions.



Task Number: 1.1.1 **Task Name:** If early, decide if it's OK to wait.	**Task Definition:** This task consists of evaluating the bus-zone for room to "sit-and-hold" to get back on schedule without block incoming buses.

Mental Demand — How mentally demanding is the task?
Very low — Very high

Physical Demand — How physically demanding is the task?
Very low — Very high

Visual Demand — How much of your vision is needed for the task?
Can look away — Can't look away

Frequency — Does this task always happen, sometimes, or does it never happen?
Never happens — At every bus stop

Understanding — Does this task make sense as it is written?
This makes no sense — This makes complete sense

Additional Notes:

14

Figure 39. Demand Survey With Example Task

Four versions of the survey were created for each focus group. Primary tasks were used to create the order of each version of the survey. All subtasks within a primary task were blocked by the primary task. The blocks were quasi-randomly sorted, then the primary tasks were removed from the survey. The versions were assigned to participants at random. Table 21 shows the blocking orders. There were four orders per topic.

Table 21. Survey Blocking Orders

Topic	Intersection	Intersection	Intersection	Intersection	Bus Stops	Bus Stops	Bus Stops	Bus Stops
Block no.	1	2	3	4	1	2	3	4
Task no.	1	4	2	3	1	4	3	2
Task no.	2	3	4	1	2	1	4	3
Task no.	3	2	1	4	3	2	1	4
Task no.	4	1	3	2	4	3	2	1

Procedures

The focus groups began with the moderator reading the moderator guide. The task diagrams were then presented one task at a time. The floor was open for discussion after the presentation of each task, and the researchers would ask if any adjustments or edits should be made to the task, or if any tasks should be added. Two researchers were available to present the task diagrams; one researcher presented the bus stops diagram, and the other presented the intersection diagram.

After the task diagram was presented, the operators were asked to rate the mental, visual, and physical demands of each task using the demand survey.

ANALYSIS

The survey results were analyzed using descriptive statistics. There are three metrics to report the survey results: original scores, weighted scores, and an overall demand score.

Original and weighted responses to the demand survey items are reported in the results. Demand responses were weighted by responses to the frequency survey item; this weight was computed as an inverse of the average of all responses, and then it was applied to the original responses as a multiplier. In this manner, statistically accounting for frequency of the task provides an indication of absolute or minimal demand. An overall demand score was derived by averaging responses across mental, visual, and physical demand.

The analysis of responses to the self-reported demand survey is shown in Appendix R. Focus group participants provide a demand score for all but primary tasks. The response scale was 1 to 10, with 1 representing the lowest and 10 representing the highest demand, and 5 representing optimal demand.

Figure 40 is a theoretical framework, loosely based on the Yerkes-Dodson Law of Arousal and Performance (Yerkes & Dodson, 1908), for evaluating the responses to the survey questions. However, here the y-axis represents frequency not performance. It depicts an ideal response pattern for any one task. It assumes there is an optimal level of demand and shows the optimal as the mean with a normal distribution. At an optimal level, demand is not too high, nor too low. Low demand may lead to a lack of engagement and high demand may lead to overloading. If a task has a mean response rate that is high and low, it should be interpreted as having a non-optimal amount of demand. Additionally, if a survey item has great variance (i.e., wide distribution) nothing can be assumed about the demand of the task other than that the responders did not agree on a level of demand for it.

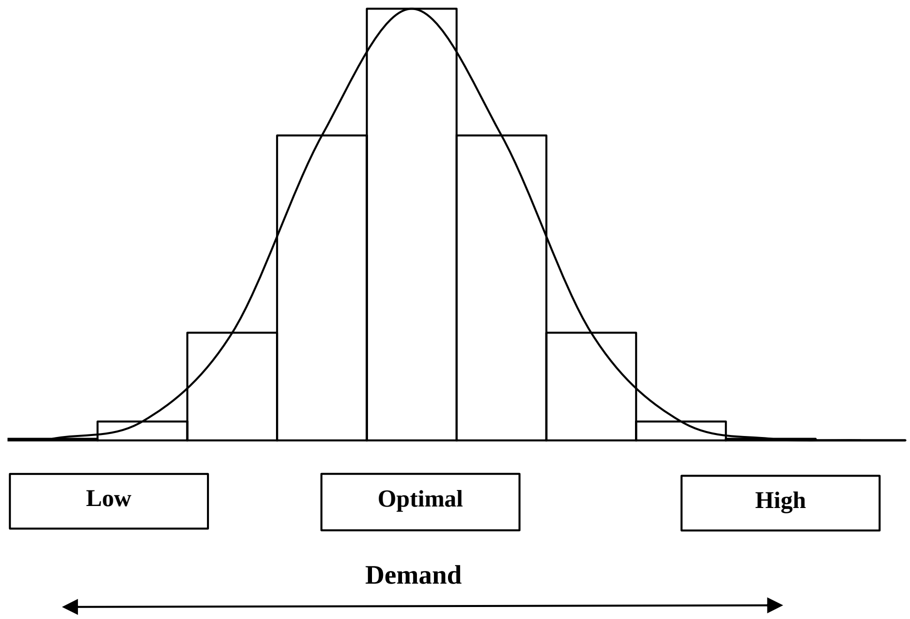


Figure 40. Workload and Performance Theoretical Optimum

Edits or adjustments to tasks and new tasks are presented as greyed and red text within the original task diagrams. Tasks are also listed in Appendices P and Q.

RESULTS

There are two sections of the results: Survey and Tasks Analysis Updates. The Survey section is detailed and discusses overall demand and its components (mental, visual, and physical). The Task Analysis Updates section is brief and contains images showing new tasks.

Survey

The survey results are discussed in this section. There are two main sections and each discusses results of the topics presented to the focus groups: Navigating an Intersection, and Arriving at Bus Stops. Subsections present overall, mental, physical, and visual demand aggregated across tasks and by tasks. Bus-operating tasks occur at any time during a route, but tasks are thought most likely to occur within the structure shown in the task diagrams in Figure 37 and Figure 38.

Understanding

The understanding scores were high enough to allow for including all original tasks in the analysis. The average rating for understanding on the scale of 1 (This makes no sense) to 10 (This makes complete sense) was high for bus stop tasks (M = 9.9, SD = 0.7) and for intersections tasks (M = 9.2, SD = 1.3).

Overall Demand

For intersections, the mean of all unweighted/original responses were rated as slightly high in demand (M = 6.9, SD = 1.8), suggesting that intersection tasks can be lead to greater than optimal demand (Figure 41, left). However, the mean of weighted responses suggests that the average overall demand shifts towards optimal (M = 6.0, SD = 1.7) compared to unweighted responses. Consideration for frequency of the task reduces the average overall demand (Figure 41, right). Additionally, the shift of the distribution implies that tasks with the highest demand occur with less frequency compared to other tasks. Accordingly, although minimal overall demand (i.e., weighted demand) may be nearly optimal, demand may be higher for some operators than others, and may change when lower frequency tasks occur.

For bus stops, the mean of all unweighted/original overall demand is normally distributed around the optimal score (M = 5.6, SD = 2.6). However, the wideness of the normal fit and the spread of the response frequencies suggest operators' scores indicate a high degree of variability or disagreement in their views of the overall demand (Figure 42, left). The mean of weighted responses suggests that overall demand scores, after taking account for task frequency, are slightly less than optimal on average (M = 4.4, SD = 2.6) (Figure 42, right). Accordingly, a conclusion cannot be made regarding overall demand for bus stops.

The trends show greater agreement regarding overall demand at intersections as compared to overall demand at bus stops.

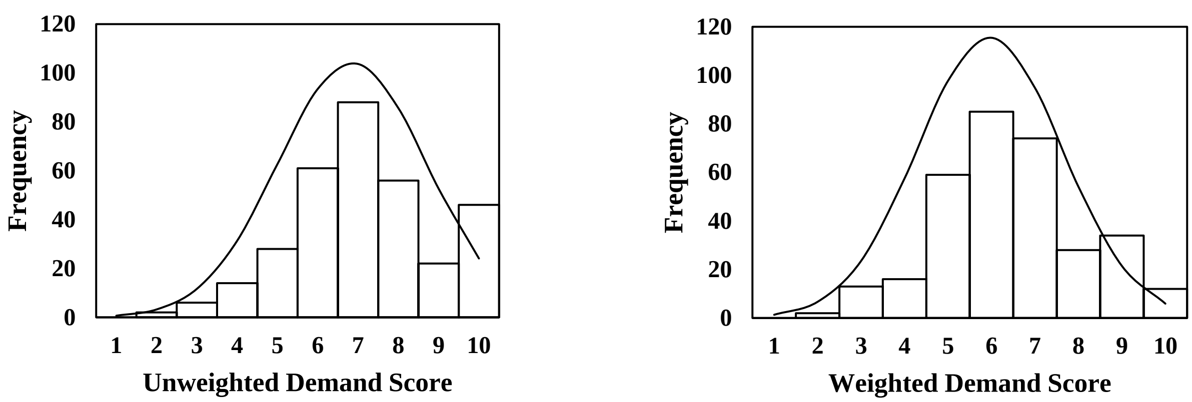


Figure 41. Intersection Unweighted (Left) and Weighted (Right) Overall Demand Ratings

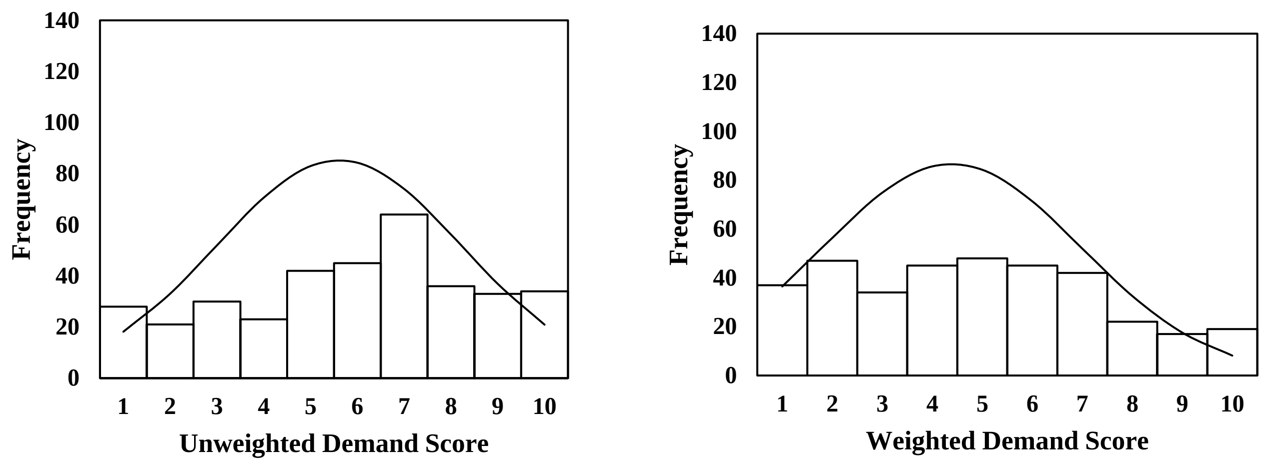


Figure 42. Bus Stop Unweighted (Left) and Weighted (Right) Overall Demand Ratings

The remainder of this section describes the components of overall demand— mental, physical, and visual—when navigating an intersection and approaching a bus stop. The results show that visual demand at intersections is strikingly high compared to physical and mental demand, which suggests that the overall demand is mostly influenced by visual demand. For bus stops, the results show that visual demand is higher than physical and mental demand. However, unlike for intersections, visual demand at bus stops has greater variance, which implies greater individual differences (i.e., some drivers experience more or less demand than others do).

Mental Demand

For intersections, the mean of unweighted/original responses for mental demand is high (M = 7.2, SD = 2.2), indicating the mental demand of intersection tasks is high. The distribution of unweighted responses suggests a slight trend toward higher ratings (i.e., negative skew) (Figure 43, left). However, the spread of responses (i.e., wideness of the normal fit) implies some effects of individual differences in the average score. Across the operators in the focus groups, when navigating an intersection, some may experience different levels of mental demand than others.

The mean of weighted responses suggests that mental demand shifts toward, but remains greater than, neutral (M = 6.3, SD = 2.0). The weighted distribution of responses has a sharp drop at the highest rating (Figure 43, right). The change from original to weighted responses represents a drop from 20 percent to 5 percent of all responses with mental demand at the highest rating of 10. This result implies that intersection-related tasks that have the highest mental demand occur less often compared to all other tasks. However, the trend also implies that most tasks consist of greater than neutral mental demand.

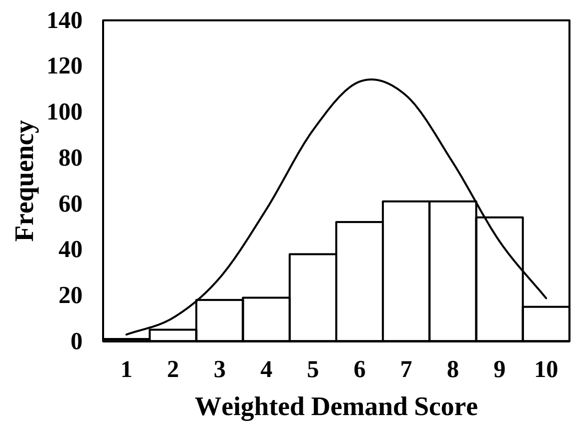


Figure 43. Intersection Unweighted (Left) and Weighted (Right) Mental Demand Ratings

For bus stops, the mean of unweighted/original responses for mental demand scored optimal with an average score (*M* = 5.3, *SD* = 3.2). Likewise, the distribution of unweighted responses suggests a normal distribution surrounded by equal variance (Figure 44, left). Variance is wide and implies greater individual differences than if it were narrower; the variance does not support a strong conclusion.

The mean of weighted responses suggests that mental demand shifts lower, after accounting for frequency, to a point below optimal (*M* = 4.1, *SD* = 3.0), but the wide variance remains. The weighted distribution of responses has a slight reduction of the highest score (Figure 44, right). This result implies that some bus stop tasks with the highest mental demand occur less often compared to other tasks. However, the trend also implies that the minimal allotment of bus stop tasks (i.e., those expected to occur most regularly) consist of mental demand equal to or less than neutral.

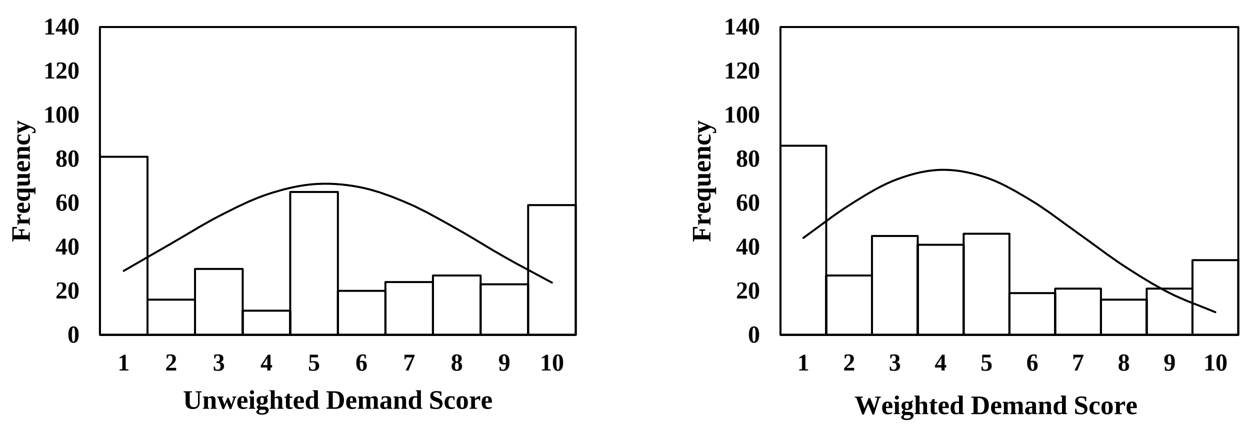


Figure 44. Bus Stop Unweighted (Left) and Weighted (Right) Mental Demand Ratings

Physical Demand

For intersections, the mean of unweighted/original responses for physical demand is optimum (*M* = 5.0, *SD* = 2.8; see Figure 45 left). However, the response distribution shows a trend toward the lower ratings of physical demand (i.e., positive skew), which suggests lower physical demand in general. Additionally, the mean of the weighted responses shifts to the lower ratings (*M* = 4.4, *SD* = 2.5; see Figure 45 right), and the highest ratings drop. The change from the highest unweighted to weighted responses (i.e., 10 ratings) drops from 14 percent to 3 percent. Accordingly, some intersection tasks have high physical demand that may not occur often.

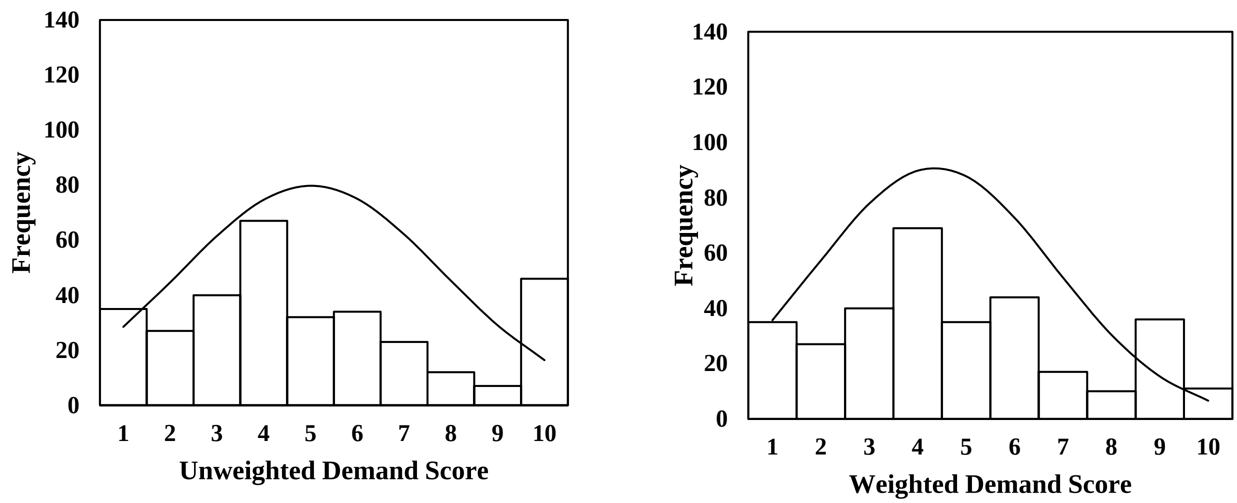


Figure 45. Intersection Unweighted (Left) and Weighted (Right) Physical Demand Ratings

For bus stops, the mean of unweighted/original responses is less than optimum (*M* = 4.3, *SD* = 3.1). Furthermore, the response distribution shows a higher frequency of lower ratings, which suggests lower physical demand in general (Figure 46, left). Additionally, the mean of the weighted responses shifts even lower (*M* = 3.4, *SD* = 2.8). The distribution shows a higher number of lower scores and a lower number of higher scores (Figure 46, right).

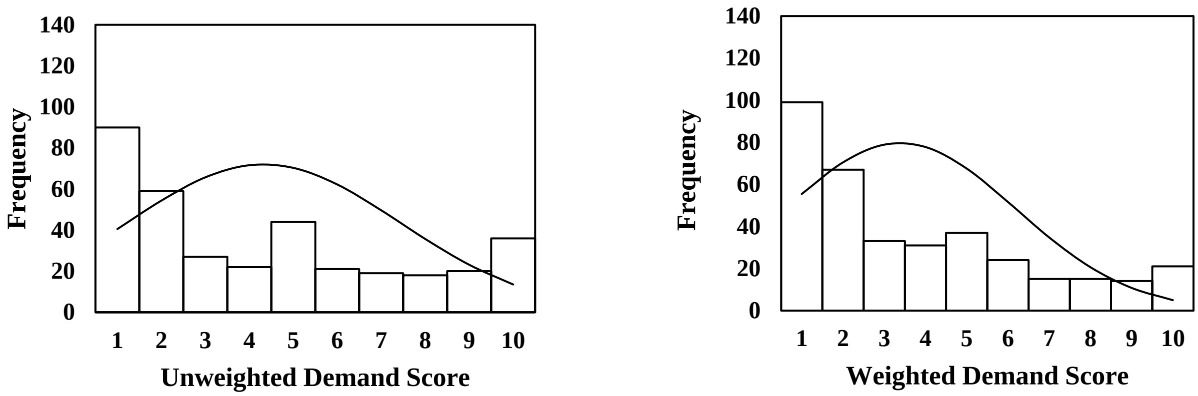


Figure 46. Bus Stop Unweighted (Left) and Weighted (Right) Physical Demand Ratings

Visual Demand

For intersections, the mean of unweighted/original responses about visual demand is high (*M* = 8.3, *SD* = 1.8), with a distribution that is negatively skewed towards high visual demand (Figure 47, left). As per the definition in the survey, operators "can't look away" from the tasks that were rated with high visual demand. Accordingly, most scores were higher than optimal, as 33 percent of all responses were 10. The weighted demand scores suggest that tasks with high visual demand occur less frequently (Figure 47, right). However, weighted visual demand is still reported as high on average (*M* = 7.2, *SD* = 1.7). The frequency weight lowered the highest demand (a rating of 10) to 8 percent of all weighted responses, a drop of 25 percent. The minimal amount of visual demand at intersections is high, with occasional increases when lower frequency tasks occur.

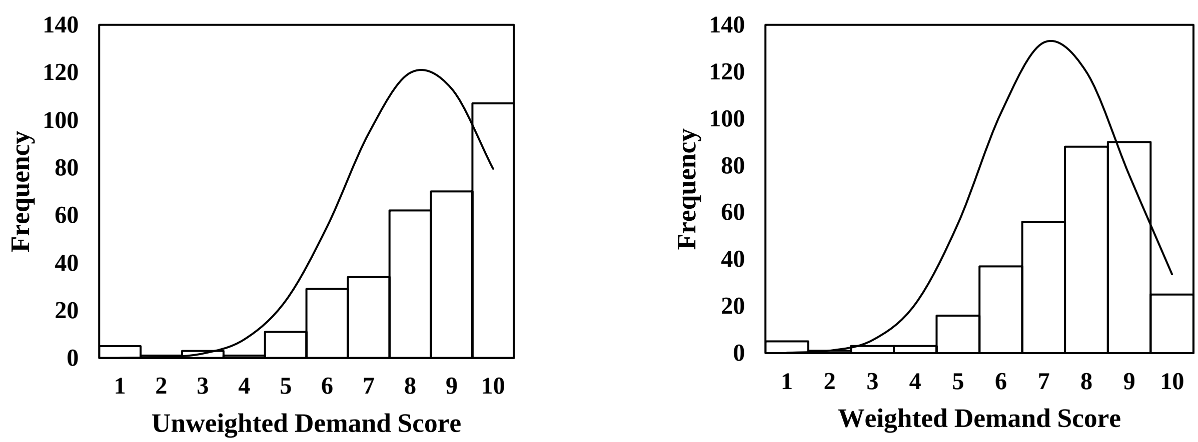


Figure 47. Intersection Unweighted (Left) and Weighted (Right) Visual Demand Ratings

For bus stops, the mean of unweighted/original responses for visual demand is high and has wide variance (*M* = 7.2, *SD* = 3.3). The response distribution is negatively skewed; bus stop tasks are rated most often as having high visual demand (Figure 48, left). Accordingly, most scores were higher than optimal; 38 percent of all responses were 10. The weighted demand scores suggest that tasks with high visual demand occur infrequently. The mean of weighted visual demand shifts to nearly optimal (M = 5.7, SD = 3.3; see Figure 48, right). The frequency weight lowered demand scores of 10, the highest demand score, to 20 percent of all weighted responses. This represents an 18 percent drop in the highest score of visual demand. The variance of the weighted response lowers the confidence in concluding visual demand is high or low at a minimum, or day-to-day. The original scores suggest that visual demand can be high on occasion as the frequency of the task is not included (i.e., if all tasks occurred all the time, visual demand would be high).

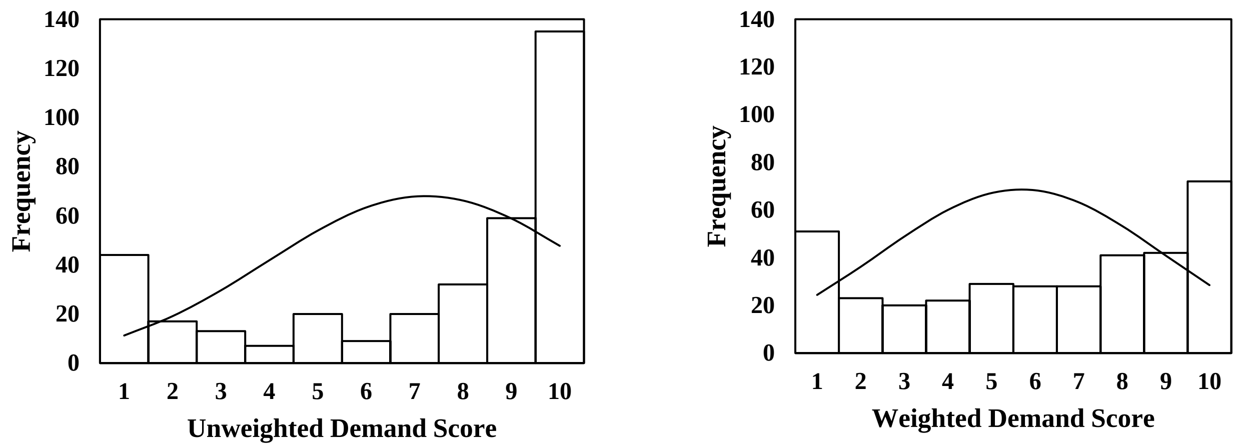


Figure 48. Bus Stop Unweighted (Left) and Weighted (Right) Visual Demand Ratings

Overall Demand by Primary Tasks

There are three primary tasks for intersections that occur sequentially and a task (Task 1) that occurs throughout navigating an intersection overlapping the other intersection tasks. The original average total demand for each of these tasks is rather high. The weighted demand tends to drop slightly closer to optimum demand depending on the task (Table 22, Figure 49).

Table 22. Intersection Primary Tasks Total and Weighted Demand

No.	Primary Task	Total Demand M (SD)	Weighted Demand M (SD)
1*	Monitor safety	6.9 (1.9)	6.1 (1.7)
2	Approach the intersection	6.8 (1.8)	5.8 (1.6)
3	Intersection entry	6.5 (2.2)	5.6 (1.8)
4	Execute maneuver	7.0 (1.9)	6.0 (1.8)

* Task 1 is continuous across tasks 2, 3, 4, and 5, but the added task demand is not included.

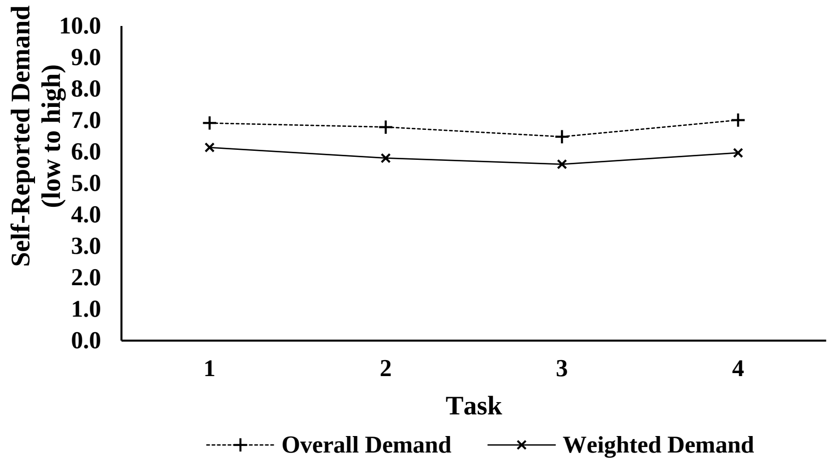


Figure 49. Intersection Overall Demand and Weighted Demand by Primary Tasks

There are four primary bus stop tasks, which all occur sequentially. The average total demand across these tasks varies considerably. The weighted demand tends to be close to optimum depending on the task; however, the demand for the final task (departure) remains high. Additionally, picking up and dropping off riders shows the lowest overall demand of all tasks for total and weighted demand; this is because some pick-up/drop-off tasks do not occur regularly. The overall demand for the final task (departure) remains high when weighted (Table 23, Figure 50).

Table 23. Bus Stop Primary Tasks Total and Weighted Demand

No.	Primary Task	Total Demand M (SD)	Weighted Demand M (SD)
1	Approach	5.9 (2.4)	5.1 (2.3)
2	Prepare for stop	6.7 (2.2)	6.2 (2.2)
3	Pick up/drop off riders	4.6 (2.6)	2.7 (2.6)
4	Departure	7.5 (1.7)	7.0 (1.7)

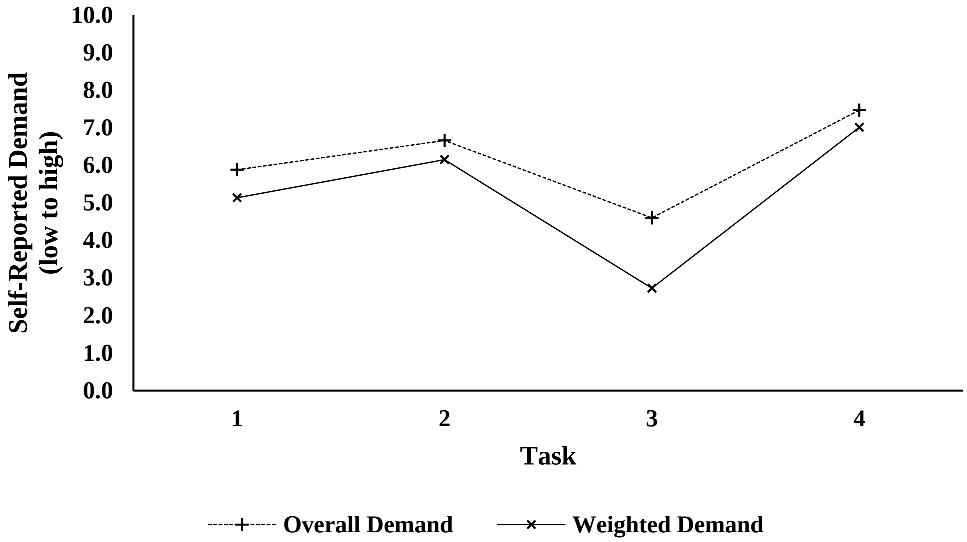


Figure 50. Bus Stop Overall Demand and Weighted Demand by Primary Tasks

Participants did not score total demand (i.e., overall demand); rather it is an aggregate score (average) of visual, physical, and mental demand scores. The remainder of the results partitions aggregated total demand into its constituent components for both intersection and bus stop tasks.

As discussed earlier, visual demand is a key component of demand at intersections. Visual demand is high across all tasks. Mental demand is also high, but not as high as visual demand. Physical demand tends to be low. The weighted responses suggest tasks that have high visual demand occur frequently. Mental and physical demand drop to a nearly or less than optimal score when weighted for frequency of occurrence, downplaying their influence on overall demand (Table 24, Figure 51).

Table 24. Intersection Primary Tasks by Unweighted and Weighted Mental, Physical, and Visual Demand

No.	Primary Task	Mental M (SD)	Physical M (SD)	Visual M (SD)	Mental Wt. M (SD)	Physical Wt. M (SD)	Visual Wt. M (SD)
1*	Monitor safety	7.3 (2.4)	5.0 (2.8)	8.4 (1.9)	6.5 (2.1)	4.5 (2.6)	7.5 (1.8)
2	Approach the intersection	7.3 (2.4)	4.8 (2.8)	8.3 (1.9)	6.2 (2.1)	4.1 (2.6)	7.1 (1.8)
3	Intersection entry	6.9 (2.1)	5.3 (2.9)	7.2 (2.8)	6.0 (1.9)	4.6 (2.4)	6.2 (2.4)
4	Execute maneuver	7.1 (2.6)	5.4 (2.8)	8.5 (1.6)	6.1 (2.3)	4.7 (2.4)	7.2 (1.4)

* Task 1 is continuous across tasks 2, 3, 4, and 5, but the added task demand is not included.

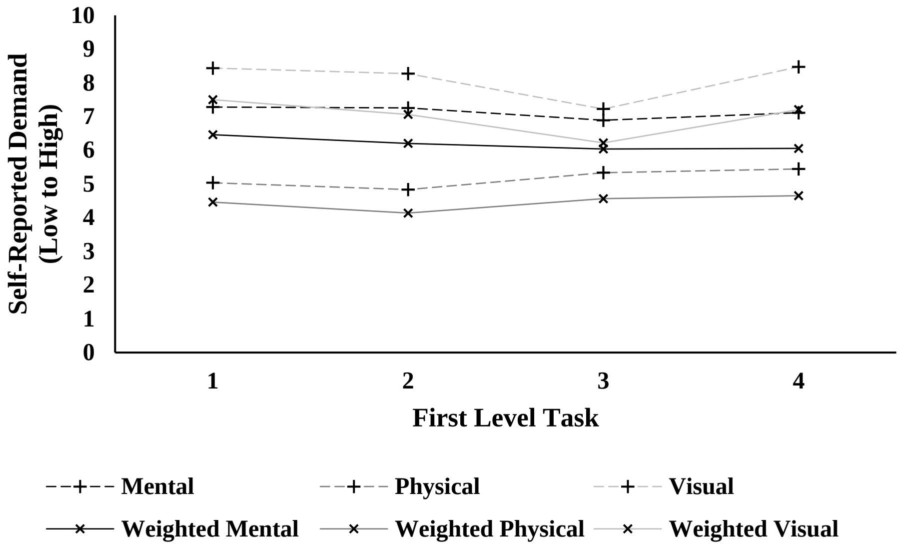


Figure 51. Intersection Demand by Demand Type by First-Level Task

Visual demand is also a key component of overall demand for bus stop tasks. However, overall demand drops considerably for all demand types when riders are dropped off and picked up. Visual demand increases more sharply for the final task of departure compared to the other demand types. There is almost no difference between unweighted and weighted visual demand, which implies that departing from bus stops is regularly very high in visual demand.

The increase in mental and physical demand from Task 3 to task 4 is gradual, and a difference between weighted and unweighted demand is present but minor as both scores are close to optimal (Table 25, Figure 52).

Table 25. Bus Stop Primary Tasks by Unweighted and Weighted Mental, Physical, and Visual Demand

No.	Primary Task	**Mental** M (SD)	**Physical** M (SD)	**Visual** M (SD)	**Mental Wt.** M (SD)	**Physical Wt.** M (SD)	**Visual Wt.** M (SD)
1	Approach	5.7 (3.3)	4.1 (2.9)	7.8 (3)	4.9 (3.0)	3.5 (2.6)	6.7 (2.8)
2	Prepare for stop	5.8 (3.3)	5.2 (3.1)	9.0 (1.8)	5.4 (3.0)	4.8 (2.8)	8.3 (3.3)
3	Pick up/drop off riders	4.5 (3.0)	3.6 (2.8)	5.7 (3.5)	2.6 (2.0)	2.2 (1.9)	3.4 (2.3)
4	Departure	6.8 (3.3)	6.0 (3.6)	9.6 (0.8)	6.4 (3.1)	5.6 (3.4)	9.0 (1.0)

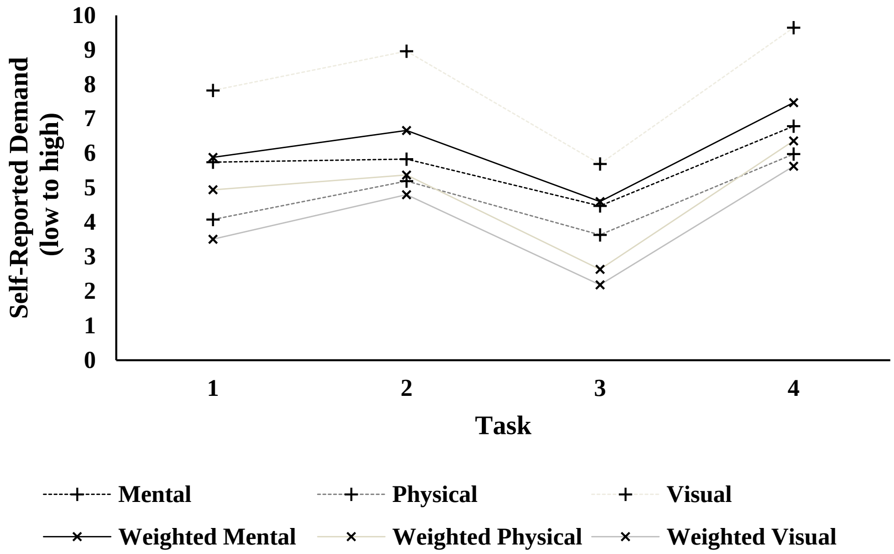


Figure 52. Bus Stop Demand by Demand Type by First-Level Task

The visual, physical, and mental demand scores discussed heretofore are averaged across subtasks. The focus group provided scores to individual tasks that belong to the primary tasks. Evaluation of the scores by these tasks allows for pinpointing the exact tasks that contribute to overall demand. The next section presents tables of tasks and the ratings scores averaged across responders.

Intersection Demand by Subtasks

This section discusses intersection tasks and contains tables that list all tasks, average demand score per task, and the frequency weights used thus far. These values were used to generate the descriptive statistics described to this point.

Task 1: Monitor safety subtasks

Relatively the most frequent, monitor safety subtasks are maintaining visual awareness and checking the left and right sides of the intersection for hazards, pedestrians, and other vehicles. The least frequent task is maintaining look-ahead time. Table 26 provides the mean and standard deviation of the demand associated with these and all other monitoring safety subtasks.

Table 26. Intersection Task 1 Subtask Weighted Demand Ratings and Frequency Weight

No.	Task Name	Mental M (SD)	Physical M (SD)	Visual M (SD)	Freq. Wt.
1.1	Visual scanning	7.7 (6.7)	6.2 (5.5)	8.8 (7.7)	0.88
1.1.1	Check left side of intersection for potential hazards.**	7.6 (7.0)	5.6 (5.1)	8.8 (8.1)	0.92
1.1.1.1	Check left side of intersection for other vehicles. **	7.3 (6.8)	5.2 (4.8)	8.6 (7.9)	0.92
1.1.1.2	Check left side of intersection for pedestrians.	7.7 (6.9)	5.0 (4.5)	8.6 (7.7)	0.90
1.1.1.3	Check left side of intersection for cyclists.	7.4 (6.6)	5.1 (4.5)	8.9 (7.9)	0.89
1.1.2	Check right side of intersection for potential hazards.**	7.2 (6.7)	5.1 (4.7)	8.9 (8.2)	0.92
1.1.2.1	Check right side of intersection for other vehicles.	7.2 (6.4)	4.6 (4.0)	8.9 (7.9)	0.89
1.1.2.2	Check right side of intersection for pedestrians. **	7.4 (7.2)	4.9 (4.7)	9.3 (9.0)	0.92
1.1.2.3	Check right side of intersection for cyclists.	7.2 (6.3)	5.1 (4.4)	8.8 (7.6)	0.87
1.2	Maintain look-ahead time. *	6.9 (5.6)	4.3 (3.5)	7.7 (6.2)	0.81
1.2.1	Maintain visual awareness of other vehicles, pedestrian **	8.8 (8.4)	5.4 (5.2)	9.3 (8.9)	0.96
1.3	Clearing the intersection.	7.3 (6.4)	4.9 (4.2)	9.0 (7.8)	0.87
1.4	Conduct scheduled mirror checks.	6.7 (6.0)	4.8 (4.3)	8.9 (8.0)	0.90
1.4.1	Count to seven. *	6.1 (4.7)	4.9 (3.7)	5.4 (4.1)	0.76
1.4.2	Looks at mirrors.	6.8 (5.8)	4.3 (3.7)	7.3 (6.3)	0.86
1.4.3	Repeat previous tasks.	7.2 (6.3)	4.9 (4.3)	8.0 (7.0)	0.88

*Least frequent tasks, **Most frequent tasks

Task 2: Approach the intersection

The most frequent “Approach the Intersection” subtasks are deciding to proceed or stop at the intersection, accelerating/coasting or decelerating, and preparing to proceed through the intersection. The least frequent tasks are checking the stoplight status, and deciding if the status is fresh or stale, as shown in Table 27.

Table 27. Intersection Task 2 Subtask Weighted Demand Ratings and Frequency Weight

No.	Task Name	Mental M (SD)	Physical M (SD)	Visual M (SD)	Freq. Wt.
2.1	Choose approach lane.	6.2 (5.2)	4.1 (3.4)	7.9 (6.6)	0.83
2.1.1	Decide approach lane given the bus route.	5.8 (4.9)	4.6 (3.9)	7.8 (6.7)	0.86
2.1.2	Choose bus maneuver for intersection.	7.6 (6.4)	4.9 (4.1)	8.6 (7.2)	0.84
2.1.2.1	Lane changing safety measures.	7.9 (6.7)	5.7 (4.8)	8.3 (7.1)	0.86
2.1.3	Move to appropriate approach lane given the bus route. *	6.8 (5.8)	4.7 (4)	8.3 (7.1)	0.86
2.2	Decide to proceed through/stop at intersection. **	8.4 (7.5)	5.2 (4.6)	9.0 (8.0)	0.89
2.2.1	Check the status of the intersection.	8.1 (6.9)	5.4 (4.7)	9.0 (7.7)	0.86
2.2.1.1	Check the stoplight status.*	6.9 (5.7)	4.1 (3.4)	8.1 (6.7)	0.82
2.2.1.2	Check the crosswalk status.	6.9 (5.9)	4.7 (4)	8.7 (7.4)	0.86
2.2.1.3	Decide if yellow light if fresh or stale. *	6.8 (5.4)	3.8 (3)	8.6 (6.8)	0.80
2.3	Accelerate/coast/decelerate the bus. **	7.0 (6.1)	5.0 (4.4)	6.7 (5.9)	0.88
2.4	Prepare for intersection entry.	7.8 (6.7)	5.2 (4.5)	8.7 (7.5)	0.87
2.4.1	Prepare the bus to stop.	7.7 (6.6)	5.2 (4.5)	7.7 (6.6)	0.87
2.4.2	Prepare the bus to proceed through the intersection. **	7.8 (6.8)	5.1 (4.5)	8.6 (7.5)	0.88

*Least frequent tasks, **Most frequent tasks

Task 3: Intersection entry

The most frequent intersection entry task is choosing the appropriate speed for the maneuver; the least frequent is doing the rock-and-roll technique. There are only two subtasks to intersection entry as shown in Table 28.

Table 28. Intersection Task 3 Subtask Weighted Demand Ratings and Frequency Weight

No.	Task Name	Mental M (SD)	Physical M (SD)	Visual M (SD)	Freq. Wt.
3.1	Scan visual field using the rock-and-roll technique.*	6.4 (5.2)	6.8 (5.5)	8.6 (6.9)	0.81
3.2	Choose appropriate speed for bus maneuver. **	7.3 (6.8)	3.9 (3.6)	5.9 (5.5)	0.93

*Least frequent tasks, **Most frequent tasks

Task 4: Execute maneuver

The final task for navigating an intersection is executing the maneuver. The most frequent subtask for this is to check bus clearance, and the least frequent is going straight through the intersection (see Table 29). Perhaps buses turn more frequently at intersections.

Table 29. Intersection Task 4 Subtask Demand Ratings (Weighted) and Frequency Weight

No.	Task Name	Mental M (SD)	Physical M (SD)	Visual M (SD)	Freq. Wt.
4.1	Turn the corner.	7.8 (6.7)	6.4 (5.5)	8.9 (7.6)	0.86
4.1.1	Square off the turn.	7.6 (6.4)	6.7 (5.6)	8.7 (7.3)	0.84
4.1.2	Check bus clearance. **	6.8 (6.3)	4.9 (4.6)	8.2 (7.7)	0.93
4.2	Go straight through the intersection. *	6.3 (4.9)	3.8 (2.9)	8.1 (6.2)	0.77

*Least frequent tasks, **Most frequent tasks

Bus Stop Demand by Subtasks

This section discusses bus stop tasks and contains tables that list all tasks, average demand score per task, and the frequency weights used thus far. Again, these values were used to generate the descriptive statistics described to this point.

Task 1: Approach

The most frequent approach subtasks are assessing “pull-in” space at the stop, finding the location of the bus stop, and deciding if the four-way flashers are needed; the least frequent tasks are checking the route schedule and deciding to wait if arriving at the stop early (see Table 30).

Table 30. Bus Stop Task 1 Subtask Weighted Demand Ratings and Frequency Weight

No.	Task Name	Mental M (SD)	Physical M (SD)	Visual M (SD)	Freq. Wt.
1.1	Check the route schedule. *	4.1 (3.3)	3.1 (2.5)	6.4 (5.1)	0.79
1.1.1	If early, decide if it is OK to wait. *	4.8 (2.8)	3.2 (1.9)	6.8 (4.0)	0.68
1.1.2	If late, approach stop as normal.	6.4 (5.4)	5.0 (4.2)	7.7 (6.5)	0.84
1.2	Find location of the bus stop. **	6.7 (6.4)	5.0 (4.8)	9.6 (9.2)	0.96
1.3	Decide if stop is needed.	6.4 (5.8)	4.4 (4.0)	8.9 (8.0)	0.90
1.3.1	Read passenger body language.	5.9 (4.9)	4.3 (3.6)	8.6 (7.1)	0.83
1.3.2	Read bus stop body language.	5.7 (4.9)	4.0 (3.4)	8.3 (7.1)	0.86
1.4	Assess “pull-in” space at bus stop. **	6.7 (6.6)	4.6 (4.5)	9.4 (9.3)	0.99
1.5	Decide if use of four-way flashers is needed. **	4.7 (4.4)	3.0 (2.8)	4.6 (4.2)	0.93

*Least frequent tasks, **Most frequent tasks

Task 2: Prepare for stop

The most frequent prepare for stop subtasks are visual scanning, tracking closing distance, and checking for traffic from the rear. The least frequent are deciding if the lift/ramp is needed and alerting riders at the bus stop (see Table 31).

Table 31. Bus Stop Task 2 Subtask Weighted Demand Ratings and Frequency Weight

No.	Task Name	Mental M (SD)	Physical M (SD)	Visual M (SD)	Freq. Wt.
2.1	Track closing distance. **	5.6 (5.5)	3.9 (3.8)	9.0 (8.9)	0.99
2.2	Visual scanning. **	6.1 (6.1)	7.0 (7.0)	9.1 (9.1)	1.00
2.2.1	Check for traffic from the rear. **	6.3 (6.2)	5.3 (5.2)	9.6 (9.4)	0.99
2.2.2	Track current lane position.	6.0 (5.7)	4.4 (4.2)	9.4 (9.0)	0.96
2.2.3	Check distance to the curb.	5.6 (5.3)	5.0 (4.8)	9.0 (8.6)	0.96
2.3	Decide if lift/ramp is needed.*	5.0 (3.4)	4.3 (2.9)	7.4 (5.1)	0.69
2.4	Alert riders at bus stop, if needed.*	5.1 (3.9)	4.3 (3.2)	7.0 (5.3)	0.76
2.5	Pull into bus stop.	6.4 (6.0)	6.7 (6.2)	9.9 (9.2)	0.93
2.5.1	Choose parking angle.	6.1 (5.4)	4.6 (4.0)	8.7 (7.7)	0.89
2.5.2	Allow for an out.	6.0 (5.7)	5.7 (5.5)	9.6 (9.2)	0.96
2.5.3	Move the bus into the stop.	5.9 (5.7)	6.0 (5.8)	9.9 (9.6)	0.97

*Least frequent tasks, **Most frequent tasks

Task 3: Pick up/drop off riders

The relatively most frequent subtasks when picking up and dropping off riders are to board riders and activate the four-way flashers. The least frequent subtasks are messaging dispatch and riders, and messaging dispatch about WhMD securement status (see Table 32).

Table 32. Bus Stop Task 3 Subtask Weighted Demand Ratings and Frequency Weight

No.	Task Name	Mental M (SD)	Physical M (SD)	Visual M (SD)	Freq. Wt.
3.1	Announce the bus stop.	4.3 (1.9)	2.3 (1.0)	2.7 (1.2)	0.44
3.2	Board riders.**	5.9 (5.2)	3.1 (2.8)	7.3 (6.5)	0.89
3.2.1	Board WhMD riders.	6.0 (3.2)	6.1 (3.2)	8.0 (4.2)	0.53
3.2.1.1	Prepare bus for WhMD riders.	5.3 (2.5)	4.6 (2.2)	6.7 (3.2)	0.47
3.2.1.1.1	Set parking brake.	3.3 (2.5)	4.7 (3.6)	4.3 (3.3)	0.77
3.2.1.1.2	Activate four-way flashers.**	4.1 (3.3)	2.6 (2.0)	4.0 (3.1)	0.79
3.2.1.1.3	Set transmission to neutral.	3.7 (2.1)	2.9 (1.6)	5.0 (2.9)	0.57
3.2.1.1.4	Kneel the bus.	3.6 (2.6)	4.7 (3.4)	4.9 (3.5)	0.71
3.2.1.2	Indicate to other riders that WhMD riders board first.	4.9 (2.5)	3.7 (1.9)	6.1 (3.2)	0.51
3.2.1.3	Ask if the WhMD rider prefers securement.	3.7 (2.0)	3.9 (2.0)	4.9 (2.6)	0.53
3.2.1.4	Ask WhMD rider for final destination.	3.6 (1.8)	2.6 (1.3)	4.9 (2.5)	0.51
3.2.1.5	Secure/do not secure WhMD rider.	5.1 (3.4)	7.1 (4.7)	7.6 (5.0)	0.66
3.2.1.6	Message dispatch about WhMD securement status. *	3.6 (1.4)	2.1 (0.9)	4.9 (1.9)	0.40
3.2.2	Board all non-WhMD riders.	4.4 (3.4)	3.3 (2.5)	8.3 (6.4)	0.77
3.2.2.1	Evaluate rider carry-ons.	6.6 (4.1)	3.3 (2.1)	9.1 (5.7)	0.63
3.2.3	Assist cyclists.	3.9 (2.1)	3.6 (1.9)	7.0 (3.8)	0.54
3.2.3.1	Engage parking brake/keep foot on brake. **	3.3 (2.8)	6.4 (5.4)	3.0 (2.5)	0.84
3.2.3.2	Kneel bus to help cyclists use bike rack, if needed.	3.3 (1.6)	4.4 (2.2)	4.9 (2.4)	0.50
3.2.3.3	Make a clear line of sight.	4.6 (2.5)	3.1 (1.8)	6.3 (3.5)	0.56
3.2.3.4	Alert cyclists to reset bike rack by honking horn. **	3.3 (1.0)	3.1 (1.0)	6.4 (2.0)	0.31
3.2.4	Monitor fare payments for correct amount. **	5.0 (4.2)	2.6 (2.2)	6.3 (5.3)	0.84
3.2.4.1	Follow “No Fare Paid” procedure for fare dodgers.	4.6 (2.4)	3.3 (1.7)	4.3 (2.2)	0.51
3.2.5	Apply fare discounts.	5.4 (3.1)	1.7 (1.0)	5.6 (3.2)	0.57
3.3	Message dispatch.*	5.3 (2.0)	3.0 (1.2)	6.0 (2.3)	0.39
3.4	Message riders.*	5.3 (2.2)	2.6 (1.1)	4.0 (1.7)	0.41

*Least frequent tasks, **Most frequent tasks

Task 4: Departure

The most frequent bus stop departure subtasks are visually demanding. These are visual scanning, departing the stop, and checking for cyclists. The least frequent subtask is checking for runners (see Table 33).

Table 33. Bus Stop Task 4 Subtask Weighted Demand Ratings and Frequency Weight

No.	Task Name	Mental M (SD)	Physical M (SD)	Visual M (SD)	Freq. Wt.
4.1	Visual scanning. **	7.0 (6.7)	6.1 (5.9)	9.4 (9.0)	0.96
4.1.1	Use the "rock-and-roll" technique. **	6.3 (6.1)	6.7 (6.5)	9.9 (9.6)	0.97
4.1.2	Check for runners. *	6.9 (5.4)	5.4 (4.3)	9.6 (7.5)	0.79
4.1.3	Check for rear traffic.	7.1 (6.7)	5.4 (5.1)	9.6 (9.0)	0.94
4.1.4	Check for cyclists. **	6.9 (6.8)	6.3 (6.2)	9.6 (9.4)	0.99
4.2	Depart from stop. **	6.6 (6.5)	5.9 (5.8)	9.9 (9.7)	0.99

*Least frequent tasks, **Most frequent tasks

Task Analysis Updates

This section reviews the tasks that were not included in the original task diagram and not included in the survey. These are the tasks that the focus groups suggested including. Accordingly, a measure of demand was not possible. The tasks were added during the focus group while a researcher presented the original task diagram.

New Tasks Added to "Navigating an Intersection"

Focus Groups 2 and 3 added new tasks to "Navigating an Intersection," which are color coded by group in Figure 53.

Group 2 added six tasks. There were three tasks added to the primary task "Monitor Safety" (Task 1) which applies throughout all tasks, as indicated with the arrow in Figure 53. A task called "Monitoring the Sidewalks," was added to checking the left and right intersections for general hazards. The third was a task for checking mirror clearance. In the words of the operators, this task was called "Look at mirror to make sure it doesn't hit something."

Three new tasks were added to the primary task "Approach the Intersection" (Task 2). Two tasks were added at the secondary level: "Awareness of Occupancy of the Bus" and "Awareness of Equipment." The third task called "Stop traffic from Being Closed in at Your Rear" was added as the tertiary level under "Choosing an Approach Lane" (Task 2.1).

Group 3 added five new tasks. One task was added to the tertiary level of "Monitor Safety" (Task1) under "Visual Scanning" (Task 1.1). Three of these tasks were added to the quaternary level under "Check the Status of the Intersection" (Task 2.2.1). These were "Landing Zone Monitoring," "Checking for Oncoming EMS¸" and "Deciding if the Intersection is Clean or Dirty." This was "Look for Traffic to Overtake the Bus." A task was added to the tertiary level of "Execute Maneuver" (Task 4) under "Turn the Corner" (Task 4.1) called "Evasive Maneuvers."

New Tasks Added to "Approaching Bus Stops"

Focus Groups 1 and 4 added new tasks to "Approach Bus Stops." These are color coded by group in Figure 54.

Group 1 added four tasks. A tertiary task called “Skip Stop” was added to the primary task “Approach” (Task 1). A tertiary task called “Use Reference Points” was added under “Prepare for Stop” (Task 2). Two tasks were added under the primary task “Pick-up and Drop-off Riders” (Task 3). A secondary task called “De-board Passengers” was added under “Pick-up and Drop-off Riders” (Task 3). A fifth-level task called “Deploy the Lift” was added under “Prepare bus for WhMD riders” (Task 3.2.1.1).

Group 4 added six tasks. A quaternary task called “Announce Time Stop to Riders” was added under the Approach primary task (Task 1) and under “If Early, is it OK to Wait?” (Task 1.1.1). Three tasks were added under “Pick Up and Drop Off Riders” (Task 3). A tertiary task called “Select Message Priority” was added under “Message Dispatch” (Task 3.3). A quaternary task called “Ask Passenger to Show Proof of Eligibility for Discount” was added under “Apply Fare Discounts” (Task 3.2.5). Another quaternary task called “Secure Chair” was added under “Board WhMD riders” (Task 3.2.1). Two tertiary tasks were added under the primary task “Departure” (Task 4) under “Visual Scanning” (Task 4.1) called “Watch for Tail Sweep” and “Check for Any Movement.”

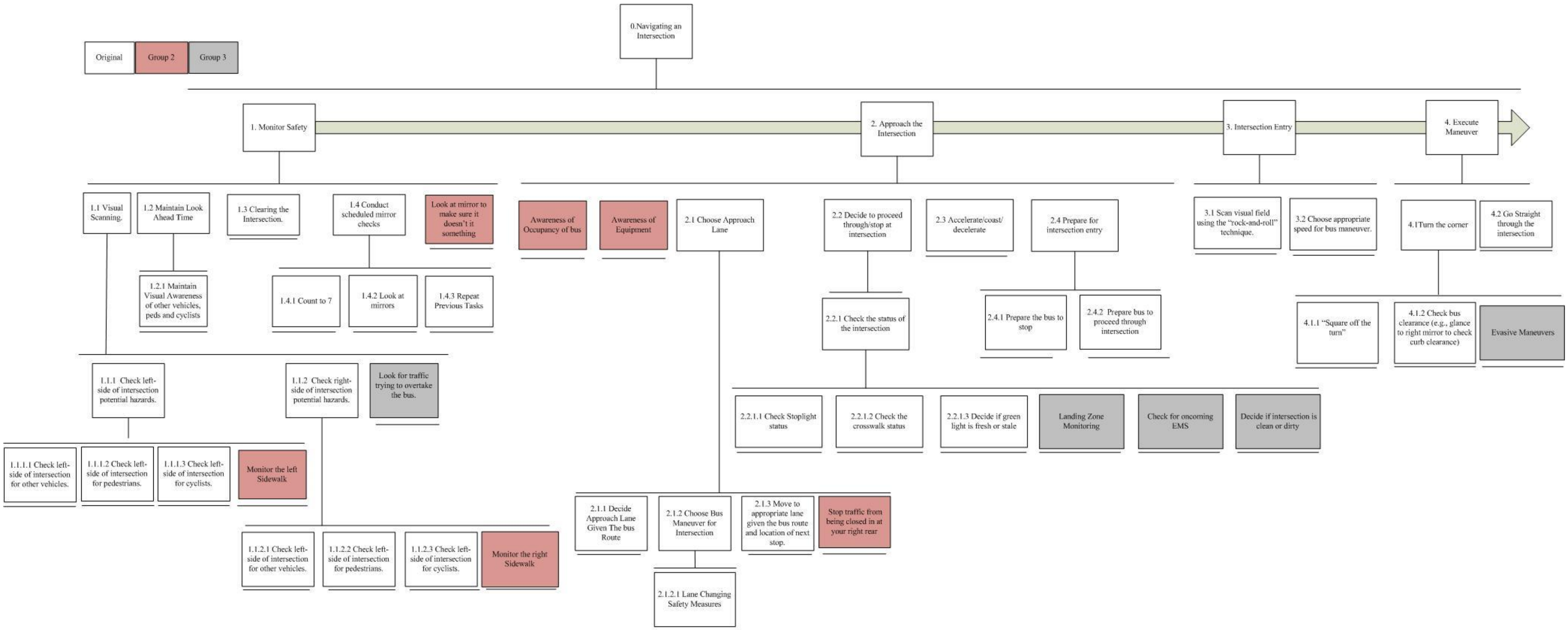


Figure 53. Navigating an Intersection Task Diagram With Focus Group Edits

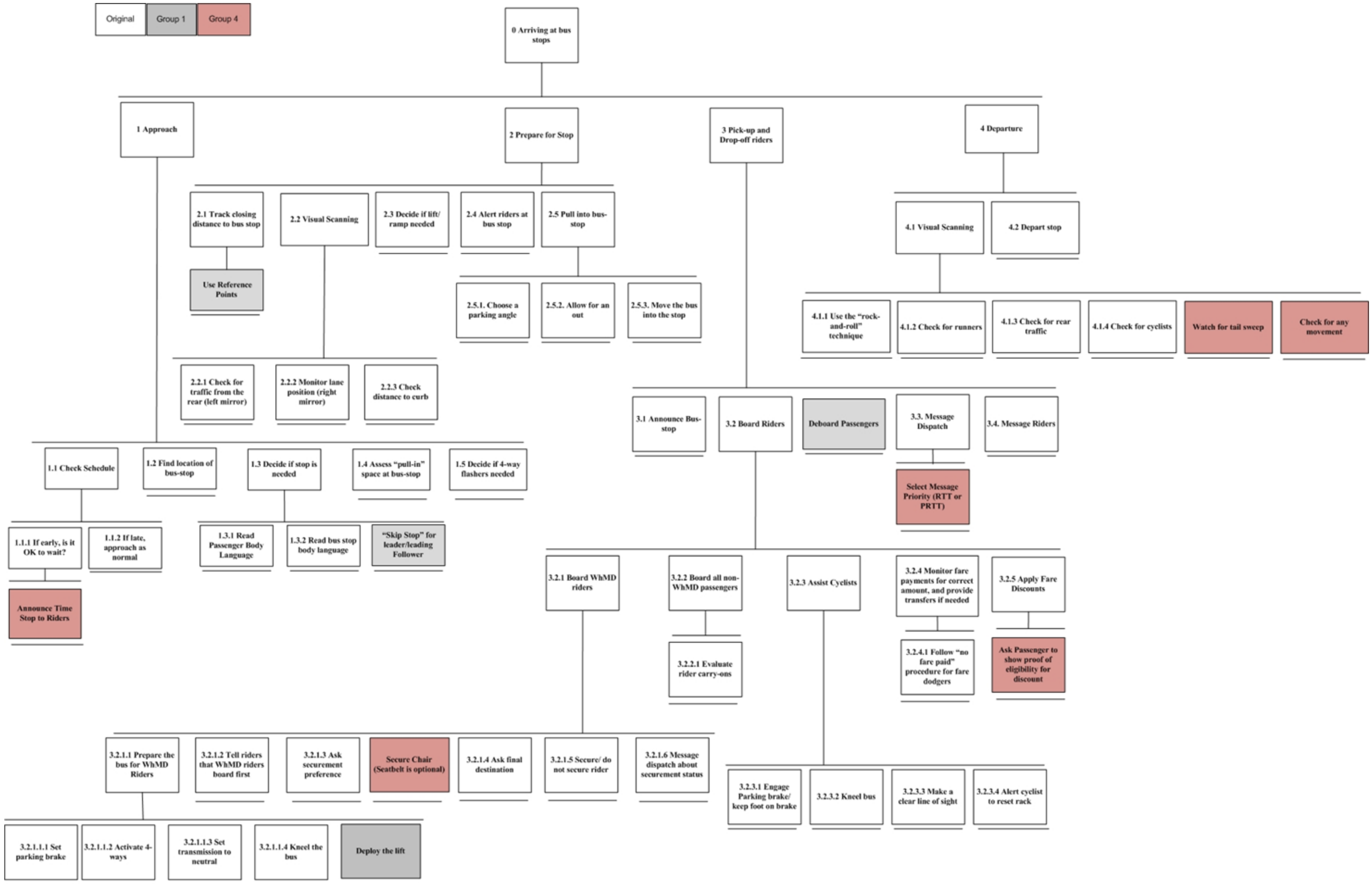


Figure 54. Arriving at Bus Stops Task Diagram With Focus Group Edits

CONCLUSIONS

Survey Conclusions

This section describes overall demand for bus stops and intersections and the contributions of mental, physical, and visual demand to overall demand.

Overall Demand

For the “Navigating an Intersection” task, overall demand has a high degree of uniformity/agreement in responses. The weighted overall demand approaches a normal distribution. When task frequency is subtracted out, task demand becomes less variant, which may lead to better predictability and generalizability. The uniformity in responses indicates a greater degree of agreement in ratings across bus operators, suggesting that operators tend to agree. The average unweighted responses show that overall demand may increase (i.e., the mean response is greater than optimal). The average weighted response was around optimal demand, which (according to our paradigm in Figure 40) implies that overall demand at intersections is typically not too high, nor too low.

For the “Arriving at Bus Stops” task, overall demand has low uniformity/agreement (i.e., a flat distribution). The larger variance means there was less agreement across survey respondents. Alternatively, this result could mean that there are large individual differences in coping with demand when approaching bus stops compared to navigating intersections. Ultimately, a conclusion on the demands of approaching bus stops is not as clear or robust compared to intersections.

The elements that make up overall demand (mental, physical, and visual demand) show a higher degree of uniformity for navigating an intersection, and lesser for approaching bus stops.

Mental Demand

For the “Navigating an Intersection” task, the survey responses show that mental demand is typically slightly greater than optimal at intersections, but not by much (demand weighted by frequency is interpreted as typical). Additionally, absolute demand (i.e., unweighted scores) is high, which suggests there are occasional instances of high mental demand.

For the “Arriving at Bus Stops” task, mental demand is typically slightly lower than optimal when approaching bus stops, but not by much. Again, the distribution of responses makes this conclusion less robust, especially for absolute demand.

Physical Demand

For the “Navigating an Intersection” task, the survey responses show that physical demand is roughly optimal at intersections. This result is counterintuitive as the task that has the most physical component to it, using the “rock-and-roll” technique, is said to occur at intersections only. Accordingly, using the “rock-and-roll” technique was rated as having the highest physical demand (M = 6.8), while squaring the turn was rated as having the second highest physical demand (M = 6.4). Based on these results, it seems that bus operators may not be fully aware of the physical demands of their jobs, but research suggests that physical stress and strain leads to operator attrition (Gobel, Springer & Scherff, 1998).

Visual Demand

High visual demand tasks are those that cannot be looked away from. For the "Navigating an Intersection" task, visual demand is high enough to suggest that it causes performance issues. Tasks that have the highest visual demand may not occur the most frequently; however, when frequency of tasks are accounted for or subtracted out, visual demand remains higher than optimal. Some tasks have high demand but low frequency. These tasks include "Maintain Look Ahead Time," "Using the Rock-and-Roll technique," "Driving Straight Through Intersections," and "Checking the Status of the Intersection." A low frequency rating may mean that not all bus operators actually do this task.

For the "Arriving at Bus Stops" task, tasks can have high visual demand, but when frequency is accounted for, visual demand becomes nearly optimal. The highest demand visual tasks at bus stops are rather infrequent. Some examples of bus stop tasks that have high visual demand are "Evaluating Rider Carry-ons," "Boarding WhMD riders," "Alerting Riders at Bus Stops," and "Deciding if the Lift is Needed." All tasks during the "Departure from the Bus Stop" task have a high demand. This result confirms the trend in workload and demand identified using heuristics of demand from Chapter 4 (broad visual inspection, focused visual search, working memory, executive function, motor demand, and non-typical). Specifically, the survey shows that operators think visual demands are high as bus operators approach bus stops, then it drops significantly when picking up and dropping off passengers. The finding is unique to the survey and is logical, given the types of tasks that occur as buses are departing. For instance, bus operators must reintegrate with traffic, and this requires significant amounts of visual attention.

- High demand tasks occur less frequently.
- Limitation: The task is hard or it does not happen frequently enough to make it reflexive (which would have lower demand, naturally).

Task Analysis Updates Conclusions

New tasks were added to both the "Navigating an Intersection" and "Arriving at Bus Stops" tasks. However, nothing is known about the demands these tasks impose. The survey did not included tasks generated by the focus group. Therefore, the tasks are listed and defined in Appendices P and Q, and are shown in the task diagrams in Figures Figure 53 and Figure 54.

Tasks added to the "Navigating an Intersection" task include:[5]

- "Monitoring the Mirror": This task consists of making sure the mirror clears (does not hit) a passenger or the infrastructure. This was a topic discussed during the prototyping study, but was not included in the original task analysis for conciseness.
- "Look for Traffic Trying to Overtake the Bus": This task consists of monitoring the environment around the bus for other drivers who may attempt to overtake buses (e.g., taking a right at an intersection where there is also a bus stop). When operators are at a bus stop that precedes an intersection there may be some inefficiencies in visual search. Chapters 4 and 5 show that broad visual search and visual demand drop substantially when dropping off and picking up passengers, then become high when departing.

[5] There are likely other tasks beyond those captured as part of this research.

- “Monitor the Left/Right Sidewalk”: This task consists of the bus operator looking for hazards on sidewalks and trying to predict if these hazards (e.g., pedestrians, animals, etc.) will enter the roadway.
- “Awareness of Bus Occupancy”: This task was added because it was suggested that operators track how many passengers are onboard and drive differently depending on the ridership. For example, they may drive more carefully if the bus is overloaded and many passengers are standing compared to when the bus is at lower capacity and all passengers have a seat.
- “Awareness of Bus Equipment”: This task was added because operators tend to want to be familiar with the bus they are driving. Not all buses accelerate at the same rate or turn in the same way. Accordingly, some effort is required to maintain an awareness of the capabilities of the bus being driven.
- “Stop Traffic from Blocking Bus in at the Right Rear”: When choosing an approach lane the bus operator may attempt to avoid blocking rear traffic.
- “Monitoring Landing Zone”: When intersections are congested, bus operators look ahead to see if there is space on the other side of the intersection before entering it. This is to avoid stopping in the middle of an intersection. If there is not enough space in the “landing zone,” the bus operator will wait to enter the intersection until there is enough space on the other side or may choose a different approach lane.
- “Check for Oncoming EMS”: Emergency service vehicles can enter intersections unexpectedly. Therefore, bus operators keep an eye out for police, fire, and ambulance vehicles.
- “Decide if Intersection is Clean or Dirty”: Some areas have more traffic than others. The same intersection may have more traffic at some times and less at other times. A dirty intersection is one that has a lot of traffic; clean does not.
- “Evasive Maneuvers”: Sometimes bus operators have to pick a maneuver to get through the intersection. It may not be an ideal maneuver, or even be legal. For instance, sometimes traffic conditions make bus operators decide to drive on curbs to get through intersections.

Tasks added to the “Arriving at Bus Stops” task include:

- “Announcing Time Stops”: This task consists of informing riders when the bus operator has to stop and wait for schedule adherence reasons. These stops are not usually planned. Whenever the bus operator gets ahead of schedule, they will stop and wait, if possible. Some routes may not provide an opportunity to make a time stop. Presumably, those are stops in which passengers complain about the bus never arriving.
- “Skipping Stops”: When buses are full, stops are skipped. The operator may radio dispatch to let them know to notify any following buses on the route.
- “Using Reference Points”: This task consists of using a fixed object on the bus to identify the curb and the vehicle’s position in space. The bus operator uses the bus, the curb, or a fixed object and watches it diminish that is how they know where they are.
- “Securing WhMD (Seatbelt is Optional)”: This task consists of securing the WhMD chair or device to the bus and providing a seatbelt if desired by the WhMD passenger. These passengers are always secured to the bus, but can opt to not wear the bus’s seatbelt.
- “Selecting Priority Levels for Outgoing Messages”: Before calling dispatch, the message priority level is chosen and then selected.

- "Asking Passengers for Discount Validation Cards": This task consists of asking for proof that the rider qualifies for a fare discount. This only happens when riders ask for a discount. Presumably, since operators are not allowed to dispute fares, it is rare for them to ask for proof of the rider qualifying for discounted fares.
- "Visual scans for Watching for Bus Tail Sweep": This task consists of monitoring the rear of the bus to make sure it clears the curb without hitting infrastructure or pedestrians.
- "Visual Scans for Checking for Movement": This task consists of searching for general hazards when the bus is departing the bus stop.

CHAPTER 6. REPORT CONCLUSIONS

This exploratory research has been conducted to provide a clearer description of the tasks and demands associated with driving a transit bus so that we can better understand the role, functional requirements, and needs for design guidance of future onboard technologies.

While rapid technology development has allowed for new devices and products to be introduced, the design of these devices has not always benefitted from a comprehensive understanding of what transit operators are already doing, the organizational policies they must comply with, and their level of workload at various points within a run. Without a comprehensive understanding of the concurrent tasks transit operators are engaged in during revenue-generating runs, appropriate pedestrian warning systems cannot be effectively implemented. This research provides insights on the missing valuable information for future DVI design guidance efforts.

Our efforts have been focused on understanding driver activities and requirements better in the context of reducing the occurrence and consequences of pedestrian strikes. However, this can potentially occur at many instances during a typical day or route, and the scope of this research has been quite broad; as noted earlier in this report, many topics have been covered, though none have been covered in great depth.

Nonetheless, much has been learned in this project and each of the research activities has yielded key findings. The individual chapters above provided conclusions specific to the various activities associated with this research. Below, we synthesize these conclusions from the various research activities into a succinct summary of the key “take-aways” from this research.

First, the initial literature review and technology questionnaire conducted as part of this project highlighted both the need to design new transit technologies in a manner that complements the information-processing requirements of bus operators’ key activities, as well as the relative paucity of detailed information about these information-processing requirements. That is, the renewed interest in providing bus operators with information that can reduce the occurrence and consequences of pedestrian strikes must be accompanied by additional research that helps to guide the development and design of these technologies. The more we know about the activities that compete for bus operators’ time and attention, the better manufacturers can design transit technologies that are consistent with their capabilities and limitations as they relate to key tasks.

Second, the prototyping study identified tasks and safety issues that are critical to thinking about the introduction of new technologies, such as the impact of current riders on hazard detection, possible conflict between drivers’ behaviors and local laws or policy (e.g., use of the horn), and impacts of new technologies (e.g., tablets) on rider perceptions about driver behaviors. While there were only eight participants in the prototyping study, it yielded interesting insights into key operational issues from the operators’ perspective.

Third, the task analyses yielded perhaps the most substantive findings in this project, and provided considerable insight into the temporal demands, information-processing needs, and variability across driving situations associated with key operator activities. No previous task analyses of transit operators have yielded this kind of information. Not only did the task analyses specify the demanding and complicated nature of specific activities (i.e., boarding/alighting riders, navigating intersections, and driving on roadways), they highlighted the frequent co-occurrence of many demands and especially the co-occurrence of visual demands in disparate portions of the roadway scene and the bus interior. It is not a surprise that the ongoing visual demands of the primary driving task should inform the placement and information content associated with the addition of new technologies to the vehicle cab. However, the complicated nature of reintegrating into traffic after a stop and driving through an urban intersection warrant specific consideration as pedestrian detection technologies and related driver alerting systems are designed. Overall, the task analyses yielded important information that can be used to support the design of future in-vehicle transit technologies. The task analysis validation study (discussed in Chapter 5) both validated the initial task analyses and added some extensions and clarifications.

Fourth, from a methodological perspective, the combinations of analytical and empirical techniques used in this project were in hindsight very effective in generating useful, actionable findings. Though preliminary and exploratory in nature, the findings are consistent with previous research, are internally consistent, and have great face validity given the number of operators and transit agencies involved in the research. Though the focus of the project was on breadth of coverage rather than on depth of detailed results, many insights have been generated.

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Zimmer, R. E., Burt, M., Zink, G. J., Valentine, D. A., & Knox Jr., W. J. (2014). *Transit safety retrofit package development* (Report No. FHWA-JPO-14-142). Washington, DC: Federal Highway Administration.

APPENDIX A. LITERATURE SEARCH AND SYNTHESIS

This section describes the approach to the literature search, reviews key literature identified during the search, and provides a list of research needs statements.

Search Term Definition

A literature search was carried out using the TRID, IEEE, and SAE databases on October 22, 2014. The results are shown in Table 34. Search key terms were combined using "OR" and "AND" operators. Search terms were selected from key documents (e.g., the Transit Safety Retrofit Package development [Volpe, 2014] and Integrated Dynamic Transit Operations [Mishra et al., 2011] research projects). Synonyms and other terms related to human interface design were used to scan for relevant literature on the front-end design of transit bus systems.

Date ranges were limited when the general search term results were too large (e.g., greater than 100 hits) to allow for a schedule-appropriate search. Table 34 shows a count of relevant abstracts that were pulled from the literature search. A manual process was used to select relevant abstracts from the total number of abstracts that came from the search terms. Titles were scanned and those with non-relevant terms (e.g., microscopic simulation and modeling) were excluded.

Table 34. Literature Search Terms.

Main Search Terms	Relevant Abstracts in TRID	Relevant Abstracts in IEEE	Relevant Abstracts in SAE
("Transit Bus") AND ("Driver vehicle interface" OR "DVI" OR "Human machine interface" OR "HMI" OR "Graphical user interface" OR "GUI" OR "User interface" OR "UI" OR "User Interaction" OR "Human machine interaction" OR "Human computer interface" OR "HCI" OR "man machine interface" OR "MMI") *Date Range: Not Limited*	7	2	2
("Bus") AND ("Advanced Public Transportation Systems" OR "APTS" OR "Automatic passenger counter" OR "APC" OR "Automatic vehicle location" OR "AVL" OR "Computer-aided dispatch" OR "CAD" OR "Demand respons*" OR "Demand responsive transit software" OR "Driver Assist* System" OR "DAS" OR "Dwell time" OR "Transit Signal Priority" OR "Geographic Information Systems") *Date Range: 2010-2014*	90	10	0
("Bus") AND ("Hold-until") *Date Range: Not Limited*	2	0	0
("Intermittent bus lane") *Date Range: Not Limited*	1	0	0
("Fare Media" OR "Bus Lane with Intermittent Priority" OR "BLIP") *Date Range: Not Limited*	4	0	0

Review of Key Literature

All documents that were obtained were reviewed to determine whether they contained information about: (1) results and conclusions related to bus operator DVI design, (2) specific research needs or gaps, (3) system effectiveness, or (4) general background information. Documents that did not contain information about any of these fields were not reviewed. Following this, documents that were not relevant to transit were also removed from the set, unless it was determined that the research source contained DVI information that was useful and directly applicable to the transit environments.

Chapter 6.Appendix B shows the full list of documents and provides summary reviews. The review process capitalized on our previous efforts reviewing crash warning systems in heavy trucks and passenger vehicles. In particular, the research team has an in-house collection of research documents and reviews for a large number of relevant research sources. This previous work was used to streamline the process of reviewing and summarizing documents for the current report. This included document reviews conducted for projects related to developing DVI guidelines (Campbell et al., 2014). In total, 18 documents were reviewed and summarized (see Chapter 6.Appendix B).

Literature Synthesis

The results of the literature synthesis are presented in a table. In the table, there are six issues that cover the key areas of interest for application of CV technology to bus transit and DVI issues. The following issues are covered.

- Bus operator DVI preferences for safety systems and performance changes,
- User interfaces to encourage operators to use transit-only shoulders or other tactical and strategic options to decrease travel time,
- Relevance of standard system quality attributes when constructing a transit operator DVI,
- Understanding of operational tasks and the complexity of operating a bus,
- Mobile data terminals, and
- CV applications and non-driving information provided to the driver.

The table consists of three columns. The first column indicates the issue that was identified in the literature review. The second column, labeled “Lessons Learned,” details specific findings related to the issue; it provides the critical synthesis of the existing research. The third column provides research needs or gaps identified in the documents reviewed. The synthesis integrates information from multiple primary research sources and goes beyond the results from individual reports to uncover research gaps. Accordingly, if integrative reviews are available for specific topics, these reviews are cited instead of a larger number of basic research sources. This simplifies the results tables below and allows us to take advantage of previous work integrating key information. From these lessons learned, 14 research needs were identified (in the third “Research Needs” column) and are discussed in Table 35.

Table 35. Issues, Lessons Learned and Research Needs.

Issue	Lessons Learned	Research Needs
(1) Bus operator DVI preferences for safety systems and performance changes	Wang et al. (2003) collected user-centered data to establish design criteria for a transit bus Forward Collision System. Their results show that certain DVIs (e.g., head-up displays) were judged not suitable by operators, and other DVIs require strategic placement and design. Some examples are: DVIs that are placed within any portion of the operator's forward field of view need to be streamlined and far off-axis of the forward view, e.g., narrow light-emitting diode bands on the A and center pillars. Collision alerts that occur when the bus is stopped may be appropriate. Operators want to adjust alert sensitivity levels. Additionally, although their system consisted of a unimodal (visual only) display, their user data suggest operators want a multimodal display with modality selection options. More recently, Pessaro (2013) evaluated a multimodal driver assist system with integrated lane guidance and collision awareness. The result found that some components of a multimodal and redundant DVI were rated less favorably (e.g., HUD, and a screen on the A-pillar) than other components (e.g., a haptic seat). Their results and the results of an older evaluation (Ward et al., 2003) suggest that the DAS, with its integrated lane control and collision avoidance assistance, facilitated some aspects of operating a bus in a narrow lane. Its usage was associated with moderate improvements in stability (e.g., lane devotions) and speed (e.g., time savings). The evaluations of the DAS did not conclude that it increased use of the bus-only shoulder, which was an operational goal of the transit agency that supported the DAS deployment. There is some inconsistency in the literature regarding operator DVI preferences. Wang et al. (2003) reported that transit drivers were generally dismissive of haptic seat warnings, due to their periodic movement in the seat and "rear-end fatigue." On the other hand, bus drivers tended to like feedback about their lane position when the vibrations were delivered via the driver seat (Pessaro, 2013).	There are two needs for this issue: (1) Substantive longitudinal/long-term data are missing from the research. There are only a limited number of evaluations of transit safety systems that have DVIs. Although it provided insight on its use during service operations, Pessaro's 2013 evaluation of the DAS was 1 month. During this brief period there were no collisions, and if there were it would be difficult to infer the role of the DAS given the brief evaluation period. To allow for inferences on the degree a collision information system (e.g., forward collision warning [FCW] or DAS) enhances safety by reducing collisions, long-term use data are needed. (2) Similarly, the relative importance of user preference and objective performance is unclear. There may be a subjective negative bias of assistance from collision prevention systems like FCW and DAS. Additionally, operator preferences may be unstable, changing over time and subject to other variables that may contribute to a lack of correspondence with changes in performance (e.g., better lane keeping). The degree that user preferences can be compared to objective performance would allow systematic selection of effective DVIs. For instance, DVI preferences may have a more prominent role if the best purpose of a system is for operators to change their disposition toward an aspect that is peripheral to the system function (e.g., use optional BOS more often in bad weather). Whereas, if the system is designed to prevent collisions then performance may trump preference.
(2) User interfaces to encourage operators to use transit-only shoulders or other tactical and strategic options to decrease travel time	There is only one research effort that brought out the notion that a technology could encourage operational use of alternative transportation demand reduction strategies (e.g., the DAS to encourage operators to use BOS). In fact, the crash data indicate that BOS collisions are infrequent, which muddies the need for a collision mitigation system specific for BOS.	There are two research needs for this issue. (1) Specific to BOS operations, research needs to confirm that a usable tactical support system (e.g., DAS for lane maintenance) leads to increased usage of BOS facilities. Additionally, the notion that DVI preferences may play a prominent role in operator disposition of BOS needs confirmation.

Issue	Lessons Learned	Research Needs
	There are a lot of miles of BOS in Minneapolis, MN. Duomo et al. (2008) estimated there were 300 miles of shoulder for bus operators to bypass traffic. Additionally, crashes related to BOS use are very infrequent. During the years 1991 to 2001, there were 20 crashes on the shoulder involving a bus, and all but one of these crashes were property damage only. There was one fatal collision in 2001 but the bus operator was found not at fault. In light of the low collision rates, the Minnesota transit agency Metro Transit reserves only $7,000 per year for damages resulting from BOS-related accidents (in Duoma, 2007). The evaluations of the DAS (Pessaro, 2013; Ward et al., 2003) show that operators accepted the notion of the system aiding lane maintenance and collision prevention. There are no performance data on the extent the system contributed to greater BOS usage. There is some evidence that operators forgo opportunities from other demand solutions, at least under certain circumstances. For instance, operators are able to use and prefer high-occupancy-toll lanes but report difficulty entering them. The HOT lane in Seattle—specifically SR 167—is reported to have entry issues due to the entry maneuver, which seems odd given strategies that could be developed given the fixed nature of the HOT lane (e.g., begin to merge earlier). The use of a HOT lane may be dependent on congestion and driver behavior in both the managed and unmanaged lanes. Operators that use I-394 in Minneapolis, MN, report that other drivers in the HOT lane, while enjoying the reduced congestion, are less likely to yield to buses (Newmark, 2014). So far the solutions to these access problems have been to change the infrastructure (e.g., make a transit-only direct access ramp to HOT lanes along the bus route). This solution might be tractable in Minneapolis where transit demand is higher; there are 38 routes on the I-394 HOT lane. Locations with lower transit volume (e.g., the HOT lanes in Orange County support two routes) may require less-costly solutions.	Alternative methods to increase BOS usage should also be considered (e.g., peer-based use measure using automated vehicle location [AVL] technology: "I see that others are using BOS today, I should too"). (2) The extent to which transit could benefit from using alternative demand reduction strategies has been discussed (e.g., transit-HOT integration in Newmark, 2014) but there are many other strategies that have not been considered, (e.g., contraflow lane reversal strategies). It is unclear which strategies operators could "choose" to use, like BOS and HOT lanes, and which are mandated by the design arrangement of the route, like changes to the infrastructure. Dynamic pricing strategies, which can be flow-based or peak-time-based, and the effects on roadway demand may result in changes to flow, which may affect bus operator tactical decisions (e.g., whether or not to merge over multiple lanes to get to the HOT). Since dynamic pricing strategies are known and flow is monitored, there may be an opportunity for presenting integrated real-time and estimated data to aid in operator choices regarding facility and lanes. It may benefit operators to know or have a stronger estimate about forward congestion well before approaching a decision point.
(3) Relevance of standard system quality attributes when constructing a transit operator DVI: *Usability* *Buildability* *Modifiability* *Security*	Designs of operator-centered systems may benefit from using tenets of traditional DVI design, which may become more pertinent as the CV market expands. DVI designers and information architects know that *usability*, *buildability*, *modifiability*, *security*, and *performance* have independent and combined effects on overall system architecture, and they know it is impossible to achieve simultaneous optimum results for all these qualities. There must be trade-offs. Relevant attributes are listed and defined below.	There is one need for this issue. The relative importance of the usability attribute for transit solutions needs to be better understood. There are no current guidelines or research findings to aid in determining how much design effort should be allotted to usability, compared to buildability and modifiability—which are two attributes that are likely to be requirements rather than options.

Issue	Lessons Learned	Research Needs
Performance	• *Usability* focuses on the ability for people to learn and use the interface quickly and effectively. • *Buildability* measured in cost and schedule, buildability is the manner in which changes can occur during development, which is inherently linked to understanding how the design corresponds with the problem to be solved. • *Modifiability* is the ability to modify the user interface once the system has been implemented. • *Security* is preventing malicious/accidental usage outside the design purpose. • *Performance* is the level of responsiveness (i.e., the number of events that can take place in a finite amount of time). As a trade-off example, designers of expanding systems that may remain under continuous development (e.g., a transportation system) may choose modifiability as the key components of a DVI architecture (e.g., a user interface architecture for bus operator information services, discussed in Vanhatupa et al., 2004). Alternatively, it is not clear the extent to which designers of transit solutions consider standard design quality attributes. There are *other* congestion solutions that are reducing traffic demands, which will likely lead to current solutions becoming less relevant over time. For instance, congestion pricing may lead to opportunities for transit to occupy available unmanaged lanes, leading to a reduced need for operators to bypass traffic using the shoulder.	There are three operational areas of investigation to provide insight on the value of usability. Usability might be differentially relevant across these areas: 1) Pre-trip 2) Service with passengers a. In motion b. Stopped (e.g., at a signal) 3) Deadheading: returning to origin or garage One might assume that usability is the most important when the operator is in motion with passengers and less important during deadheading, but this needs to be confirmed. Of course, this depends on operator tasks, which are explored in a different issue. The degree to which operators are able to interact with the DVI quickly and effectively without error within the three operational areas is unknown for transit mobility applications or setting up safety applications.

Issue	Lessons Learned	Research Needs
(4) Understanding operational tasks and the complexity of operating a bus	In a general sense, people strategically prioritize tasks in order to ensure they complete the main or highest priority task, and to do so they may devote less effort and attention towards any other concurrent tasks. There are dozens of tasks and subtasks that vehicle operators prioritize. The priority assigned to these tasks may change depending on how many difficult to predict variables play out (i.e., driving stochastic). Göbel et al. (1998) found increased operator stress occurred when buses arrive and depart from stops; when responding to invalid tickets, operating in the rain, using mirrors, opening doors, and during wait-time. Göbel et al. (1998) also found that bus drivers perform multiple tasks 80% of the time they are driving, although the tasks they reported are not too complicated (e.g., accelerating and activating turn signals, slowing down and opening doors, conversing with passengers and opening doors). Wei et al. (2014) compiled a task analysis of how bus operators carry out left turns at unprotected left turn intersections. Their compilation provides a more granular perspective than Göbel et al. (1998) as their focus was on the specific left turning situation. The analysis provides a time-series explanation of tasks and subtasks. The quantity of tasks depended on intersection geometry and varied within the stages of executing the maneuver—the approach to an intersection, entering the intersection, preparing to turn, executing the turn, and post turn.	There is only one need for this issue. It is not clear the extent to which designers and decision-makers incorporate knowledge of operator tasks in their designs. Do they use behavioral data to support design decisions? Both Göbel et al. (1998) and Wei et al. (2014) compiled operator tasks for the purpose of influencing design for instrument panel displays to be less visually demanding and for collision avoidance systems to support left turns, correspondingly. Only the work of Göbel et al. has been applied and validated. The instrument panel designs that came from their work reduced visual demand, but this was over a decade ago. Recently, operator workspaces have become visually complex and cluttered (see Söderström, 2013).
(5) Mobile Data Terminals (MDTs)	MDTs serve many purposes in transit operations; this is likely to expand with the applications enabled by CV technology. Due to the cyclical nature of ordering transit vehicles, MDTs and other displays and controls for ancillary systems are not always factory-fitted. Many guideline-type documents (Börner et al., 2006; International Organization for Standardization 16121) do not address the issue of retrofit systems added to the bus post-order. Additionally, non-driving-related technologies are perceived as a potential source of distraction by drivers (D'Souza & Maheshwari, 2012). There are a variety of MDTs on the market. These range from liquid crystal displays to touchscreens.	There are three needs for this issue. (1) What visual, manual, and cognitive demands are imposed by the use of MDTs? (2) Do the presence of multiple, retrofitted, interfaces have an effect upon operator workload or driver performance? Is there a need for unified interfaces for non-driving tasks in buses? Can multiple displays be consolidated into a unified interface? Where should (factory-fitted or retrofitted) MDTs be located? (3) Do different types of MDTs have different visual demand levels?

Issue	Lessons Learned	Research Needs
(6) CV applications/ non-driving information provided to the driver.	Connected Vehicle Reference Implementation Architecture consists of several non-safety applications that involve providing information to the transit operator (i.e., have a DVI component). Connection Protection involves “hold until” messages. Dynamic Ridesharing can involve paratransit and route guidance messages, Dynamic Transit Operations can involve manifest and route updates, systems can interact with on-board fare management, Intermittent Bus Lanes must signal availability to the operator, and Transit Stop Requests must be signaled to non-fixed route operators. Connection protection (CVRIA, 2014) involves providing “hold until” messages, but drivers may wait when they know connecting trains are delayed regardless of whether they receive a “hold until” message (Cluett et al., 2005). Dynamic Ridesharing (CVRIA, 2014) can involve paratransit and route guidance messages, while Dynamic Transit Operations (CVRIA) can involve manifest and route updates. Intermittent Bus Lanes (CVRIA, 2014) provides messages to the driver when a traffic management center has cleared operators to move onto the shoulder. How proposed and emerging CV applications are integrated into transit operations has not been extensively explored (Schweiger, 2012).	There are five needs for this issue. (1) What type of information is required in different CV mobility messages? Are there standardized message formats that should be utilized? Should drivers acknowledge messages (e.g., provide receipt of notice to dispatch)? (2) What type of, and in what format should, transit connection protection messages be provided? Do transit operators need information about the number of riders connecting? (3) When should these updates be provided to the operator? Is scheduling message delivery needed to prevent operator distraction? (4) How should the availability of shoulder space be signaled to the operator? (5) Should CV technology be used to eliminate operator tasks such as transfers, fare collection, and ridership counts? What type of fallback procedures are needed if CV-based systems fail? Without an integrated point of sale (POS), how can transfer creation and validation be improved using ITS?

Transit SME Working Group

This section describes the status of the transit SME working group. One of the key functions of this group is their input to the research needs (including identifying any high priority research needs that they see which are not currently reflected in the gap analysis). Transit SMEs are in a unique position. They understand the demands placed upon transit agencies, the potential benefits and drawbacks associated with different technologies, and the possible unanticipated effects from implementing different ITS technology. The members of the working group were asked to provide feedback on the research needs, and their input on research approaches were solicited. Input from the transit SME working group will help ensure that the project generates information useful to the transit community.

The research team views this working group's input as invaluable to the success of the project and is continuing efforts to include a wide range of members. In addition to recruiting additional and varied transit agencies, ongoing efforts at recruitment are targeting metropolitan planning organizations, ITS providers, and original equipment manufacturers.

Working Group Members

The working group includes representatives from different transit agencies, ITS suppliers, and OEMs. Currently, there are nine members in the working group as listed in Table 36.

Table 36. SME Working Group Members.

Name	Title	Affiliation
Fred Nelson	Transportation Manager	Spokane Transit Spokane, WA
Gary Nyberg	Manager of Technology Systems	Metro Transit Minneapolis, MN
Robert Huyck	Safety Director	Greater Cleveland Regional Transit Authority Cleveland, OH
Steve Yaffe	Transit Services Manager	Arlington Transit Arlington, VA
Brian Sherlock	Driver and Safety Committee Member	King County Metro Transit Seattle, WA
Tyre Fant	IT Administrator	Minnesota Valley Transit Authority Burnsville, MN
Courtney Daragan	Sr. Director, Engineering – Product Development	Zerox Transport Solutions, Inc. Columbia, MD
Todd Allen	Director of Government & Community Relations	RouteMatch Software Raleigh-Durham, NC
Sam Shartzer	Manager – Controls Engineering	Proterra Greenville, SC

Future Working Group Actions

Through the assistance of the Federal Transit Administration, contact was made with members of the Transit Connected Vehicle Stakeholder Steering Group. This group consists of representatives from a metropolitan planning organization, a city, as well as multiple transit agencies (n = 12), state

Departments of Transportation (DOTs; $n = 2$), ITS vendors ($n = 7$), and OEMs ($n = 5$). Communication with the steering group members is ongoing. Expanding the group will facilitate future effects on this project. Additional discussion with the working group will contribute to developing the Modal and Application Gaps Research Plan.

Gap Analysis

This section describes the research gap analysis that was performed. The research gaps were derived from the research needs described in Table 35. The two techniques described below, Stakeholder Rankings and Internal Research Gap Analysis, were used to facilitate the process of ranking the research gaps. Each research gap was presented in simple language, phrased as a question, and organized into topic areas. This was done with the intent of making the gap analysis manageable and approachable for the working group.

Two methods were used to assess the research gaps. The first was a ranking by stakeholders, completed electronically by transit experts. The result of the Stakeholder Rankings was used to reduce and conceptually focus the full list to the top five research gaps. These top five research gaps were evaluated using a second method, an internal research gap analysis. The Internal Research Gap Analysis used a set of predefined metrics (i.e., cost, relevance, impact, availability) to assess each research gap. The internal analysis was completed by research staff using a consensus method. The method used in these rankings and analyses, as well as the results of both efforts, is described below.

Stakeholder Rankings

Method

An online ranking assessment was distributed to participants in the working group and working group recruits. The form was sent to 28 individuals. Of those, eight fully completed the rankings and two individuals partially completed the rankings. The form contained 22 research questions separated into five topic areas. These five topic areas were the following.

1. General bus operation policy and practice
2. Driver performance with technology support
3. Information needs of bus drivers given new capabilities
4. Bus driver interactions with onboard technology systems
5. Retrofit system issues

Respondents were asked to sort the research questions in order of importance within each of the five topic areas. There was a final question that asked respondents to rank order the topic areas.

Two values were calculated from the stakeholder rankings: a within-topic rank value and a cross-topic rank. The within-topic rank value presents the average rank of a question based on all responses within the topic area. The within-topic rank is presented as the calculated rank value, followed by the relative ranking within-topic in parenthesis. This allows for examination and comparison within an individual topic area. For example, Question 1 in Topic Area 1 received an average rank of 1.2, making it the top-ranked question within Topic Area 1, whereas Question 2 received an average rank of 2.6, making it the third-ranked question within the topic area, and Question 3 received an average rank of 2.2, making it the second-ranked within the topic area.

The cross-topic rank is calculated as the product of the average rank of a question and the rank assigned to the topic area. This allows for examination and comparison of individual questions across all topic areas. The cross-topic rank is presented as the calculated rank value, followed by the relative ranking across all questions in all topics in parenthesis. For example, Topic Area 1 (General Bus Operation Policy and Practice) received an average rank of 3.25 and Question 1 (Is there more we can learn about what bus drivers are doing behind the wheel that can support system designs and designs for displays and controls?) received an average rank of 1.2, which results in a product of 3.9. The result that the relative rank was 1 indicates that Question 1 was the question with the highest cross-topic ranking of all questions.

Results

The results of the online ranking assessment are discussed in this section. Table 37 is a list of the topic areas, the number or respondents sorting questions within each area, and the average rank values for that topic area.

Table 37. List of topic areas, number of respondents and ranks, ordered by average rank.

Topic area	Number of Respondents	Average Rank *
Topic Area 3. Information needs of bus drivers given new capabilities	8	2.00
Topic Area 4. Bus driver interactions with onboard technology systems	8	2.50
Topic Area 2. Driver performance with technology support	8	2.75
Topic Area 1. General bus operation policy and practice	10	3.25
Topic Area 5. Retrofit system issues	8	4.50

* The average rank value was used to generate cross-topic ranks for each research question.

The topic areas and the research questions are described below. The results of the assessment are listed for each question. The questions ranked as the top five (i.e., cross-topic rank 1 through 5) were assessed using the internal research gap analysis, described later.

Topic Area 1: General bus operation policy and practice

The following questions deal with general bus operation policy and practice (i.e., what agencies are doing and what bus drivers are doing). Obtaining a full and comprehensive understanding of general bus operation may facilitate the alignment of technology with pertinent service issues that are most in need of a solution.

The within-topic rank is presented as the calculated rank value, followed by the relative ranking within-topic in parenthesis. Likewise, the cross-topic rank is presented as the calculated rank value, followed by the relative ranking across all questions in all topics in parenthesis.

1. Is there more we can learn about what bus drivers are doing behind the wheel that can support system designs and designs for displays and controls?
    - Calculated Within-Topic Rank: 1.2 (relative within-topic rank = 1)
    - Calculated Cross-Topic Rank: 3.9 (relative cross-topic rank = 1)
2. Are there regional differences in bus operational policy and practice that need to be collated into a guide to aid in system design considerations?
    - Calculated Within-Topic Rank: 2.6 (relative within-topic rank = 3)
    - Calculated Cross-Topic Rank: 8.5 (relative cross-topic rank = 17)
3. Are there data on bus crashes that can be used to better understand safety issues?
    - Calculated Within-Topic Rank: 2.2 (relative within-topic rank = 2)
    - Calculated Cross-Topic Rank: 7.2 (relative cross-topic rank = 10)

Topic Area 2: Driver performance with technology support

The questions below address research gaps in bus driver performance while using technology systems from CVs or ITS.

1. What are the long-term effects of the existing collision mitigation or avoidance systems (e.g., collision avoidance, lane keeping, pedestrian detection) on bus driver performance, acceptance and use?
    - Calculated Within-Topic Rank: 2.63 (relative within-topic rank = 3)
    - Calculated Cross-Topic Rank: 7.2 (relative cross-topic rank = 11)
2. What is the relative importance of bus driver preference and objective performance for trade-off decision (i.e., what aspects of usability trump driving performance, and vice versa)?
    - Calculated Within-Topic Rank: 2.25 (relative within-topic rank = 1)
    - Calculated Cross-Topic Rank: 6.2 (relative cross-topic rank = 5)
3. Should onboard technology, with displays that provide information or warnings to the bus driver, be designed to reduce current driver tasks by automating, facilitating, or eliminating tasks related to transfers, fare collection, and ridership counts?
    - Calculated Within-Topic Rank: 2.38 (relative within-topic rank = 2)
    - Calculated Cross-Topic Rank: 6.5 (relative cross-topic rank = 7)
4. Can onboard technology, with a display that provides information or warnings to the bus driver, be designed to actually encourage bus drivers to use optional facilities that could improve travel time (e.g., bus-only shoulders, managed HOT lanes, etc.)?
    - Calculated Within-Topic Rank: 2.75 (relative within-topic rank = 4)
    - Calculated Cross-Topic Rank: 7.6 (relative cross-topic rank = 12)

Topic Area 3: Information needs of bus drivers given new capabilities

The questions below address research gaps regarding the information needs of bus drivers given the types of information that can be provided using onboard technology systems from CVs or other ITS development efforts.

1. Assuming that bus drivers would benefit from information about forward congestion on their expected route, how far ahead of congestion should information be provided to bus drivers?
   - Calculated Within-Topic Rank: 3.88 (relative within-topic rank = 3)
   - Calculated Cross-Topic Rank: 7.8 (relative cross-topic rank = 13)
2. For onboard systems that provide information to bus drivers, what types of information are required in messages about factors that affect route schedule adherence or other bus mobility factors?
   - Calculated Within-Topic Rank: 2.25 (relative within-topic rank = 1)
   - Calculated Cross-Topic Rank: 4.5 (relative cross-topic rank = 2)
3. Assuming that bus drivers would benefit from knowing about rail, paratransit, or other travelers who expect to transfer to their bus, HOW should such “connection protection” information be provided to bus drivers?
   - Calculated Within-Topic Rank: 3.88 (relative within-topic rank = 3)
   - Calculated Cross-Topic Rank: 7.8 (relative cross-topic rank = 13)
4. Should messages to bus drivers be shown in a standardized format?
   - Calculated Within-Topic Rank: 3.25 (relative within-topic rank = 2)
   - Calculated Cross-Topic Rank: 6.5 (relative cross-topic rank = 6)
5. Assuming that bus drivers would benefit from knowing about rail, paratransit, or other travelers who expect to transfer to their bus, what information about “connection protection” should be displayed or provided to bus drivers? For instance, at any time during a route, a connection protection message could tell a bus drivers about the number of expected riders connecting or transferring, and when they are expected to arrive at the transfer station, but it is not known if this information is useful.
   - Calculated Within-Topic Rank: 3.88 (relative within-topic rank = 3)
   - Calculated Cross-Topic Rank: 7.8 (relative cross-topic rank = 13)
6. The availability of driving space in bus lanes that also allow other traffic (i.e., status of “Intermittent Bus Lanes”) can be provided to bus drivers. Assuming this is important information for bus drivers, how should this be signaled to them?
   - Calculated Within-Topic Rank: 3.88 (relative within-topic rank = 3)
   - Calculated Cross-Topic Rank: 7.8 (relative cross-topic rank = 13)

Topic Area 4: Bus driver interactions with onboard technology systems

The questions below address research gaps for bus driver interactions with onboard technology systems.

1. In general, how important is the design of what drivers directly interact with (e.g., user interface usability) compared to the back-end architectures?
   - Calculated Within-Topic Rank: 2.63 (relative within-topic rank = 3)
   - Calculated Cross-Topic Rank: 6.6 (relative cross-topic rank = 8)

2. For specific systems that require bus drivers to interact with them during the different phases of a run (e.g., the pre-trip, when stopped with passengers onboard, boarding and alighting passengers, or when deadheading), how important is it to ensure systems are simple and easy to use at these different phases compared with ensuring that pertinent systems, which may be difficult to use, are at least present and available?
    - Calculated Within-Topic Rank: 2.25 (relative within-topic rank = 2)
    - Calculated Cross-Topic Rank: 5.6 (relative cross-topic rank = 4)
3. Technology can now provide a wide array of information to bus drivers. Is it of interest to learn when updates on paratransit arrival status and route chances, messages manifest provided to the bus driver?
    - Calculated Within-Topic Rank: 3.63 (relative within-topic rank = 4)
    - Calculated Cross-Topic Rank: 9.1 (relative cross-topic rank = 18)
4. What visual, manual, and cognitive demands are imposed by the use of Mobile Data Terminals or systems with a similar driver interface?
    - Calculated Within-Topic Rank: 2.00 (relative within-topic rank = 1)
    - Calculated Cross-Topic Rank: 5.0 (relative cross-topic rank = 3)
5. Can technology systems be designed to actually encourage bus drivers to use optional facilities that could improve travel-time (e.g., bus-only shoulders, managed HOT lanes, etc.)?
    - Calculated Within-Topic Rank: 4.5 (relative within-topic rank = 5)
    - Calculated Cross-Topic Rank: 11.3 (relative cross-topic rank = 20)

Topic Area 5: Retrofit system issues

The questions below address research gaps regarding retrofit system issues.

1. Does the presence of multiple interfaces from different onboard systems that have been added to the bus after fabrication have an effect on bus driver workload or driver performance?
    - Calculated Within-Topic Rank: 3.13 (relative within-topic rank = 3)
    - Calculated Cross-Topic Rank: 20.3 (relative cross-topic rank = 22)
2. When there are multiple systems each with their own interface, is there a need to unify the interfaces for non-driving tasks in buses?
    - Calculated Within-Topic Rank: 2.25 (relative within-topic rank = 2)
    - Calculated Cross-Topic Rank: 14.1 (relative cross-topic rank = 21)
3. Can multiple displays be consolidated into a unified interface for all types of information (e.g., one display with information from non-driving operational tasks and driving related tasks)?
    - Calculated Within-Topic Rank: 1.5 (relative within-topic rank = 1)
    - Calculated Cross-Topic Rank: 10.1 (relative cross-topic rank = 19)
4. For mobile data terminals, either those installed by the bus manufacturer or added after fabrication, where should the mobile data terminals be located?
    - Calculated Within-Topic Rank: 3.13 (relative within-topic rank = 3)
    - Calculated Cross-Topic Rank: 6.8 (relative cross-topic rank = 9)

Internal Research Gap Analysis

Method

Analysis of the stakeholder rankings indicate that Questions 1, 5, 9, 15, and 17 were the top five stakeholder-indicated research gaps (as measured by the cross-topic ranking). These research gaps were evaluated and ranked internally by project team members using a simple five-point scale gap analysis method. The research gaps were subjectively rated by senior researchers using the following four criteria.

1. Estimated impact of research on sustainability and mobility in transit (termed *Impact*)
2. The quantity of available research (termed *Availability*)
3. Expected cost of conducting research (termed *Cost*)
4. Relevance to interface design (termed *Relevance*)

The rating scale values for these metrics are shown in Figure 55. The scale values allow for summing the responses across the four metrics to provide an overall score for each question. The lowest rating, a value of 1 equated to low impact, low originality, extensive schedule requirements, and low relevance for the four metrics. Alternatively, the higher scores equated to desired aspects. The value 5 equated to significant impact, a unique contribution to the body of knowledge, reasonable schedule requirements, and high relevance.

Estimated impact of research on sustainability and mobility in transit.

No direct impact on sustainability/mobility, but possible benefits to secondary aspects.		**Leads to moderate improvements to sustainability/mobility.**		**Leads to significant and clearly demonstrable improvements to sustainability/mobility.**
1	2	3	4	5

Quantity of available research.

There is some existing research that is applicable but it is only indirectly related to the topic.		**There is directly applicable existing research, but important issues remain unresolved.**		**There is no directly relevant existing information that can be applied to the results (i.e., this research is essential).**
1	2	3	4	5

Expected cost of conducting research.

Multi-year, multi-phase project requiring a large research and engineering team and significant equipment investment.		**One- or two-year project with small to medium sized project team working less than full-time and possibly some equipment investment.**		**Relatively short project duration with small project team, and minimal or no equipment investment.**
1	2	3	4	5

Relevance to interface design.

There is only a theoretical connection between the research gap and design issues and this topic is unlikely to matter to most DVI designers.		**There could be a logical link between a research gap and design issues, but it is not a documented or existing design need.**		**The research gap addresses a known design issue or problem based on existing applications/systems or actual system implementations (i.e., field operational tests).**
1	2	3	4	5

Figure 55. Rating Scales and Response Values for the Internal Research Gap Analysis.

Results

This section provides the results of the internal gap analysis, as shown in Table 38. The responses to each metric were summed for each rater for each question. This summed value was used to rank order the questions. Following this, an average of the ranks was computed to provide an overall score for each research question across the raters. Based on this, a cross-topic rank was calculated for the internal research gap analysis.

This internal cross-topic ranking was compared to the cross-topic ranking obtained from the stakeholder rankings. The comparison, and a following consensus process, was used to determine the highest priority research gaps in consideration of the project schedule and resources. Although there was not (nor would there necessarily be an expectation of) a complete agreement between stakeholder and internal scores, there was a high level of consistency between the two rankings. The combined average that resulted from rank ordering the sum of ratings showed that Questions 1 and 17 were the highest ranked by the stakeholders and the internal ranking process, as shown in Table 39. Thus, these two questions will be carried forward for further empirical investigation under this research effort.

Table 38. Ratings and Ranks from the Internal Research Gap Analysis

Rater	Question	Impact	Availability	Cost	Relevance	Sum	Rater Rank
1	1	3	4	5	5	17	2
1	5	3	4	2	5	14	5
1	9	3	4	4	4	15	4
1	15	5	3	3	5	16	3
1	17	5	5	5	4	19	1
2	1	4	4	5	5	18	1
2	5	3	4	5	4	16	3
2	9	4	4	4	4	16	3
2	15	3	4	3	4	14	5
2	17	5	5	4	4	18	1
3	1	3	3	5	5	16	3
3	5	3	4	2	5	14	5
3	9	5	4	5	4	18	1
3	15	5	3	3	5	16	3
3	17	4	5	3	5	17	2

Table 39. Internal and Stakeholder Cross-Topic Ranking Comparison

Question	Internal Cross-Topic Rank	Stakeholder Cross-Topic Rank
Question 1. Is there more we can learn about what bus drivers are doing behind the wheel that can support system designs and designs for displays and controls?	2	1
Question 5. What is the relative importance of bus driver preference and objective performance for trade-off decision (i.e., what aspects of usability trump driving performance, and vice versa)?	3	5
Question 9. For on-board systems that provide information to bus drivers, what types of information are required in messages about factors that affect route schedule adherence or other bus mobility factors?	3	2
Question 15. For specific systems that require bus drivers to interact with them during the different phases of a run (e.g., the pre-trip, when stopped with passengers onboard, boarding and alighting passengers, or when deadheading), how important is it to ensure systems are simple and easy to use at these different phases compared ensuring that pertinent systems, which may be difficult to use, are at least present and available?	2	4
Question 17. What visual, manual, and cognitive demands are imposed by the use of mobile data terminals or systems with a similar driver interface?	1	3

Summary and Conclusions

This final section provides a summary of the efforts and results discussed in this report, and the conclusions drawn from the results of these efforts. The conclusions contain some discussion on considerations for the research work plan.

Summary

CV technologies offer the potential for increased safety and mobility in transit operations. Many of the ITS technologies that are available now, such as AVL, can be supplemented or replaced through a CV-based solutions (CVRIA, 2014). However, these solutions must be implemented in a manner that minimizes the risk of visual, manual, or cognitive distraction. The goal of this research project was to better understand how to integrate CV systems into the transit environment in a manner that facilitates operating a transit bus and also maintains operational safety.

This process began with a structured literature search through multiple research indexes (TRID, IEEEXplore, and SAE). This search revealed a number of different existing ITS technologies for transit, as well as some initial explorations of CV technology to support different transit needs. Interestingly, while many of the identified documents describe information that can be provided to the transit operator, very few discussed the DVI component. Additionally, few results discussed the unique demands placed on transit operators beyond safely driving the vehicle, such as fare collection, transfers, and route schedule adherence. These non-driving activities, along with passengers, have been identified as common distractions for transit operators (D'Souza & Maheshwari, 2012).

Based on the results of the literature review, in consideration of the CVRIA transit-related applications, and after consultation with stakeholders, an initial set of research gaps were identified. These gaps can be generally grouped into the following topics.

1. Bus operator DVI preferences for safety systems and performance changes
2. User interfaces to encourage operators to use transit-only shoulders or other tactical and strategic options to decrease travel-time
3. Relevance of standard system quality attributes when constructing a transit operator DVI
4. Understanding operational tasks and the complexity of operating a bus
5. MDTs
6. CV applications/non-driving information provided to the driver.

These research needs were reviewed with the transit SME working group and evaluated by the research team to determine which research questions should be considered for examination in the later tasks in this project. The SMEs provided a rank order for the research questions. Following this, the research team assessed the top five ranked questions identified by the SMEs. There were two research questions from this top ranking set that will serve as the basis for the research plan. The two research questions are:

1. Is there more we can learn about what bus drivers are doing behind the wheel that can support system designs and designs for displays and controls?
2. What visual, manual, and cognitive demands are imposed by the use of MDTs or systems with a similar driver interface?

Throughout the development of the research plan, the research team will continue working with the SME working group to expand or refine the pertinent research needs.

The results of this gap analysis indicate that it is important to understand more about the tasks that bus-operators are obliged to do, and the demands that existing and developing technologies can impose upon drivers. In particular, the task analysis methodology:

- is relatively quick and inexpensive to perform,
- directly incorporates the knowledge and experience of bus operators,
- yields valuable details about the nature, sequence, and priorities across tasks and,
- is easy for transit agencies to understand and use.

In general, information that can help address the two research questions above will provide both general insights with broad application for the design of interfaces for transit operators, as well as specific information that can help inform future versions of the *Human Factors Design Guidance for Driver Vehicle Interfaces* (Campbell et al., 2014).

APPENDIX B. LITERATURE REVIEW TABLE

Reference	Findings
Börner, C. J., Hoormann, H. J., Rizor, H. G., Hütter, G., Kraus, W., Bigalke, S., ... Küchmeister, G. (2006). *Driver's workplace in motor coaches: Recommendations for ergonomic design* (Informal Document No. GRSG-91-3). Geneva: UN ECE.	**Method and Research Question:** [Guidelines document]. Very poor documentation on how the study was conducted to generate guidelines. Appears to have included some JACK-like computer-aided dispatch work to determine anthropometric details. Work references (but a search does not reveal) "Driver's workplace in motor coaches: Recommendations for ergonomic design." **Findings:** Work provides: • Visibility requirements for controls and displays. • Display types: Central and peripheral. • Recommends displays/controls for communications to the far right side of the IP area. No other mention of displays/controls for transit ITS.
Cluett, C., Jenq, J. H., & Saito, M. (2005). Utah Transit Authority's connection protection system: Perceptions of riders and operators. *Journal of Public Transportation, 8*(3), 73-87.	**Method and Research Question:** A connection projection system was examined via survey and qualitative analysis. It issued a message that stated "hold at (station name) until (time)" via connecting buses' onboard mobile data terminal, if the lateness of a connecting train was within a predetermined threshold (e.g., 3 minutes). A large sample of riders (522) and operators (251) completed surveys to assess the CP system. Of operators, the 251 responses represented a 28 percent response rate. Findings: • Overall, 41 percent of riders reported missing connections under CP compared to 47 percent without. • Bus operators indicated that they wait for connecting passengers anyway (i.e., 8% of operators say they will never wait without a CP message, and 47% say they always wait); they may wait for up to 3 minutes. • Operators' willingness to wait depends on their perceptions of their onboard passengers, or the flexibility in their schedules: "onboard passengers are at risk of missing their later connections… only 4 in 10 operators say they would wait if their schedules were tight; 7 in 10 would wait if they perceived their schedules to be not too tight." • Operator-reported compliance with the "Hold Until" message was low at 51 percent compliance, and operators thought that most CP messages were unnecessary—this was when the "hold until" message was issued but the connecting train arrived on time, which is a reliability issue. In total, 64 percent of all messages were viewed as unnecessary. • Suggestions: training (CV relevant), integrate bus/train location, improve prediction accuracy, increase management integration of system.
Diab, E. I., & El-Geneidy, A. M. (2012). Understanding the impacts of a combination of service improvement strategies on bus running time and passenger's perception. *Transportation Research Part A: Policy and Practice, 46*(3), 614-625.	**Method and Research Question:** Evaluation of multiple interventions for transit system improvement. Findings: • No DVI relevant topics discussed. • Some tangential issues, such as how their dispatch provided information via radio and not through MDT, could be brought in.

Reference	Findings
D'Souza, K. A., & Maheshwari, S. K. (2012). Multivariate statistical analysis of public transit bus driver distraction. *Journal of Public Transportation, 15*(3), 1-23.	**Method and Research Question:** Survey research with regression modeling of results. An expansion of the 2006 Salmon et al. survey. Transit bus operators were surveyed as to the major sources (rating) and time duration of various distractions during their shift. **Findings:** • Passenger interactions (passenger on phone, talking, ahead of standing line, etc.) were the highest rated. • Ticket machine was rated highly and had a longer duration: 61 percent, 56 percent. • Climate control: 56 percent, 34 percent. • Reading route sheet: 57 percent, 27 percent. • Audible alerts: 67 percent, 46 percent. • General broadcasts: 71 percent, 57 percent. • Personal broadcasts: 67 percent, 48 percent. • No specific DVI information in paper.
Figliozzi, M. A., Feng, W. C., Laferriere, G., & Feng, W. (2012). *A study of headway maintenance for bus routes: Causes and effects of "bus bunching" in extensive and congested service areas* (Report No. OTREC-RR-12-09). Portland: Oregon Transportation Research and Education Consortium.	**Method and Research Question:** The authors made a visualization tool for agency managers and operators for understanding bus bunching (note: no mention of operator DVI or driver-centered info anywhere). Bus bunching is associated with longer waiting times for some riders, uneven passenger distribution, overcrowding in late buses, and an overall decrease of level of service and capacity. Six-months of archived automatic vehicle location and automatic passenger count data were used to make a dynamic interactive bus monitoring framework using a Google Maps Application Programming Interface. Users of the Google API can "play" the movements of buses on a route to determine bus bunching propagation and identify factors that may contribute to bunching. Data were from TriMet. Trimet has a notable history with the use of bus dispatching systems that used AVL, APC, dead reckoning sensors, and mobile radio systems (see Strathman, 2001). **Findings:** From their analysis of AVL and APC data (there are no data on DVI performance), they found that: • Bus bunching is associated with the first stop for high frequency zones where there is no headway control and operators cannot communicate with each other. • Leading buses carry much larger passenger loads than following buses (e.g., 20 extra passengers). • The leading predictors of bus bunching are late departure from the last stop for the leading bus and less passengers boarding for the following bus.

Reference	Findings
Göbel, M., Springer, J., & Scherff, J. (1998). Stress and strain of short haul bus drivers: Psychophysiology as a design oriented method for analysis. *Ergonomics, 41*(5), 563-580.	**Method and Research Question:** Psychophysiological measures were used to determine levels of stress on transit drivers before and after the implementation of an ergonomic instrument panel. Video images from two cameras mounted within the driver cabin were reviewed to develop a task analysis of bus driver tasks. Dependent measures, including heart rate, heart rate variability, and eye-movement, were analyzed relative to each of the tasks in the task analysis. **Findings:** • The redesigned instrument panel reduced the number of control and display elements from 64 to 30 by combining simultaneously used functions and adding second-order features for rarely used operations. • Task duration was reduced by an average of 23 percent when using the redesigned instrument panel. • Psychophysiological measures indicated that strain was reduced as a result of the redesigned instrument panel.
Handley, J. C. (2014, January). *Statistical analysis to isolate effects of driver performance on schedule adherence.* Paper presented at the Transportation Research Board 93rd Annual Meeting, Washington, DC.	**Method:** Archived CAD/AVL data from nine months during 2011 were analyzed using regression modeling for schedule adherence. Data include 249 days of service operation with over 700,000 records. Additional data for covariate analysis were the operator, time points, distance between time points, number of stops between time points, the dwell time at each time point (measured using door-open to door-closed time), automated passenger count data at time points, and an operator ID for each arrival. Schedule adherence (primary analysis variable): The time difference between scheduled arrival and actual arrival. This can be positive or negative. **Research Question:** In a general sense, being early, late, or on time at one time point results in being in the same state at the next time point. Individual differences on schedule adherence and the contributing factors (covariates) are unknown. **Findings:** • Schedule adherence showed autocorrelation—adherence at a time point was positively correlated with adherence at the previous point. • The majority of arrivals were within 6 minutes late and 3 minutes early. • Distance, stop counts, dwell time were not significant covariates. • The operator, however, was a significant factor. Operators increased variation in schedule adherence—there are no explanatory covariates for individual operator difference. **Key Point:** There are considerable differences among operators in schedule adherence. Some operators are consistently late, adding to their lateness (or earliness). Yet, pooled together the effect of a unitary “operator” is closer to zero.

Reference	Findings
Kozub, C. A. (2013). *Transit bus operator distraction policies* (TCRP Synthesis 108). Washington, DC: Transportation Research Board.	**Method and Research Question:** [Synthesis report] Review of the federal, state, and local policies on bus operator distraction. Included a survey of 33 agencies across 20 states regarding their distraction policies. Findings: • Agency policies typically addressed personal communications distraction and not distractions from transit duties, such as farebox or MDT distractions.
Larwin, T. F., & Koprowski, Y. (2012). *Off-board fare payment using proof-of-payment verification* (TCRP Synthesis 96). Washington, DC: Transportation Research Board.	**Method and Research Question:** [Synthesis report] Review of off-board payment methods. Included a survey and case studies of different transit agencies in the United States and Canada. **Findings:** • Only operator interaction mentioned in report is proof-of-payment for bus-rail transfers. • Operators (drivers) are not expected to check proof-of-payment. • CV apps, such as integrated multi-modal electronic payment, could change this.
Lee, Y. K., Chon, K. S., Hill, D. L., & Desai, N. (2001). Effect of automatic vehicle location on schedule adherence for mass transit administration bus systems. *Transportation Research Record*, *1760*, 81-90.	**Method and Research Question:** Pre-post automatic vehicle location technology implementation at Baltimore, MD, mass transit authority. The AVL system was used to communicate deviations from schedule (either positive or negative) to the driver from dispatch. Data was collected from four routes over 8 weeks (4 weeks pre, 4 weeks post). In the post-implementation, dispatchers communicated messages to drivers based on AVL data regarding route/schedule adherence (1 minute early, 3 minutes late), mechanical problem indications, and service adjustments. **Findings:** • Most operators check their schedules at each time point. • Operators attempt to make adjustments if running early/late, regardless of AVL presence. • Significant effects were present for arrival on time at main time point (p = 0.0003; d = 0.0143), early arrival at time point (p = 0.0793; d = 0.0333), and link travel time (effect on next time point; p = 0.0772; d = 0.0336). • While the AVL increased schedule adherence, it did not have an effect statistically.
Lin, P. S., Lee, C., Kourtellis, A., & Saxena, M. (2010). *Evaluation of camera-based systems to reduce transit bus side collisions* (Technical Report No BDK85 Two 977-08). Tampa, FL: Center for Urban Transportation Research.	**Method and Research Question:** [Evaluation of aftermarket video imaging systems to reduce blind zone]. Twenty-eight bus drivers completed a static and closed-course drive to assess: (1) distance/depth perception in static conditions, (2) distance/depth perception in static conditions, (3) field of view (FOV) in dynamic conditions, and (4) driver opinions. **Findings:** • Camera systems can provide consistent distance/depth perception in static conditions. • Minimum cut-in distances were average of 2 to 3 ft. closer than with mirrors (similarto C/VIS work at VTTI/NHTSA). • Equivalent FOV is available with the camera systems. • Eighty-five percent of drivers believe the system will eliminate blind zones.

Reference	Findings
Newmark, G. L. (2014). HOT for Transit? Transit's experience of high-occupancy toll lanes. *Journal of Public Transportation, 17*(3), 97.	**Review Paper:** Reviews a limited set of literature on the 12 high-occupancy toll lanes in the United States and the notion of the integration of transit service with demand reduction strategies. **Key Points:** • Access expansion without capacity expansion (e.g., tolls on existing managed lanes to allow low-occupancy vehicle traffic to also use managed lanes) could worsen conditions for transit operating lanes previously managed using occupancy restrictions. • HOT lanes are already showing problems with traffic either not yielding to transit or blocking HOT ingresses.
Pessaro, B. (2013). Impacts of the Cedar Avenue driver assist system on bus shoulder operations. *Journal of Public Transportation, 16*(1), 83-95.	**Method and Research Question:** [Evaluation of Assist System] A transit agency deployed a shoulder operation driver assist system. The goals of deploying the system were: 1. Operational (e.g., enhance drivers' confidence for using shoulder lanes in bad weather); and, 2. Service-related (e.g., reduced travel time, increase reliability, safety and customer satisfaction). A naturalistic A/B testing method was used with a group of six operators that were assigned to the corridor the DAS was designed to support. Data were collected as they drove without then with the DAS for 1 month for each portion of the study. A group of 25 operators responded to survey questions 9 months after the DAS was introduced to general service. Additionally, 135 passenger surveys were completed. The DAS provided lane guidance and collision awareness information. The DAS alerted operators of lane deviations and provided proximity alerts for pedestrians and other vehicles. **Findings:** • Naturalistic A/B study: o Eighty-eight percent of operators agreed that the DAS was easy to use, and 64 percent said it helped to reduced stress. o Operators describe the head-up display as distracting—it shows "too many things." o In responding to the "mild" steering wheel torque, operators stated that they did not like anything having control over the steering besides themselves. • Operator surveys: o Snow caused traffic to encroach on the shoulder, which the DAS did not recognize but the operators could accommodate. o Operators stated that the DAS pushed them toward snow build-up that they would otherwise avoid—driving over snow would cause too rough of a ride for passengers, increasing complaints. o The DAS prompted operators to steer back toward the center of the shoulder—earlier DAS work stated drivers "hug" the fog line, which means they do not always operate/drive in the center (see Ward et al., 2003). • Passenger surveys: o Most passengers (83%) did not notice the DAS.

Reference	Findings
	○ Most passengers (97%) were satisfied with both the reliability and on-time performance of their route, measured only after the DAS was installed.
Reinach, S. J., & Everson, J .H. (2001a). Driver-vehicle interface requirements for a transit bus collision avoidance system (SAE Paper No. 2001-01-0052). *Society of Automotive Engineers 2001 World Congress*.	**Methods:** Data from three sources—interviews with Massachusetts Bay Transit Authority driving instructors and bus operators, naturalistic observation (i.e., ride-alongs), and review of MBTA's bus operator training manual—were used to characterize the transit bus operating environment, the operator working environment, and the operator's workstation, and to identify the operator performance requirements. Five types of driving maneuvers that were expected to benefit from a frontal and side collision avoidance system were identified. Sixteen crash scenarios were identified as countermeasure intervention opportunities for the transit bus CAS. A set of functional requirements for the DVI were developed based on the crash scenarios and previous CAS research. **Key Findings and Recommendations:** **DVI specifications process:** • Identify the transit bus operating environment. • Identify bus operator requirements. • Develop functional requirements: ○ Detect the presence of, recognize, and identify vehicles, pedestrians, and roadside objects in the proximity of the CAS-equipped vehicle. ○ Determine the likelihood of a collision involving the CAS-equipped vehicle. ○ Given a certain (predetermined) likelihood of collision, warn the driver of the hazardous situation. ○ If necessary, take temporary and limited control of the CAS-equipped vehicle to avoid a collision or mitigate its severity. • Develop DVI requirements. Seventeen functional requirements for the transit bus DVI are listed. These requirements relate to distraction, passenger attention to the CAS, comprehension, presentation characteristics, driving environment, operation, status, discriminability with regard to other bus systems, operator workload, etc.

Reference	Findings

Reinach, S. J., & Everson, J. H. (2001b). The preliminary development of a driver-vehicle interface for a transit bus collision avoidance system. *Intelligent Transportation Society of America Eleventh Annual Meeting and Exposition.*	**Methods:** Tools and methods that were used included structured interviews, informal discussions, a focus group with the MBTA driving instructors and bus operators, naturalistic observation, reviews of past collision warning and avoidance system research, and characterizations of the operating environment.
	
	Key Findings and Recommendations:
	• Some of the DVI requirements identified were:
	  ○ The display must support operator training requirements, such as lateral scanning and looking ahead.
	  ○ The display must minimize the potential to attract passenger attention.
	  ○ The display must be clearly conveyed and understood during high and low light or glare conditions.
	  ○ The display must be clearly conveyed and understood over noise generated from the bus interior.
	  ○ The display must be capable of being presented and understood under high vibration conditions.
	• HUDs were found to be unacceptable for presentation of CAS information because:
	  ○ They have a significant potential to obstruct the bus operator’s forward view.
	  ○ Implementing the HUD in the appropriate position (6 to 10 degrees below the line of sight) is expected to be difficult.
	  ○ HUDs in other vehicle types have not been shown to be unequivocally superior to other modalities.
	  ○ Reconfigurable HUD technology is not yet commercially available.
	• A multi-stage collision warning approach was recommended due to the necessity to not induce hard braking. Two levels of display information criticality (caution and warning) were recommended.
	• Redundant modality coding was recommended because of the presence of a high amount of mechanical (vibration) and sound noise present, in addition to the high visual demands of the job. A proposed warning signal consisted of combination of a visual bus icon, nonverbal localized tone, and haptic brake pulsing and steering wheel resistance.

You, H., Oesterling, B., Bucciaglia, J., Lowe, B., Gilmore, B., & Freivalds, A. (1997). *Bus operator workstation evaluation and design guidelines* (TCRP Report 25). Washington, DC: Transportation Research Board.	**Method and Research Question:** [Synthesis report] Review of operator workstation ergonomics. **Findings:** • Table 2.1 provides a list of tasks performed. • Workstation dimensions modeled with JACK. • Describes an MDT-type device. Located to the right of the IP, similar to most current placements.

Reference	Findings

Wang, X., Lins, J., Chan, C. Y., Johnston, S., Zhou, K., Steinfeld, A., ... & Zhang, W. B. (2003). *Development of requirement specifications for transit frontal collision warning system* (Report No. FTA-TRI-05.2) Retrieved from www.fta.dot.gov/12351_4598.html	**Method and Research Question:** [User Centered and Standard Design] Operators and trainers from urban cities were consented and provided input for the design of an FCW system user interface. There were three phases: (1) collect DVI recommendations, (2) design, and (3) evaluate.
	
	Data collection led to an outline of operator behaviors pertinent to DVI design (e.g., where they look and how they survey their environment, their use of mirrors to observe the location of rear-wheels, review of the "Smith-system," etc.)
	
	Findings:
	Key relevant findings:
	• Operator behaviors:
	    o Drivers practice earlier braking rather than harder braking.
	    o "…proper operator behavior will lead to no forward or sideswipe accidents at all - even those for which the operator was not at fault."
	    o When turning, operators visually locate the rear wheel in their mirrors prior to moving the steering wheel as knowing the position of the "pivot point" rear wheel aids drivers in avoiding collisions.
	    o Forward looking behavior is described as a "yo-yo" action in that operators look up the road, then back in, then back up the road, etc. The look-ahead phase allows more lead time for reactions.
	    o Operators rarely look down at their dashboard.
	• Design recommendations for an FCW:
	    o HUDs were proven not suitable as operators were averse to anything consuming any portion of their forward field of view.
	    o Sensors need to work to provide alerts when the bus is stopped.
	    o Allow operators to adjust the alert sensitivity levels.
	    o Provide training and reference materials (e.g., an operator's cheat sheet).
	    o Use a multimodal display with modality selection options—not directly tested in this study, per se.

Ward, N. J., Gorjestani, A., Shankwitz, C., Donath, M., Boer, E., & DeWaard, D. (2003). B*us rapid transit lane assist technology systems. Volume 2: Bus driver stress while operating in narrow dedicated bus shoulders: A pilot study* (Report No. FTA-MN-26-7003). Retrieved from www.its.umn.edu/Research/FeaturedStudies/brt/laneassist/LAfinal2.pdf	**Method and Research Question:** Ten transit bus operators drove an empty bus equipped with a DAS on dedicated, narrow-width bus shoulders in heavy and light traffic. Subjective and performance measures were collected to determine whether the DAS reduced driver stress and improved driving performance. The DAS was comprised of GPS, onboard geospatial database, and forward radar, and provided lane guidance and collision prevention information. DVI consisted of HUD, control panel visual display, and haptic displays (seat and constant feedback steering). A usability questionnaire was administered and objective performance measures were obtained.
	
	Findings:
	• Usability questionnaire:
	    o When driving with the DAS, drivers attended less to lane width and road geometry and instead focused on the DAS function and components.
	    o Attention was given to traffic as a major stressor both with and without the DAS.

Reference	Findings
	○ Most drivers agreed that the DAS would be most beneficial to bus operations in rural areas, on highways, and during poor visibility conditions such as night or inclement weather. ○ Some drivers found the HUD to be obstructive during normal weather and daylight conditions. Also, some drivers found the virtual “side mirror” to be distracting and redundant. ○ Drivers reported concerns regarding GPS reliability and the steering haptic display. Some drivers felt they had to “work hard to fight against the steering.” • Objective performance measures: ○ Speed was reduced by a margin of ~1.1 mph when using the DAS. ○ Lane variability was reduced by a margin of 0.04 m when traffic was estimated to be high volume. ○ Departures from the shoulder boundaries were shorter in duration (0.6 to 1.1 s), and response times to boundary departures were faster by 0.4 s when using the DAS. ○ There were many temporary failures of GPS system—subsequently, drivers expressed desire for a GPS failure warning. ○ Note: the data show that some operators drive near the fog line rather than in the middle of the shoulder.

APPENDIX C. INSTRUCTIONS FOR ONLINE RANKING

Please complete the following survey. Do not leave any survey items unanswered.

We are trying to determine which topics are most relevant to current designs for controls and display designs for bus driver systems, and what it is that system designers need to know in order to move forward with designing controls and displays.

This ranking activity can lead to research that has importance for the overall transit community, in terms of mobility, sustainability and bus driver performance and safety.

There are 6 survey items. The first 5 are topic areas that pertain to emerging technologies (e.g., Connected Vehicles and Intelligent Transportation systems initiatives). The 6th item is a rating of the topic areas.

The five areas are:

1. General bus operation policy and practice
2. Driver performance with technology support
3. Information needs of bus drivers given new capabilities
4. Bus driver interactions with onboard technology systems
5. Retrofit system issues

Within each topic area there are multiple research topics. We want you to re-order them to show the relative importance of the research questions within the topics.

Within each topic area, please do the following:

1. Sort the research questions to represent the order in which you think they should be considered.
2. Research questions that you think are relevant and important should be dragged to the top.
3. Research questions that you think are not relevant and important should be dragged towards the bottom.

Again, the 6th item asks you to order the importance of the four topic areas. This item is to help prioritize the topic areas and identify which area should be a primary focus of design guidance research.

You can edit your responses until the survey is complete.

APPENDIX D. QUESTIONNAIRE AGENCY RECIPIENT DISTRIBUTION LIST

Agencies in Group 1 received solicitation e-mails sent May 4 June 25 July 18 July 22, and July 24 2015.
Agencies in Group 2 received solicitation e-mails sent June 11 July 18 July 22, and July 24 2015.
Agencies in Group 3 received a solicitation e-mail sent July 22, 2015.

Ridership data from public transportation ridership report 4th Quarter 2004: Estimated unlinked transit passenger trips. www.apta.com/resources/statistics/Documents/Ridership/2014-q4-ridership-APTA.pdf

E-mail Group	Location	Agency	Ridership AVG WKDY 2014 (*1000s)
1	New York City, NY	Metropolitan Transportation Authority	2,547.9
1	Washington DC	Washington Metropolitan Area Transit Authority	829.2
1	Philadelphia, PA	Southeastern Pennsylvania Transportation Authority	436.6
1	Baltimore, MD	Maryland Transit Administration	283.3
1	Miami, FL	Miami-Dade Transit	240.7
1	Minneapolis, MN	Metro Transit	219.1
1	Miami, FL	Broward County Transportation Department	135.4
1	Dallas, TX	Dallas Area Rapid Transit Authority	126.3
1	Arlington Heights, IL	Pace Suburban Bus Service	106.5
1	Orlando, FL	Central Florida Regional Transportation Authority (Lynx-bus)	92.1
1	Rockville, MD	Montgomery County Department of Transportation Ride On	86.6
1	Denver, CO	Denver Regional Transportation District	86.3
1	Wasatch Front, UT	Utah Transit Authority	72.1
1	Charlotte, NC	Charlotte Area Transit System	69.1
1	Sacramento, CA	Sacramento Regional Transit District	49.7
1	Arlington, VA	Arlington Transit	9.8
1	Eugene, OR	Lane Transit District	*
2	Chicago, IL	Chicago Transit Authority	878
2	Houston, TX	METRO	235.7
2	San Diego, CA	San Diego Metropolitan Transit System	176.3
2	San Antonio, TX	VIA Metropolitan Transit	135.5
2	Lansing, MI	Capital Area Transportation Authority	38
2	Oakland, CA	Alameda-Contra Costa Transit District	NA
2	Las Vegas, NV	Regional Transportation Commission of Southern Nevada	NA
3	Richland, WA	Ben Franklin Transit	275
3	Spokane, WA	Spokane Transit	39.8
3	Lakewood, WA	Pierce Transit	33.3

E-mail Group	Location	Agency	Ridership AVG WKDY 2014 (*1000s)
3	Olympia, WA	Intercity Transit	14.6
3	Bremerton, WA	Kitsap Transit	10.4
3	Dayton, WA	Columbia County Public Transportation	*
3	Port Angeles, WA	Clallam Transit	*
3	Hoquiam, WA	Grays Harbor Transit	*
3	Everett-Aurora Village, WA	Community Transit	*
3	Clark County, WA	Clark County Transit	*
3	Grant County, WA	Grant Transit Authority	*
3	Coupeville, WA	Island Transit	*
3	Port Townsend, WA	Jefferson Transit	*
3	Wenatchee, WA	Link Transit	*
3	Shelton, WA	Mason Transit	*
3	Longview, WA	RiverCities Transit	*
3	Bellingham, WA	Whatcom Transportation	*
3	Burlington, WA	Skagit Transit	*
3	Centralia, WA	Twin Transit	*
3	Walla Walla, WA	Valley Transit	*

APPENDIX E. TRANSIT BUS TECHNOLOGY QUESTIONNAIRE

Transit Bus Technology

This questionnaire seeks information about different technologies that are present on transit buses. Completing this questionnaire should take less than 10 minutes.

If you have any questions or difficulty with the questionnaire please contact Justin Morgan (morgan@battelle.org, 206-528-3243) or Justin Graving (gravingj@battelle.org, 206-528-3268).

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: Human Factors for Connected Vehicles Modal and Application Gaps Research: Questionnaire

Investigators:

Battelle Memorial Institute
Dr. John L. Campbell, campjohn@battelle.org, (206) 528-3254
Dr. Justin F. Morgan, morgan@battelle.org, (206) 528-3243
Mr. Justin S. Graving, gravingj@battelle.org, (206) 528-3268

Virginia Tech Transportation Institute
Dr. Richard J. Hanowski, rhanowski@vtti.vt.edu, (540) 231-1513

I. Purpose of this Research Project

Pedestrians struck by buses are one of the largest safety problems associated with transit. Connected vehicle technology allows for vehicles and infrastructure to communicate, and can help address safety issues such as bus-pedestrian collisions. The National Highway Traffic Safety Administration (NHTSA) is sponsoring this research project to examine the best ways of presenting safety information to transit bus operators.

This questionnaire is being distributed to transit agencies to determine the types of technologies present on transit buses, and how drivers interact with those technologies. The results of this study will be published by NHTSA and will be used to help generate design principles for transit bus safety systems.

II. Procedures

If you agree to participate, you will be asked to:
1. Provide basic information about your transit bus fleet
2. Indicate which technologies are present on your buses
3. Indicate if transit bus operators have to interact with the technologies during their shifts and, if so, how the operator interacts with the technology
4. Provide a picture of the transit bus operator's workstation (driver space).

Completing this questionnaire should take no more than 10 minutes.

III. Risks

The risks associated with your participation are minimal, and similar to those encountered in a normal office environment.

IV. Benefits

No promise or guarantee of benefits has been made to encourage you to participate. There are no direct benefits to your participation. You may enjoy participating in the study. The information you provide may benefit the design of future transit bus pedestrian collision warning systems.

V. Extent of Anonymity and Confidentiality

Data collected in this study will be treated as confidential. We are not collecting data about any individuals. Instead, we are interested in what technologies your fleet has deployed. Your name, as well as your agency name, will not be associated with any of the study data. Your responses will be identified using only a code (e.g., Agency 2). Identifying metrics, such as fleet size, will be grouped to prevent direct identification (e.g., fleet size of 50-75 full-size buses). No identifying information about you or your agency will be provided to any state or federal agency.

The sponsor of this project, NHTSA, may publicly release data, in final reports or other publication or media for scientific, educational, research or outreach purposes. Additionally, NHTSA may be required to release data due to Freedom of Information Act or other Open Government Initiative request. Data will not be released in raw form. Any data released will not be linked to your name or contact information, and

Fleet Demographics

These questions are designed to give us some basic information about your fleet and operations.

What modes of transit service does your agency use?

Please check all that apply.

- ❑ Commuter Rail
- ❑ Heavy Rail
- ❑ Light Rail
- ❑ Demand Response
- ❑ Motor Bus
- ❑ Other

If you selected other, please list other services here

____

How many of the following buses are in your agency's fleet?

Articulated buses and buses 40ft long or greater ______________

Motocoaches ______________

Demand Responsive/ Paratransit ______________

Add any clarification notes on Fleet size here:

____

What is your agency's approximate daily ridership for transit buses?

Transit bus average daily ridership ____________________

Add any clarification notes on ridership here:

____

How many permanent transit bus routes does your agency offer?

Number of permanent transit bus routes ____________________

Add any clarification notes on bus routes here:

____

What is the approximate area, in square miles, that your agency serves?

Approximate area served in square miles ____________________

Add any clarification notes on service area here:

____

Technologies Used in Your Transit Bus Fleet

For each of the following technologies, we are interested in four things.

1. Used in Fleet. Is this technology used in your fleet? This can include partial implementation.

2. Driver Interacts with Tech Using Displays and Controls. Does the driver have to interact with the technology during a shift, even once?

3. Tech has a Stand-Alone Display. Does the technology have a standalone set of displays and controls, or are the displays and controls shared with another technology (such as the mobile data terminal)? For example, a lane departure warning system that has a unique display and controls would be considered stand-alone, while automated vehicle location/computer aided dispatch (AVL/CAD) and automatic passenger counter (APC) both communicating to the bus driver through a mobile data terminal would not be considered integrated.

4. Retrofitted to Existing Fleet: Was the technology part of the original vehicle acquisition or was it added after the vehicle went in-service as a retrofit? An example of a retrofit would be installing a system on an existing fleet, like adding a pedestrian detection system that calls out to warn pedestrians of an approaching bus.

Technologies

	Used in Fleet	Driver Interacts with Tech Using Displays and Controls	Tech has Stand-Alone Display	Retrofitted to Existing Fleet
Automatic In-vehicle Announcements/Annunciators	❑	❑	❑	❑
Automatic Fare Collection	❑	❑	❑	❑
Automatic Head Signs	❑	❑	❑	❑
Automatic Passenger Counter	❑	❑	❑	❑
Autonomous Cruise Control	❑	❑	❑	❑
Blind Spot Detection System	❑	❑	❑	❑
Computer Aided Dispatch or Automatic Vehicle Location (CAD/AVL)	❑	❑	❑	❑
Mobile Data Terminal	❑	❑	❑	❑
Connection Protection	❑	❑	❑	❑
Forward Collision Warning	❑	❑	❑	❑
Infotainment On-Board (in-vehicle traveler information system)	❑	❑	❑	❑
Lane Departure Warning	❑	❑	❑	❑
Side Object Detection System	❑	❑	❑	❑
Transit Signal Priority	❑	❑	❑	❑
Vehicle Guidance and Control (Vehicle Assist & Automation)	❑	❑	❑	❑
Vehicle Health Monitoring	❑	❑	❑	❑
Video Monitoring System	❑	❑	❑	❑
Covert Alert	❑	❑	❑	❑
Call Warning for Pedestrians (Talking Bus)	❑	❑	❑	❑
Pedestrian Collision Warning System (in-vehicle alert)	❑	❑	❑	❑
WiFi for Passengers	❑	❑	❑	❑

Are there any other technologies your fleet uses?

Technology 1 ______________________

For Technology 1

- ❑ Driver Interacts with Tech
- ❑ Tech has Stand-Alone Display
- ❑ Retrofitted to Existing Fleet

Technology 2 ______________________

For Technology 2

- ❑ Driver Interacts with Tech
- ❑ Tech has Stand-Alone Display
- ❑ Retrofitted to Existing Fleet

Technology 3 ______________________

For Technology 3

- ❑ Driver Interacts with Tech
- ❑ Tech has Stand-Alone Display
- ❑ Retrofitted to Existing Fleet

If you have any questions or difficulty with the questionnaire please contact Justin Morgan (morgan@battelle.org, 206-528-3243) or Justin Graving (gravingj@battelle.org, 206-528-3268).

Please provide a photograph of the bus driver space. This should be an overhead view showing all displays and controls the driver must use. If you use mobile data terminals (MDTs) in your buses, please ensure that is part of the picture. An example of the type of image we would like is provided below.

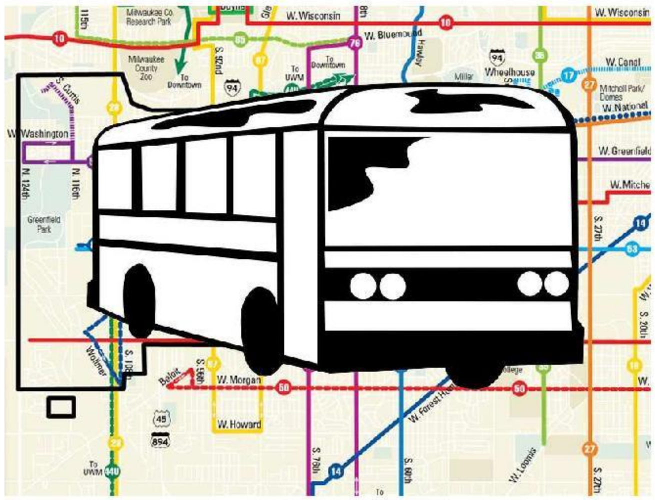
The survey is asking for one image. If you would like to share additional images please email them to Justin Graving: gravingj@battelle.org

Any additional details can be provided here

If you have any questions or difficulty with the questionnaire please contact Justin Morgan (morgan@battelle.org, 206-528-3243) or Justin Graving (gravingj@battelle.org, 206-528-3268).

APPENDIX F. PROTOTYPING STUDY RECRUITMENT FLYER

Transit Bus Drivers Needed for Research Study



Battelle is performing a research study for the National Highway Traffic Safety Administration looking at how warning messages should be presented in transit buses. If you choose to participate in this study, you will be asked to:

- Schedule a time to participate in a 2 hour session
- Learn about connected vehicle safety technology for transit buses
- Participate in a focus group to identify how warning messages should be provided

Total time is expected to be 2 hours, with total compensation of $60. Compensation for your participation will be provided at $30/hour. $15 will be provided for completing the study, for total compensation of $75 in cash.

For more information, contact:

Justin Graving

Battelle

(206) 528-3268 / gravingj@battelle.org

APPENDIX G. PROTOTYPING CONSENT FORM

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: HFCV Modal and Application Gaps Research: Prototyping Study

Investigators: **Battelle Memorial Institute**
Dr. John L. Campbell, campjohn@battelle.org, (206) 528-3254
Dr. Justin F. Morgan, morgan@battelle.org, (206) 528-3243
Mr. Justin S. Graving, gravingj@battelle.org, (206) 528-3268

Virginia Tech Transportation Institute
Dr. Richard J. Hanowski, rhanowski@vtti.vt.edu, (540) 231-1513

I. Purpose of this Research Project

Pedestrians struck by buses are one of the largest safety problems associated with transit. Connected vehicle technology allows for vehicles and roads to communicate, and can help address safety issues such as bus-pedestrian collisions. The National Highway Traffic Safety Administration (NHTSA) is sponsoring this research project to examine the best ways of presenting safety information to transit bus operators. Approximately 10 transit bus operators will be asked to participate in this part of the study. The results of this study will be published by NHTSA and will be used to help generate design principles for transit bus safety systems.

II. Procedures

If you agree to participate, you will be:

1. Provided with background information on connected vehicles and the technology to warn buses about pedestrians.
2. Asked to participate in table-top scenarios with 4 other transit bus operators. The scenarios will describe a pedestrian-relevant scenario that a transit bus operator could face.
3. Provided with different examples of how pedestrian warning information could be presented to the operator.
4. Given the opportunity to suggest other ways of warning the operator to the pedestrian's presence.

The meeting will last no more than 2 hours. Nothing about your participation, nor any information that can personally-identify you, will be shared with your employer or any state or federal agency.

III. Risks

The risks associated with your participation are minimal. First, there is risk of psychological stress similar to that experienced while explaining details related to your job; second, there is the risk that you may find some of the questions about your job to be sensitive and this may cause discomfort. The likelihood you will experience stress during this interview depends on your susceptibility to social anxiety. If social situations cause significant anxiety for you, you may consider withdrawing from this study.

Virginia Tech Institutional Review Board Project No. 14-954
Approved July 29, 2015 to February 17, 2016

IV. Benefits

No promise or guarantee of benefits has been made to encourage you to participate. There are no direct benefits to your participation. You may enjoy participating in the study. The information you provide may benefit the design of future transit bus pedestrian collision warning systems.

V. Extent of Anonymity and Confidentiality

Data collected in this study will be treated as confidential. Your name and other identifying data will not be associated with any of the study data. Your data will be identified using only a code (e.g., Participant 5). No information about you will be provided to your employer or any state or federal agency.

Audio and video recording will be used to supplement the researcher's notes. These recordings will be used to ensure complete notes and will then be destroyed. Audio recordings will not be released to your employer, the research sponsor, or anyone outside the research team.

Non-identifying information from the analyses may be put in a public database, available to anyone on the internet. Other data that might allow you to be identified will be stored in a controlled-access database. The information in this database will be available only to researchers who have received IRB approval and completed a data sharing agreement that maintains your confidentiality. They may only view your data in a secure environment. Please note that traditionally-used identifying information about you, such as your name or telephone number, will not be put into either public or controlled-access databases for this project.

The investigators listed on the first page of this form will have access to the collected data. The Virginia Tech (VT) Institutional Review Board (IRB) may view the study's data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

All data collected as part of this research will be destroyed September 2018.

VI. Compensation

You will be compensated for your participation in the meeting. Compensation will be $30 per hour, prorated to the next half-hour. For completion of the study you will be provided an extra $15 in cash. As the expected duration of the study is 2 hours, the maximum compensation is $75 ($60 for time, plus $15 for completing the study). This will be paid to you in cash at the conclusion of your participation.

VII. Freedom to Withdraw

It is important for you to know that you are free to withdraw from this study at any time without penalty. You are free not to answer any questions that you choose or respond to what is being asked of you without penalty. Should you withdraw or otherwise discontinue participation, you will be compensated for the portion of the project completed in accordance with the Compensation section of this document.

VIII. Questions or Concerns

Should you have any questions about this study, you may contact one of the research investigators whose contact information is included at the beginning of this document.

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

IX. Subject's Consent

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date__________
Subject signature

____
Subject printed name

Virginia Tech Institutional Review Board Project No. 14-954
Approved July 29, 2015 to February 17, 2016

APPENDIX H. PROTOTYPING STUDY MODERATOR GUIDE

Consent Script

In a quiet room, provide the consent form to the participant. Read the following to the participant:

We are asking you to volunteer as a participant in a focus group on how technology can help reduce bus-pedestrian crashes. Should you choose to participate, this study will involve the following:

This focus group will consist of a series of table-top scenarios. The scenarios are based on bus-pedestrian crashes. The composition of each scenario is based on real-world events. I [as the moderator] will guide you through each scenario, one scenario at a time. For each scenario, we will work as a group to generate a list of activities the bus operator may have had in mind during the scenario. Each scenario is relevant to the interaction design of current and future transit pedestrian detection and warning systems. Once we have generated a list of operator tasks, we will work as a group to design the display and control aspects of a system that can reduce the occurrence of buses striking pedestrians.

I [as the moderator] will work collaboratively with you to assemble the controls and displays (i.e., front-end design). The focus group will be carried out in an interactive free-form manner. We will provide you with a response book for you to write your responses down. You will be encouraged to discuss your responses and ideas with the group.

The risks associated with your participation are minimal, but there are a few you should be aware of. First, there is risk of psychological stress similar to that experienced while explaining details related to your job; second, there is the risk that you may find discussion topics about your job to be sensitive and this may cause discomfort. The likelihood you will experience stress during this focus group depends on your susceptibility to social anxiety. If social situations cause significant anxiety for you, you may consider withdrawing from this study.

All of the information we collect will be held confidential. We will not discuss your participation with your employer, or any other entity. Please take as much time as you need to read the consent form. It outlines what we will ask you to do, provides your rights and responsibilities as a participant in research and, most importantly, lets you know that you can discontinue participation at any time without penalty. Please let me know if you have any questions before signing.

Answer any questions that may arise. Ensure participant signs both copies. Collect one copy of the signed consent statement and ensure the participant has a copy to keep

Ground Rules

Prior to the start of the prototyping study, inform participants of the ground rules for participation.

There are some ground rules we need to follow.

Please, write down your ideas in the response book before talking about them with the group.

Allow others who are speaking to complete what they are saying.

Keep in mind that we are working as a group and that all opinions are valuable. To encourage ‘outside of the box’ thinking, please consider that any current practices you may be aware of may not apply. Imagine that there are no authorities on the topic that are present in-group, including the moderator.

Contribute to the discussion. There may be times when you are the only person in the group that feels a particular way. Please speak up when this occurs.

Are there any questions?”

Answer any questions that may arise.

Moderator Guide

This Moderator’s Guide serves as a framework to help the moderator generally cover the topics of interest. However, given that this is a moderated discussion, these questions should be considered to be more as “touch points” rather than fixed topics. The moderator will follow-up on related topics opportunistically, with the objective of exploring issues related to the topics of interest.

GREET FOCUS GROUP:

I am the moderator for today’s discussion. The purpose of today’s focus group is to talk about pedestrian detection and technology. Specifically we are interested in tasks that bus drivers carry out and how to design a pedestrian detection and warning system that has in-vehicle controls and displays for the bus driver.

DISCLOSURES

I work for a research company called Battelle Memorial Institute. My job is conduct the focus group for my client, the National Highway Traffic Administration (NHTSA) of the U.S.Department of Transportation. I have no stake in your answers and my job will continue regardless of what is said here today. I encourage you to be honest and feel free to offer both positive and negative comments.

This session is being recorded. A record of today’s information will help immensely for evaluating the ideas that are set forth by this group. Evaluation of the content in the recording will be carried out at a later date. The recording will be kept confidential, not be shared with anyone, including the project sponsors, and will be destroyed after the evaluation is complete. Names, personal identifying information and any likeness of yourself will be purposefully excluded from any reports or documents that are generated based on our discussions today.

OVERVIEW OF TABLETOP ACTIVITY AND RESPONSE BOOKLET.

The purpose of the focus group is to work together to develop a paper-prototype of the controls and displays of a pedestrian detection and warning system for bus drivers. The large image on the table will help us to think about all the factors associated with bus-pedestrian crashes. We will work through about a half dozen crashes and will use a response booklet to guide this process (show response book). For each crash I want you to write down tasks that may be on-going for the bus driver, and jot down notes on what a pedestrian detection and warning system might do in the situation, and what the controls and displays would look like. I will be asking questions throughout the focus group today. We will also work together to assemble the paper-prototype of the pedestrian detection and warning system.

CONDUCT TABLE TOP ACTIVITY

APPENDIX I. PROTOTYPING STUDY RESPONSE BOOK

Blank pages removed

Focus Group Response Book

Topic: Messages to prevent transit bus collisions with pedestrians.

9/15/15

1

Survey Questions

1. What is your age?	
2. What is your gender?	
3. Are you currently a bus driver?	
4. How many years of experience do you have working as a bus driver?	

3

Introduction

Table top exercise instructions

The main purpose of the focus group is to brainstorm ideas for a pedestrian warning system. The following topics will be part of the focus group:

- Locations for alert displays
- What the alerts should look like
- When/where pedestrian alerts should occur
- What should other on-board technologies do when an pedestrian is detection.
- Operator control settings

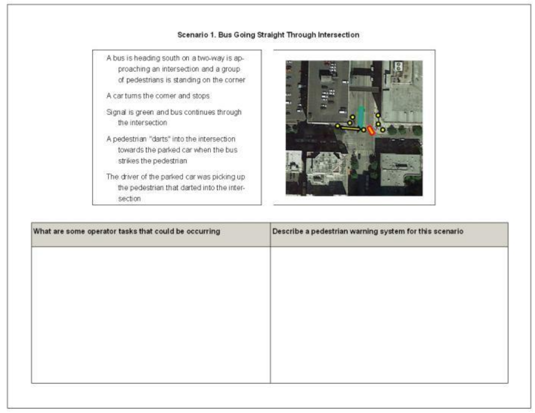
We will talk about several pedestrian incidents to generate ideas for a pedestrian system. We will use this response booklet to guide the process.

There are two pages in the book for each scenario. The **top page** illustrates the incident, and there is space to write down any operator tasks that come to mind regarding the scenario. There is also space to write any ideas for a pedestrian detection system.

The **bottom page** provides sketch space for drawing ideas for pedestrian warnings.

Use both the top and bottom pages to document ideas for pedestrian warning systems. We will ask questions throughout the focus group today to encourage some general discussion.

Please share your ideas during the focus group!


Scenario 1. Bus Going Straight Through Intersection

A bus is heading south on a two-way is approaching an intersection and a group of pedestrians is standing on the corner

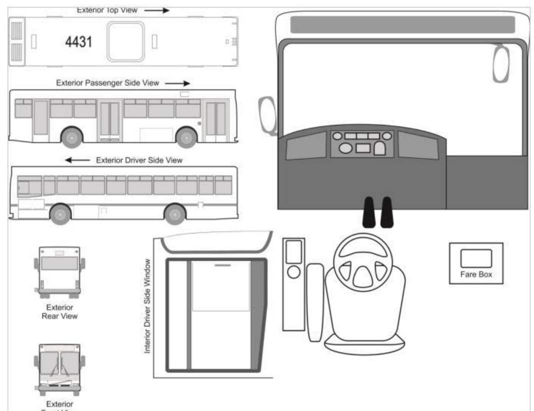
A car turns the corner and stops

Signal is green and bus continues through the intersection

A pedestrian "darts" into the intersection towards the parked car when the bus strikes the pedestrian

The driver of the parked car was picking up the pedestrian that darted into the intersection

What are some operator tasks that could be occurring	Describe a pedestrian warning system for this scenario



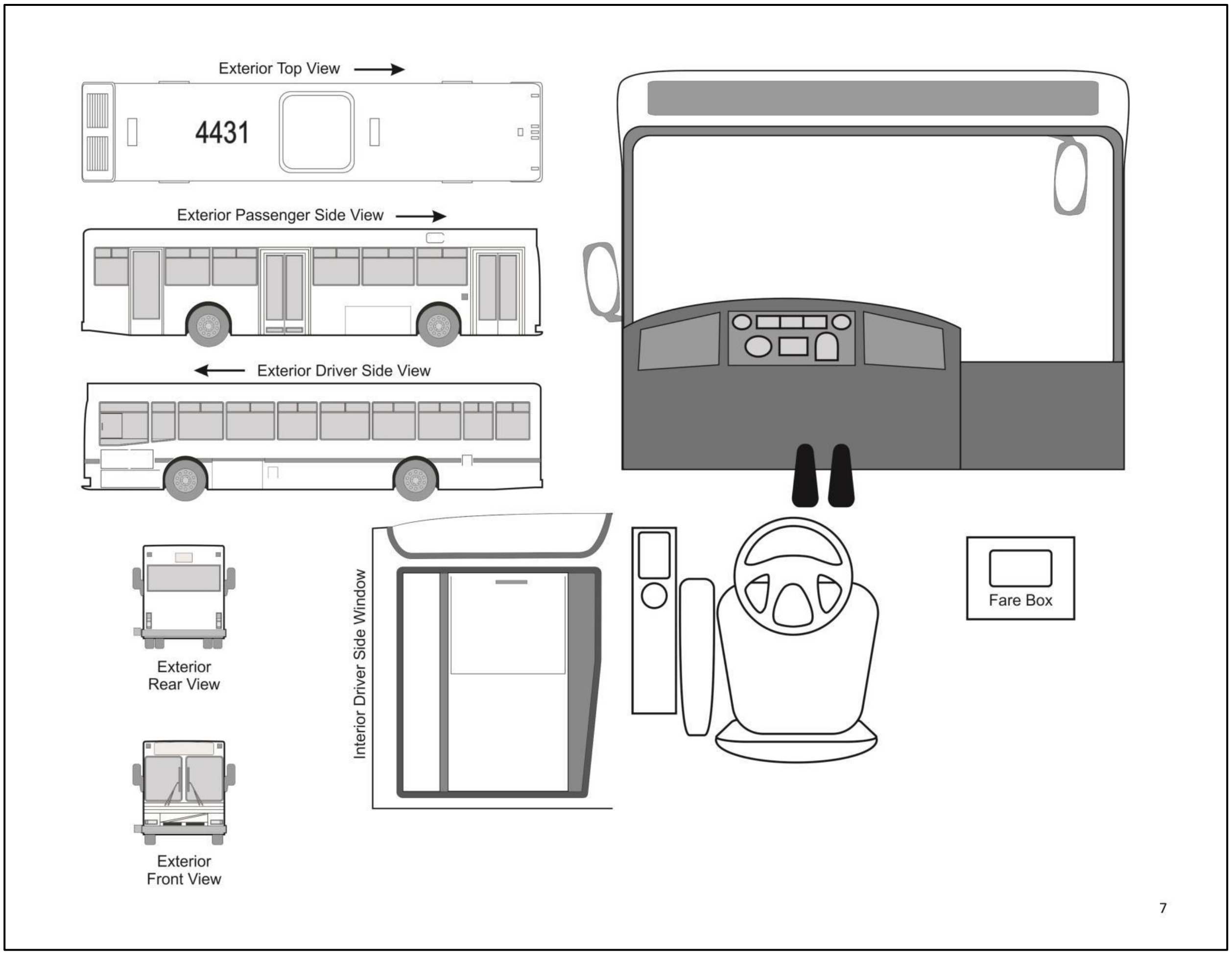
5

Scenario 1. Bus Going Straight Through Intersection

- A bus driving on a two-way road is approaches an intersection where a group of pedestrians is standing on the corner
- A car turns the corner and stops (red)
- Intersection is green and the bus continues through the intersection
- A pedestrian "darts" into the intersection towards the parked car when the bus strikes the pedestrian
- The driver of the parked car was picking up the pedestrian that darted into the intersection

What are some operator tasks that could be occurring	Describe a pedestrian warning system for this scenario

6

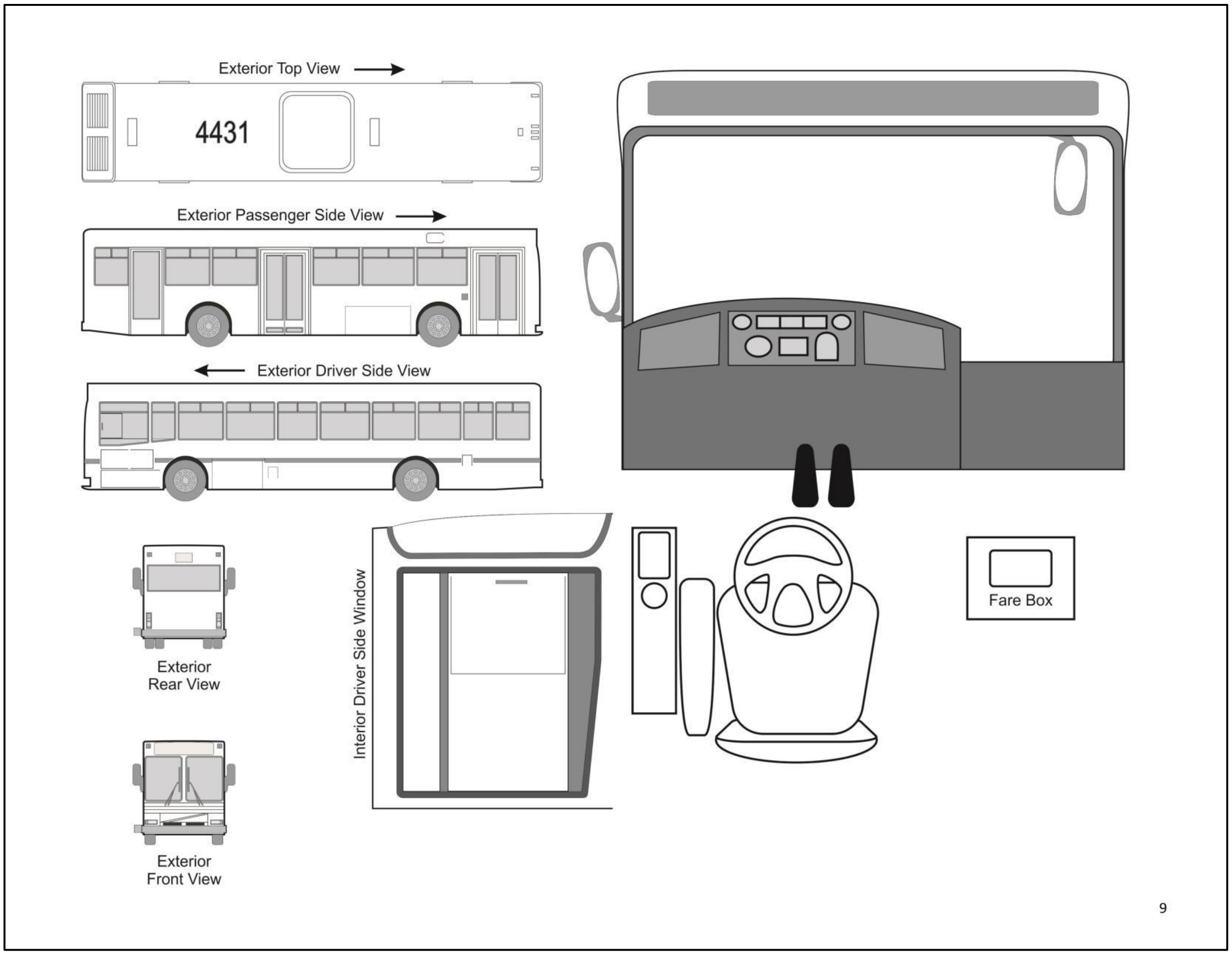

Exterior Top View
4431
Exterior Passenger Side View
Exterior Driver Side View
Exterior
Rear View
Exterior
Front View
Interior Driver Side Window
Fare Box
7

Scenario 2. Bus Turning Right at Night

- Bus prepares to turn right onto the main road at a t-intersection.
- A pedestrian is waiting to cross the main road to get to the store across the street
- Conditions were dark and the pedestrian was not visible to the driver.
- Signal is green, permitting the bus to turn, and the bus turns right
- The pedestrian enters the intersection and is struck by the rear duals of the bus.

What are some operator tasks that could be occurring	Describe a pedestrian warning system for this scenario

8

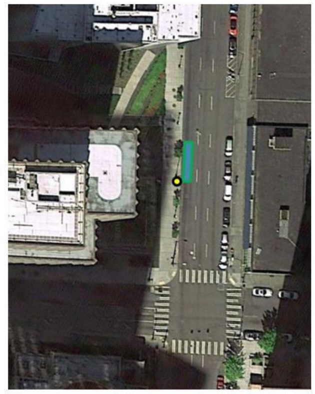

Exterior Top View
4431
Exterior Passenger Side View
Exterior Driver Side View
Exterior Rear View
Exterior Front View
Interior Driver Side Window
Fare Box
9

Scenario 3. Mirror Clips Pedestrian.

A bus heading south on a one way approaching the next stop located after the next cross street.

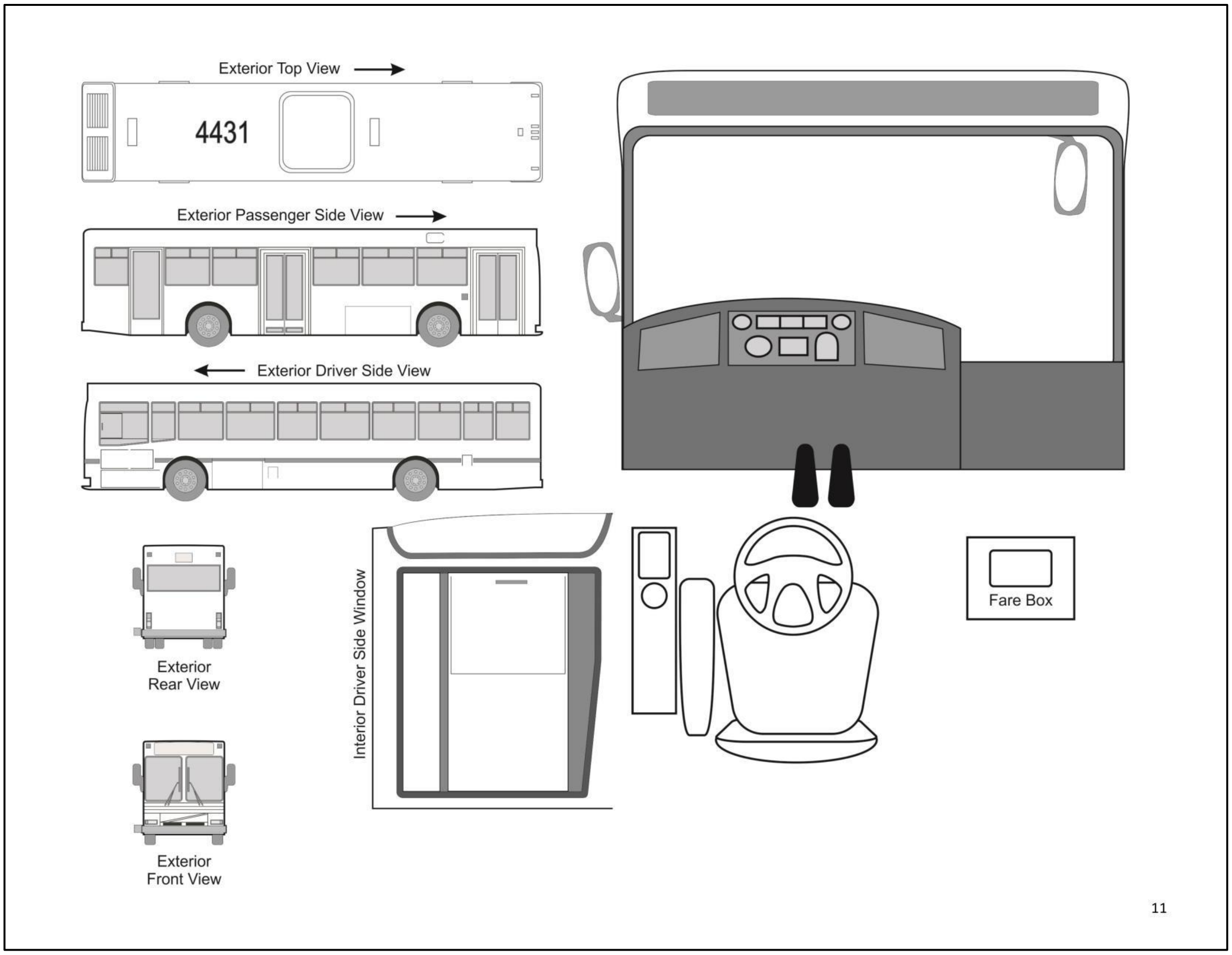
A pedestrian is standing on the, mid-block, and local shrubbery block the bus driver's view of the pedestrian

The bus merges into the adjacent lane, preparing for passengers to board at the stop after the cross street. The pedestrian, looking the opposite direction, does not see the approaching bus and is struck by the bus mirror



What are some operator tasks that could be occurring	Describe a pedestrian warning system for this scenario

10


Exterior Top View
4431
Exterior Passenger Side View
Exterior Driver Side View
Exterior
Rear View
Exterior
Front View
Interior Driver Side Window
Fare Box
11

Scenario 4: Left Turn in Heavy Traffic.

A bus driver drops of passenger before making a left turn.

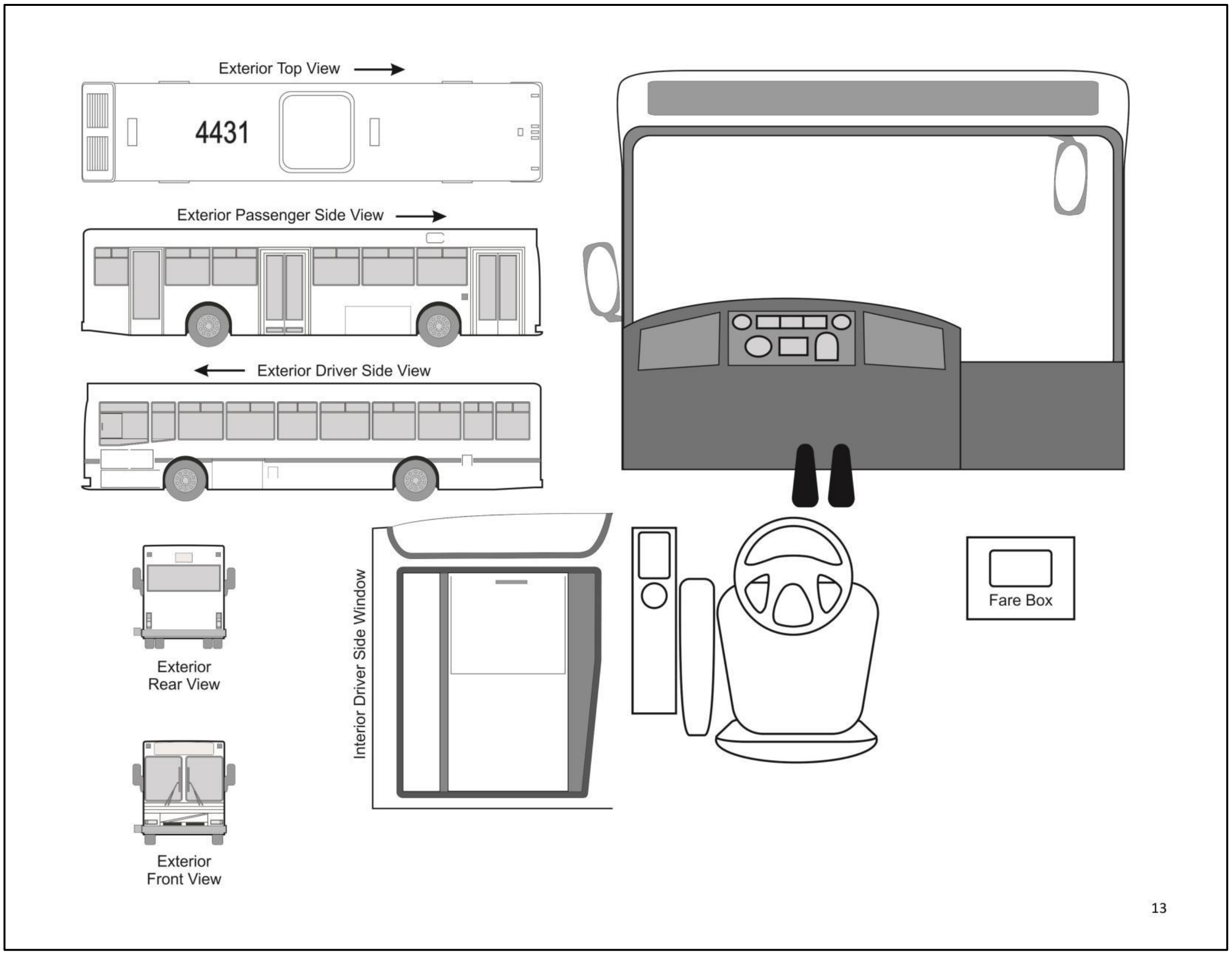
Traffic to the left of the driver is present and potentially blocking the operators view.

A group of pedestrians on the corner enters the intersection when the operator turns left.

The bus strikes the group of pedestrians

What are some operator tasks that could be occurring	Describe a pedestrian warning system for this scenario

12



Exterior Top View
4431
Exterior Passenger Side View
Exterior Driver Side View
Exterior Rear View
Exterior Front View
Interior Driver Side Window
Fare Box
13

Scenario 5. Left Turn into a Transit Station

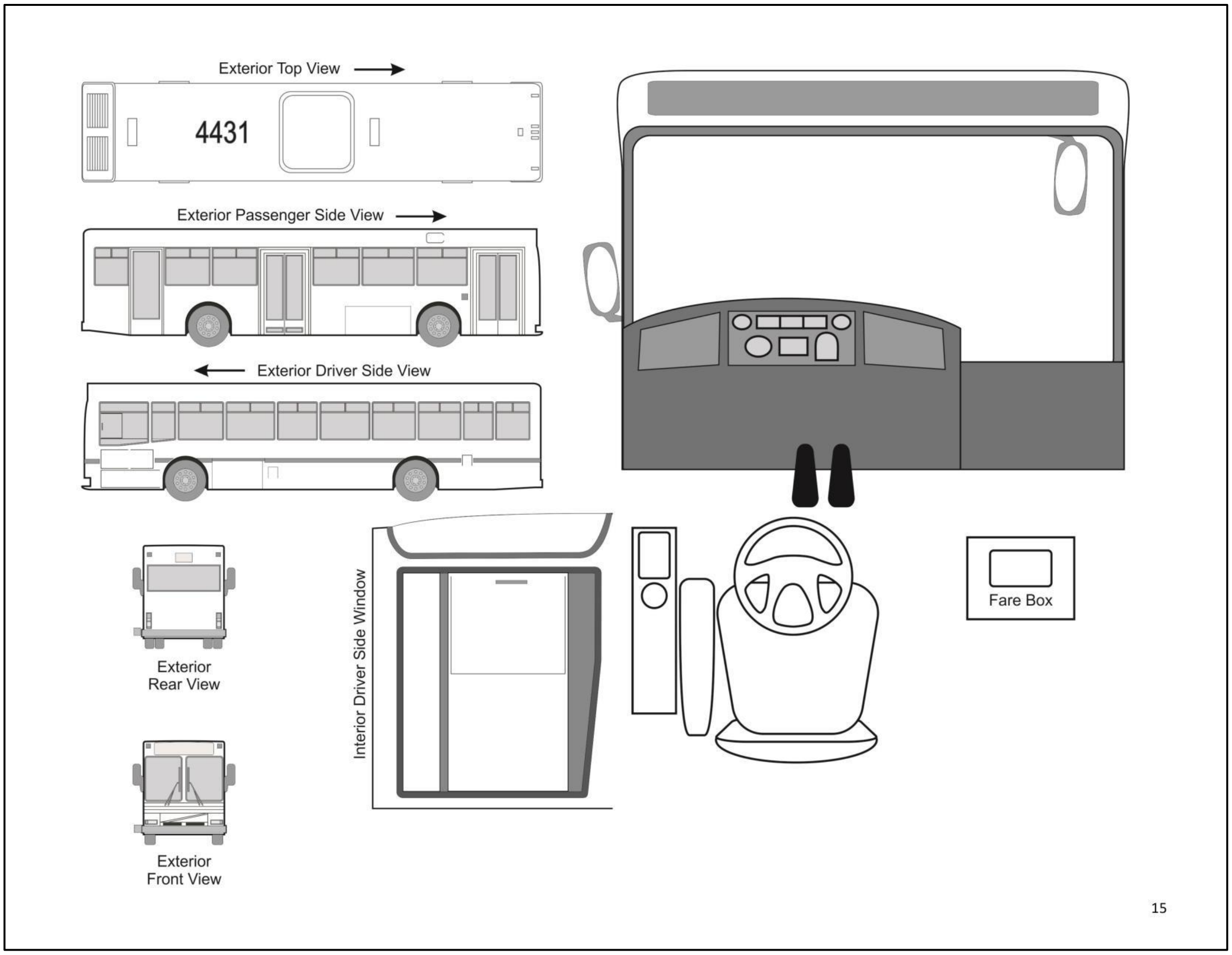
A bus turning left into a transit stop confuses a horn honk from an oncoming bus driver as a permissive signal to take the right-of-way.

The operator the other bus honked the horn to warn of the pedestrian in the cross-walk

The operator of the striking bus did not look to his left and continued to enter the intersection and stuck the pedestrian.

What are some operator tasks that could be occurring	Describe a pedestrian warning system for this scenario

14

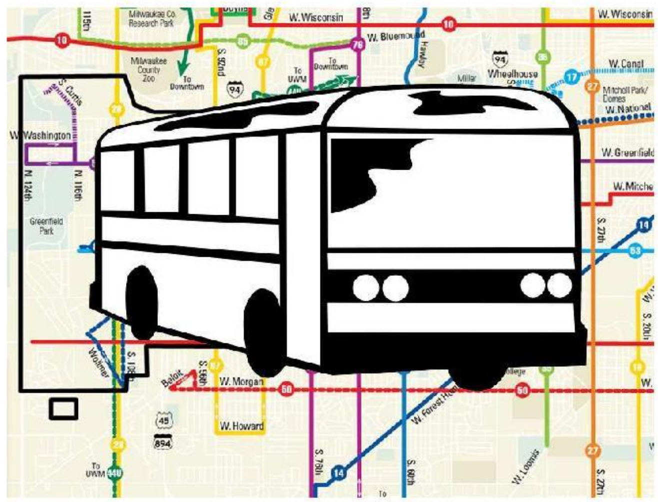

Exterior Top View
4431
Exterior Passenger Side View
Exterior Driver Side View
Exterior Rear View
Exterior Front View
Interior Driver Side Window
Fare Box
15

Last Page

17

APPENDIX J. TASK ANALYSIS RECRUITMENT FLYER

Transit Bus Drivers Needed for Research Study



Battelle is performing a research study for the National Highway Traffic Safety Administration looking at how warning messages should be presented in transit buses. If you choose to participate in this study, you will be asked to:

- Have a researcher ride along while you drive a route
- Participate in an in-person or telephone interview to discuss how technology should be integrated on the bus

Total interview time is expected to be 2 hours. Compensation for the interview will be provided at $30/hour. $15 will be provided for completing the study, for total compensation of $75 in cash.

For more information, contact:

Justin Graving

Battelle

(206) 528-3268 / gravingj@battelle.org

APPENDIX K. TASK ANALYSIS CONSENT FORM (INCENTIVE VERSION)

Informed Consent for Participants
in Research Projects Involving Human Subjects

Title of Project: Human Factors for Connected Vehicles Modal and Application Gaps Research: Task Analysis

Investigators: **Battelle Memorial Institute**
Dr. John L. Campbell, campjohn@battelle.org, (206) 528-3254
Mr. Justin S. Graving, gravingj@battelle.org, (206) 528-3268

Virginia Tech Transportation Institute
Dr. Richard J. Hanowski, rhanowski@vtti.vt.edu, (540) 231-1513

I. Purpose of this Research Project

Pedestrians struck by buses are one of the largest safety problems associated with transit. Connected vehicle technology allows for vehicles and infrastructure to communicate, and can help address safety issues such as bus-pedestrian collisions. The National Highway Traffic Safety Administration (NHTSA) is sponsoring this research project to examine the best ways of presenting safety information to transit bus operators. Approximately 5 transit bus operators will be asked to participate in this part of the study. The results of this study will be published by NHTSA and will be used to help generate design principles for transit bus safety systems.

II. Procedures

If you agree to participate, you will be asked to:

1. Allow a researcher to observe you working during revenue-service operations. The researcher may take notes, but will not take audio or visual recordings.
2. Schedule a time to meet with a researcher for a phone interview or an in-person interview at an office-type location.
3. During the meeting, provide some basic background on your professional driving experience and discuss what is involved as you perform your work duties. The researcher will ask questions about what is competing for your attention and how you balance the demands.

The meeting will last no more than 2 hours. Nothing about your participation, nor any information that can personally-identify you, will be shared with your employer or any state or federal agency.

III. Risks

The risks associated with your participation are minimal, and similar to those associated with your normal transit bus driving duties. The risks associated with the interview portion of the study are similar to those found in normal office environments.

Virginia Tech Institutional Review Board Project No. 14-954
Approved February 18, 2016 to February 17, 2017

IV. Benefits

No promise or guarantee of benefits has been made to encourage you to participate. There are no direct benefits to your participation. You may enjoy participating in the study. The information you provide may benefit the design of future transit bus pedestrian collision warning systems.

V. Extent of Anonymity and Confidentiality

Data collected in this study will be treated as confidential. Your name and other identifying data will not be associated with any of the study data. Your data will be identified using only a code (e.g., Participant 5). No information about you will be provided to your employer or any state or federal agency.

Audio recording will be used to supplement the researcher's notes. These recordings will be used to ensure complete notes and will then be destroyed. Audio recordings will not be released to your employer, the research sponsor, or anyone outside of the research team.

The sponsor of this project, NHTSA, may publicly release data, in final reports or other publication or media for scientific, educational, research or outreach purposes. Additionally, NHTSA may be required to release data due to Freedom of Information Act or other Open Government Initiative request. Data will not be released in raw form. Any data released will not be linked to your name or contact information, and any personally identifying information will be redacted, edited or removed. Other data that might allow you to be identified will be stored in a controlled-access database. The information in this database will be available only to researchers who have received Institutional Review Board (IRB) approval and completed a data sharing agreement that maintains your confidentiality. They may only view your data in a secure environment. Please note that traditionally-used identifying information about you, such as your name or telephone number, will not be put into either public or controlled-access databases for this project.

The investigators listed on the first page of this form will have access to the collected data. The Virginia Tech (VT) IRB may view the study's data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

All data collected as part of this research will be destroyed 3 years after the project ends (i.e., data will be destroyed in September 2018).

VI. Compensation

You will be compensated for your participation in the meeting. Compensation will be $30 per hour, prorated to the next half-hour. You will be provided an extra $15 in cash for completing all study activities. As the expected duration of the study is 2 hours, the maximum compensation is $75 ($60 for time, plus $15 for completing the study). This will be paid to you in cash at the conclusion of your participation.

VII. Freedom to Withdraw

It is important for you to know that you are free to withdraw from this study at any time without penalty. You are free not to answer any questions that you choose or respond to what is being asked of you without penalty. Should you withdraw or otherwise discontinue participation, you will be compensated for the portion of the project completed in accordance with the Compensation section of this document.

VIII. Questions or Concerns

Should you have any questions about this study, you may contact one of the research investigators whose contact information is included at the beginning of this document.

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

IX. Subject's Consent

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date__________
Subject signature

____
Subject printed name

APPENDIX L. TASK ANALYSIS CONSENT FORM (NO INCENTIVE VERSION)

Informed Consent for Participants
in Research Projects Involving Human Subjects

Title of Project: Human Factors for Connected Vehicles Modal and Application Gaps Research: Task Analysis

Investigators: **Battelle Memorial Institute**
Dr. John L. Campbell, campjohn@battelle.org, (206) 528-3254
Mr. Justin S. Graving, gravingj@battelle.org, (206) 528-3268

Virginia Tech Transportation Institute
Dr. Richard J. Hanowski, rhanowski@vtti.vt.edu, (540) 231-1513

I. Purpose of this Research Project

Pedestrians struck by buses are one of the largest safety problems associated with transit. Connected vehicle technology allows for vehicles and infrastructure to communicate, and can help address safety issues such as bus-pedestrian collisions. The National Highway Traffic Safety Administration (NHTSA) is sponsoring this research project to examine the best ways of presenting safety information to transit bus operators. Approximately 5 transit bus operators will be asked to participate in this part of the study. The results of this study will be published by NHTSA and will be used to help generate design principles for transit bus safety systems.

II. Procedures

If you agree to participate, you will be asked to:

1. Allow a researcher to observe you working during revenue-service operations. The researcher may take notes, but will not take audio or visual recordings.
2. Schedule a time to meet with a researcher for a phone interview or an in-person interview at an office-type location.
3. During the meeting, provide some basic background on your professional driving experience and discuss what is involved as you perform your work duties. The researcher will ask questions about what is competing for your attention and how you balance the demands.

The meeting will last no more than 2 hours. Nothing about your participation, nor any information that can personally-identify you, will be shared with your employer or any state or federal agency.

III. Risks

The risks associated with your participation are minimal, and similar to those associated with your normal transit bus driving duties. The risks associated with the interview portion of the study are similar to those found in normal office environments.

IV. Benefits

No promise or guarantee of benefits has been made to encourage you to participate. There are no direct benefits to your participation. You may enjoy participating in the study. The information you provide may benefit the design of future transit bus pedestrian collision warning systems.

V. Extent of Anonymity and Confidentiality

Data collected in this study will be treated as confidential. Your name and other identifying data will not be associated with any of the study data. Your data will be identified using only a code (e.g., Participant 5). No information about you will be provided to your employer or any state or federal agency.

Audio recording will be used to supplement the researcher's notes. These recordings will be used to ensure complete notes and will then be destroyed. Audio recordings will not be released to your employer, the research sponsor, or anyone outside of the research team.

The sponsor of this project, NHTSA, may publicly release data, in final reports or other publication or media for scientific, educational, research or outreach purposes. Additionally, NHTSA may be required to release data due to Freedom of Information Act or other Open Government Initiative request. Data will not be released in raw form. Any data released will not be linked to your name or contact information, and any personally identifying information will be redacted, edited or removed. Other data that might allow you to be identified will be stored in a controlled-access database. The information in this database will be available only to researchers who have received Institutional Review Board (IRB) approval and completed a data sharing agreement that maintains your confidentiality. They may only view your data in a secure environment. Please note that traditionally-used identifying information about you, such as your name or telephone number, will not be put into either public or controlled-access databases for this project.

The investigators listed on the first page of this form will have access to the collected data. The Virginia Tech (VT) IRB may view the study's data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

All data collected as part of this research will be destroyed 3 years after the project ends (i.e., data will be destroyed in September 2018).

VI. Compensation

Compensation will not be provided. Your participation is completely voluntary.

VII. Freedom to Withdraw

It is important for you to know that you are free to withdraw from this study at any time without penalty. You are free not to answer any questions that you choose or respond to what is being asked of you without penalty. Should you withdraw or otherwise discontinue participation, you will be compensated for the portion of the project completed in accordance with the Compensation section of this document.

VIII. Questions or Concerns

Should you have any questions about this study, you may contact one of the research investigators whose contact information is included at the beginning of this document.

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

IX. Subject's Consent

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date__________
Subject signature

____
Subject printed name

APPENDIX M. TASK ANALYSIS RIDE ALONG NOTES FORM

Observation Checklist

Session:

Date: **Route:**

Time: **Vehicle:**

Total number of pages in checklist:

Photography:

- ☐ Driver area – overhead view
- ☐ MDT (if present)
- ☐ Individual photos of each technology's HMI
- ☐ Individual photos of any job aids/work-arounds present

In-Route Observation:

No	Action/Technology Use	Phase			
		Rte	Apr	Brd	Dpt
1					
2					
3					
4					
5					
6					

APPENDIX N. VALIDATION CONSENT FORM (INCENTIVE VERSION)

Informed Consent for Participants
in Research Projects Involving Human Subjects

Title of Project: HFCV Modal and Application Gaps Research: Diagramming Bus Operating Tasks.

Investigators: **Battelle Memorial Institute**
Dr. John L. Campbell, campjohn@battelle.org, (206) 528-3254
Mr. Justin S. Graving, gravingj@battelle.org, (206) 528-3268

Virginia Tech Transportation Institute
Dr. Richard J. Hanowski, rhanowski@vtti.vt.edu, (540) 231-1513

I. Purpose of this Research Project

Pedestrians struck by buses are one of the largest safety problems associated with transit. Connected vehicle technology allows for vehicles and roads to communicate, and can help address safety issues such as bus-pedestrian collisions. The National Highway Traffic Safety Administration (NHTSA) is sponsoring this research project to examine the best ways of presenting safety information to transit bus operators. The goal for this study is to diagram bus operating tasks. The diagram may be used by systems engineers to link system designs to operating requirements.

Approximately 10 transit bus operators will be asked to participate in this part of the study. The results of this study will be published by NHTSA and will be used to help generate design principles for transit bus safety systems.

II. Procedures

If you agree to participate, you will be:

1. Provided with background information on connected vehicles transit technology.
2. Asked to help make a diagram of bus operating tasks.
3. Asked to rate the workload and demand of specific bus operating tasks.
4. Given the opportunity to suggest ways to improve bus operation.

The meeting will last no more than 2 hours. Nothing about your participation, nor any information that can personally-identify you, will be shared with your employer or any state or federal agency.

III. Risks

The risks associated with your participation are minimal. First, there is risk of psychological stress similar to that experienced while explaining details related to your job; second, there is the risk that you may find some of the questions about your job to be sensitive and this may cause discomfort. The likelihood you will experience stress during this interview depends on your susceptibility to social anxiety. If social situations cause significant anxiety for you, you may consider withdrawing from this study.

Virginia Tech Institutional Review Board Project No. 14-954
Approved February 18, 2016 to February 17, 2017

IV. Benefits

No promise or guarantee of benefits has been made to encourage you to participate. There are no direct benefits to your participation. You may enjoy participating in the study. The information you provide may benefit the design of future transit bus pedestrian collision warning systems.

V. Extent of Anonymity and Confidentiality

Data collected in this study will be treated as confidential. Your name and other identifying data will not be associated with any of the study data. Your data will be identified using only a code (e.g., Participant 5). No information about you will be provided to your employer or any state or federal agency.

Audio and video recording will be used to supplement the researcher's notes. These recordings will be used to ensure complete notes and will then be destroyed. Audio recordings will not be released to your employer, the research sponsor, or anyone outside the research team.

Non-identifying information from the analyses may be put in a public database, available to anyone on the internet. Other data that might allow you to be identified will be stored in a controlled-access database. The information in this database will be available only to researchers who have received IRB approval and completed a data sharing agreement that maintains your confidentiality. They may only view your data in a secure environment. Please note that traditionally-used identifying information about you, such as your name or telephone number, will not be put into either public or controlled-access databases for this project.

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All data collected as part of this research will be destroyed by September 2018.

VI. Compensation

You will be compensated for your participation in the meeting. Compensation will be $30 per hour, prorated to the next half-hour. For completion of the study you will be provided an extra $15 in cash. As the expected duration of the study is 2 hours, the maximum compensation is $75 ($60 for time, plus $15 for completing the study). This will be paid to you in cash at the conclusion of your participation.

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VIII. Questions or Concerns

Should you have any questions about this study, you may contact one of the research investigators whose contact information is included at the beginning of this document.

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

IX. Subject's Consent

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date__________
Subject signature

____
Subject printed name

Virginia Tech Institutional Review Board Project No. 14-954
Approved February 18, 2016 to February 17, 2017

APPENDIX O. VALIDATION CONSENT FORM (NO INCENTIVE VERSION)

Informed Consent for Participants
in Research Projects Involving Human Subjects

Title of Project: HFCV Modal and Application Gaps Research: Diagramming Bus Operating Tasks.

Investigators:

Battelle Memorial Institute
Dr. John L. Campbell, campjohn@battelle.org, (206) 528-3254
Mr. Justin S. Graving, gravingj@battelle.org, (206) 528-3268

Virginia Tech Transportation Institute
Dr. Richard J. Hanowski, rhanowski@vtti.vt.edu, (540) 231-1513

I. Purpose of this Research Project

Pedestrians struck by buses are one of the largest safety problems associated with transit. Connected vehicle technology allows for vehicles and roads to communicate, and can help address safety issues such as bus-pedestrian collisions. The National Highway Traffic Safety Administration (NHTSA) is sponsoring this research project to examine the best ways of presenting safety information to transit bus operators. The goal for this study is to diagram bus operating tasks. The diagram may be used by systems engineers to link system designs to operating requirements.

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4. Given the opportunity to suggest ways to improve bus operation.

The meeting will last no more than 2 hours. Nothing about your participation, nor any information that can personally-identify you, will be shared with your employer or any state or federal agency.

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Virginia Tech Institutional Review Board Project No. 14-954
Approved February 18, 2016 to February 17, 2017

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Non-identifying information from the analyses may be put in a public database, available to anyone on the internet. Other data that might allow you to be identified will be stored in a controlled-access database. The information in this database will be available only to researchers who have received IRB approval and completed a data sharing agreement that maintains your confidentiality. They may only view your data in a secure environment. Please note that traditionally-used identifying information about you, such as your name or telephone number, will not be put into either public or controlled-access databases for this project.

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All data collected as part of this research will be destroyed by September 2018.

VI. Compensation

You will be compensated for your participation in the meeting. Compensation will be $30 per hour, prorated to the next half-hour. For completion of the study you will be provided an extra $15 in cash. As the expected duration of the study is 2 hours, the maximum compensation is $75 ($60 for time, plus $15 for completing the study). This will be paid to you in cash at the conclusion of your participation.

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IX. Subject's Consent

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____ Date__________
Subject signature

____
Subject printed name

Virginia Tech Institutional Review Board Project No. 14-954
Approved February 18, 2016 to February 17, 2017

APPENDIX P. VALIDATION STUDY MODERATOR GUIDE

Start here

Consent Script

We are asking you to volunteer as a participant in a focus group on bus operating tasks. Should you choose to participate, this study will involve the following:

We will make a diagram of bus operating tasks. We made drafts of these diagram to help start us off, and we will work together to finalize them.

Afterward, you will be asked to complete a survey. The survey will ask about the mental and physical demands of each task in the diagram.

Paige and I will talk you through the diagram, and we'll ask for your input as part of the process. The input we're looking for is about accuracy of the tasks and the workflow represented by the diagram.

The focus group will be interactive and free-form manner. Please feel free to speak up at any time.

The risks associated with your participation are minimal, but there are a few you should be aware of. First, there is risk of psychological stress similar to that experienced while explaining details related to your job; second, there is the risk that you may find discussion topics about your job to be sensitive and this may cause discomfort. The likelihood you will experience stress during this focus group depends on your susceptibility to social anxiety. If social situations cause significant anxiety for you, you may consider withdrawing from this study.

All of the information we collect will be held confidential. We will not discuss your participation with your employer, or any other entity. Please take as much time as you need to read the consent form. It outlines what we will ask you to do, provides your rights and responsibilities as a participant in research and, most importantly, lets you know that you can discontinue participation at any time without penalty. Please let me know if you have any questions before signing.

Moderator Guide

Paige and I are the moderators for today's focus group discussion. We are interested in tasks that bus drivers carry out. An understanding of tasks can help to design bus technologies, like a pedestrian detection and warning system.

DISCLOSURES

Paige and I work for a research company called Battelle Memorial Institute. My job is to conduct the focus group for our client, the National Highway Traffic Safety Administration, a department of the U.S. Department of Transportation.

I have no vested interest in your answers and my job will continue regardless of what is said here today. I encourage you to be honest and feel free to offer both positive and negative comments.

This session is being recorded. A record of today's information will help immensely for evaluating the ideas that are set forth by this group. Evaluation of the content in the recording will be carried out at a later date. The recording will be kept confidential, not be shared with anyone, including the project sponsors, and will be destroyed after the evaluation is complete. Names, personal identifying information and any likeness of yourself will be purposefully excluded from any reports or documents that are generated based on our discussions today.

OVERVIEW OF THE DIAGRAMMING ACTIVITY AND RESPONSE BOOKLET.

The purpose of the focus group is to diagram bus-operating tasks. We will show a diagram we've already made. Our job for the day is to verify the accuracy of the diagram, and add tasks that were missed.

The tasks in the diagram are mostly those that occur while actually driving and picking up passengers. Tasks that happen when the bus is stopped but are included, but discussed in ways that show how they affect driving. For instance, sending a message to dispatch may occur when the bus is stopped, but may also occur when driving if needed.

There is a survey about the mental and physical demands of the tasks. You will be asked to complete the survey after we make our diagram.

Ground Rules

There are some ground rules we need to follow.

Allow others who are speaking to complete what they are saying.

Keep in mind that we are working as a group and that all opinions are valuable.

Contribute to the discussion. There may be times when you are the only person in the group that feels a particular way. Please speak up when this occurs.

Regarding the survey, please, write down your responses in the response book before talking about them with anyone in the group.

Are there any questions?

Stop here

APPENDIX Q. VALIDATION STUDY FOCUS GROUP WORKBOOK

Focus Group Instructions and Demographic Survey

Order of Todays Activities:

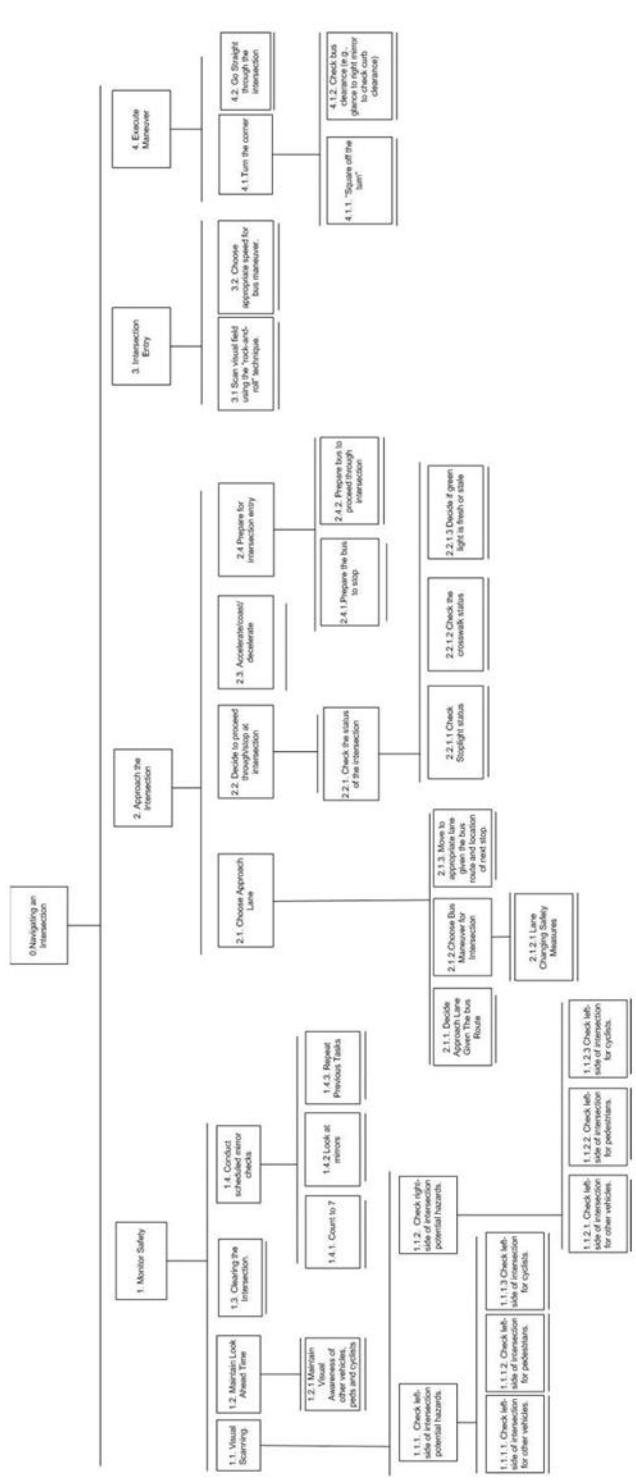
1. Consent forms
2. Demographics survey
3. Read Instructions
4. Diagram Tasks
5. Complete Survey

1

Survey Questions

1. What is your age?	
2. What is your gender?	
3. Are you currently a bus driver?	
4. How many years of experience do you have working as a bus driver?	

3



0 Navigating an Intersection
1. Monitor Safety
1.1. Visual Scanning.
1.1.1. Check left-side of intersection potential hazards.
1.1.1.1. Check left-side of intersection for other vehicles.
1.1.1.2. Check left-side of intersection for pedestrians.
1.1.1.3 Check left-side of intersection for cyclists.
1.1.2. Check right-side of intersection potential hazards.
1.1.2.1. Check left-side of intersection for other vehicles.
1.1.2.2. Check left-side of intersection for pedestrians.
1.1.2.3 Check left-side of intersection for cyclists.
1.2. Maintain Look Ahead Time
1.2.1 Maintain Visual Awareness of other vehicles, peds and cyclists
1.3. Clearing the Intersection.
1.4. Conduct scheduled mirror checks.
1.4.1. Count to 7
1.4.2 Look at mirrors
1.4.3. Repeat Previous Tasks
2. Approach the Intersection
2.1. Choose Approach Lane
2.1.1. Decide Approach Lane Given The bus Route
2.1.2 Choose Bus Maneuver for Intersection
2.1.2.1 Lane Changing Safety Measures
2.1.3. Move to appropriate lane given the bus route and location of next stop.
2.2. Decide to proceed through/stop at intersection
2.2.1. Check the status of the intersection
2.2.1.1 Check Stoplight status
2.2.1.2 Check the crosswalk status
2.2.1.3 Decide if green light is fresh or stale
2.3. Accelerate/coast/ decelerate
2.4 Prepare for intersection entry
2.4.1 Prepare the bus to stop
2.4.2. Prepare bus to proceed through intersection
3. Intersection Entry
3.1 Scan visual field using the "rock-and-roll" technique.
3.2. Choose appropriate speed for bus maneuver.
4. Execute Maneuver
4.1 Turn the corner
4.1.1. "Square off the turn"
4.1.2. Check bus clearance (e.g., glance to right mirror to check curb clearance)
4.2. Go Straight through the intersection

7

Survey

9

Instructions: This is a five question survey that is repeated for each task in the large diagram. There is one survey on each of the remaining pages in this book. Please use as many surveys as are necessary to provide your responses to all tasks on the larger diagram.

There is blank space on each page for providing any additional information that you think is important.

The majority of the pages will already have the task number and name written at the top of the page. If task names or numbers are missing, please write the task number or name at the top of the page.

The five survey questions ask for estimations of mental demand, physical demand, visual demand, frequency, and your understanding of the task. These terms are defined below.

Definitions:

Mental demand: How much mental and perceptual activity is required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Is the task easy or demanding, simple or complex, exacting or forgiving?

Physical demand: How much physical activity was required (e.g.. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Visual demand: How much eyes-on effort is needed? How much of your vision is necessary for the task? Can you look away from the task? Does this task case fixed stares? This should be considered as the proportion of time that a bus operator's eyes are directed toward a task, either the primary task of driving or secondary tasks.

Frequency: How often does the task occur on any given work day? On a regular route Does this task always happen, sometimes, or does it never happen.

Understanding: To what degree do you understand the task-card you're evaluating? Does the task make sense or not.

Tear out this page if it helps to keep track of the survey definitions.

There is an example of how to respond to the survey on the next page.

<u>In most instances, the order of the tasks in the survey is different than the order in which they were presented. Please make note the task name and number at the top of the page when filling out the survey.</u>

Task Number:	Task Name:
1.1	Fill Kettle

Mental Demand

How mentally demanding is the task?

Very low — Very high

Physical Demand

How physically demanding is the task?

Very low — Very high

Visual Demand

How of your vision is needed for the task?

Can look away — Can't look away

Frequency

Does this task always happen, sometimes, or does it never happen?

Never happens — Always happens

Understanding

Does this tasks make sense as it is written?

This makes no sense — This makes complete sense

Task Number: 1.1 **Task Name:** Visual Scanning.	**Task Definition:** This task consists of searching for hazards and glances at mirrors through the front passenger door. This task requires rotating the head and torso. These rotations are for glancing at the front door, mirrors, and through the front door.

Mental Demand — How mentally demanding is the task?

Very low — Very high

Physical Demand — How physically demanding is the task?

Very low — Very high

Visual Demand — How much of your vision is needed for the task?

Can look away — Can't look away

Frequency — Does this task always happen, sometimes, or does it never happen?

Never happens — At every bus stop

Understanding — Does this task make sense as it is written?

This makes no sense — This makes complete sense

Additional Notes:

APPENDIX R. TASKS FOR ARRIVING AT BUS STOPS

Status	Task Number	Task Name	Task Description
Original	1	Approach the bus stop	This task consists of driving towards or approaching the bus stop.
Original	1.1	Check the route schedule	Checking the schedule consists of looking at the schedule/timetable. It may require deciding if the driving speed is adequate to arrive on time. “Make sure you’re not running hot if this is a time spot"
Original	1.1.1	If early, decide if it’s OK to wait	This task consists of evaluating the bus-zone for room to “sit-and-hold” to get back on schedule without block incoming buses.
FG 4	1.1.1.x	Announce time stop	Announce to riders that this is a time stop and we will be waiting for x minutes to indicate why the bus is stopped.
Original	1.1.2	If late, approach stop as normal	This task consists of proceeding to the bus-zone to exit/board passengers and proceed to the location of the next bus stop.
Original	1.2	Find location of the bus stop	This task consists of visually scanning for bus stop features (e.g., bus zone markings, a bus stop sign, boarding and alighting platforms, etc.). In some areas, overgrown vegetation may block from seeing identifiable features of the bus stop.
Original	1.3	Decide stop is needed	Deciding to stop at the bus stop consists of visually scanning for people waiting at the bus stop, and checking if the onboard “stop-request” is active
Original	1.3.1	Read Passenger Body Language	This task consists of reading expressions to decide if riders/passengers want to exit the bus. Passengers may or may not pull the ‘stop-request’ but may move towards the door to give the impression that they want to get off.
Original	1.3.2	Read Bus Stop Body Language	This task consists of reading expressions of people waiting at bus stops. Sometimes people are waiting for different buses.
FG 1	1.3.2	Read Bus Stop Body Language	"I make people get up and walk" by driving passed the shelter and stopping at the bus-stop sign. There's a good amount of space between the shelter in the stop. If there's no movement, and I'm a hundred feet away, I keep going (12:00, ch1)
FG 1	1.3.3	Skip stop for leader/leading follower	If a same-route bus is at stop (due to loading, traffic, etc.) and no passengers on your bus want off, skip stop and go to next stop. Go around, If “Leader” or “follower” is present and no passengers need to de-board. May require communicating with leader or follower about who picks up passengers. (7:30, ch1) Flashers mean, "Go-around" "My Follower is going to be on my tail if I stop for everyone who doesn't need to be picked up" (10:10, ch1)
Original	1.4	Assess “pull-in” space at bus stop	Deciding where to stop at a bus stop consists of evaluating the available space at the bus stop, and deciding where to park the bus for picking-up and dropping-off riders. The presence of other buses at the bus stop makes this task more difficult.
FG1	1.4	Assess “pull-in” space at bus stop	Other vehicles are a problem too. E.g., illegally parked UPS drivers, Uber drivers, other traffic.
Original	1.5	Decide if use of 4-ways flashers needed	This task consists of deciding if turning on the 4-way flashers is required given the environment the bus is being driven in. Four-way flashers are most commonly used when driving downtown and not in the suburbs.

Status	Task Number	Task Name	Task Description
FG 1	1.5	Decide if use of 4-ways flashers needed	CORRECTION Not downtown, but in suburbs. It's policy to not use flashers downtown. * If you get off the road then you don't have to use your flashers. *Downtown, we use our 4-ways for breakdowns. *The 4-ways are a signal to approaching buses (downtown) to indicate that you're going to be there a while and approaching buses will want to leave enough space to get out (i.e., leave an out). *"Use 4-ways when running hot and killing time."
Original	2	Prepare for the bust stop	This task consists of preparing to stop at the bus stop to pick-up and drop off riders.
Original	2.1	Track closing distance to the bus stop	Tracking closing distance consists of continually assessing the distance between the bus and the bus stop. This is accomplished by looking at the amount of visible road between the bus and bus stop.
FG 1	2.1	Track closing distance to the bus stop	Using reference point to position your vehicle (19:45) *Especially if the bike rack is down. There needs to be room for the passenger get the bike off the rack.
FG 1	2.1.x	References Points	Use a fixed object on the bus to identify the curb and the vehicle position. When you are looking for space disappearing to allow you to know where your vehicle is. Use the bus, the curb or a fixed object. As you watch it diminish then you know where you are. "The last thing you do is look in the mirror to see where you ended up, sometimes the tires striking the curb helps with this."
Original	2.2	Visual Scanning	Visual scanning consists of searching for hazards. It also consists of glances at mirrors and through the front passenger door. It requires rotating the head and torso. These rotations are for glancing at the door, the mirrors, and through the front window
Original	2.2.1	Check for traffic from the rear	Checking for traffic approaching from the rear consists of visually inspecting the left mirror for approaching vehicles. The status of traffic is kept in “working memory” while other tasks are carried out.
FG 4	2.2.1	Check for traffic from the rear	Also checking for movement of anything that needs to be avoided (e.g., pets, pedestrians, trash in the road).
Original	2.2.2	Track current lane position	This task consist of checking the location of the bus relative to the lane line (i.e., fog line) by looking in the right mirror.
FG 4	2.2.2	Track current lane position	Pivot points are used; nighttime driving makes it hard to see the fog-line.
Original	2.2.3	Check distance to the curb	This task consists of tracking the lateral space between the bus and curb. This space is tracked by making glances through the windows in the front door.
FG 1	2.2.3	Check distance to the curb	Track pedestrians, pedestrians can be standing right on the curb.
FG 4	2.2.3	Check distance to the curb	Glances are made through the side mirror too.
Original	2.3	Decide if lift/ramp is needed	This task consists of visually inspecting the bus stop for riders with wheeled mobility devices (WhMDs) that need the lift/ramp. Deploying the lift effects speed and stopping location. Some operators also use the lift for other riders (e.g., riders using a cane, walker, etc.).

Status	Task Number	Task Name	Task Description
FG 1	2.3	Decide if lift/ramp is needed	Quote from Ch. 2 7:25
Original	2.4	Alert riders at bus stop	This task consists of alerting waiting riders at the bus stop. Some bus operators honk their horn. Other operators may gesture by waving their hands. Visually impaired riders may require an alert to know the bus has arrived at the stop.
Original	2.5	Pull into the bus stop	This task consists of rotating the steering wheel and applying the brakes, and pulling into the bus stop.
FG 1	2.5	Pull into the bus stop	Better name is "Positioning the bus"
Original	2.5.1	Choose parking angle	This task is a decision about how to position the bus (e.g., at an angle or straight). An angle can get the bus door nearest the stop and keep the rear tires on the road. This helps with rear-tire traction for departure.
FG 1	2.5.1	Choose parking angle	This is a traffic control technique
Original	2.5.2	Allow for an out	This task is a decision about how to allow proper space for departing. There must be adequate space between the bus and any parked cars.
FG 1	2.5.2	Allow for an out	Some buses need more of an out than others do (e.g., articulating buses).
Original	2.5.1	Move the bus into the stop	This task is the final maneuver into the bus stop.
Original	3	Pick-up and drop-off riders	This task consists of picking up and dropping off riders
Original	3.1	Announce Bus Stop	This task requires announcing the bus stop name. It requires recalling the name from memory. It may not be necessary for buses with an auto-announce system. However, auto-announcers sometimes announce the wrong bus stop name because of GPS errors.
FG 1	3.1	Announce Bus Stop	Especially for blind people - "or you do palm writing. Write the route on their hand"
FG 1	3.2	De-board Passengers	Riders are de-boarding the bus through the back door if possible.
Original	3.2	Board Riders	This task consist of allowing all riders board.
Original	3.2.1	Board WhMD rider(s)	This task consists of boarding WhMD riders. It does not occur at all stops and may be infrequent.
FG1	3.2.1	Board WhMD rider(s)	If this task occurs before boarding other riders, its purpose is to keep the seats available. "There is more room to work this way" May have to block people using the lift. This is difficult – that's why some operators may let the non-WhMDs on first. *Riders may request the lift - "this can throw your whole game-plan off" Weather can impact this: most operators will want to get most people in quickly so there are less angry people - this would require letting non-WhMD riders on last.

Status	Task Number	Task Name	Task Description
Original	3.2.1.1	Prepare bus for WhMD rider(s)	This task consists of setting up the bus to assist the WhMD rider as needed.
Original	3.2.1.1.1	Set parking brake	This task consists engaging the parking brake.
Original	3.2.1.1.2	Activate 4-way flashers	This task consists of activating the 4-way flashers as required by the roadway/location (e.g., downtown or not).
FG 1	3.2.1.1.2	Activate 4-way flashers	May be automatic.
Original	3.2.1.1.3	Set transmission to neutral.	This task consists of setting the transmission to neutral.
Original	3.2.1.1.4	Kneel the bus	This task consists of activating the kneeling system and kneeling the bus. Kneeling is an automatic feature on newer buses.
FG 1	3.2.1.1.4	Kneel the bus	May turn on brakes (check video)
FG 1	3.2.1.1.5	Deploy the lift	deploying the lift activates the 4-ways for most buses (19:03 ch2)
Original	3.2.1.2	Indicate to other riders that WhMD riders board first.	This task consists of telling non-WhMD riders that WhMD riders board first. A combination of verbal notification and hand gestures may be used.
Original	3.2.1.3	Ask if the WhMD rider prefers securement.	This task consist of asking the WhMD rider of they want to be secured in the bus restrain system. WhMD riders may elect not to be secured. Some operators secure all WhMD riders by default.
FG 4	3.2.1.x	Secure Chair (Seatbelt is optional)	Operator has to secure the chair/device to the bus but doesn't have to use the seatbelt (WhMD securement has two stages)
Original	3.2.1.4	Ask WhMD rider for final destination.	This task consists of asking for the WhMD rider's final destination. There is a "wheel-stop" request button on some buses.
Original	3.2.1.5	Secure/do not secure WhMD rider.	This task consists of securing the WhMD rider, or not. The subtasks are not included in the task analysis.
Original	3.2.1.6	Message dispatch about WhMD securement status.	This task consists of using integrated fare and dispatch messaging system to message dispatch about WhMD rider securement status. This is sometimes only done when the WhMD rider is not secured.
FG 1	3.2.1.6	Message dispatch about WhMD securement status.	No hot key, may use phone to call it in
FG 4	3.2.1.6	Message dispatch about WhMD securement status.	System has a button that says "Wheelchair Deny Seat Belt". Helps if bus takes a sharp turn that causes rider to fall to document that rider declined the seatbelt.
Original	3.2.2	Board all non-WhMD riders.	This task is the decision to allow waiting riders to board.
Original	3.2.2.1	Evaluate rider carry-ons	This requires deciding if a rider is allowed on the bus given an item they are carrying with them (e.g., alcohol, a battery, gas can, etc.).
Original	3.2.3	Assist Cyclists	This task consists of assisting cyclists as necessary. However, assisting them does not occur at every stop. Also, it should be of low general demand because the cyclist is

Status	Task Number	Task Name	Task Description
			responsible for using the bike rack. However, there are a few tasks bus operators do to ensure safety.
Original	3.2.3.1	Engage parking brake/keep foot on brake.	This task consists of activating the bus parking brake.
Original	3.2.3.2	Kneel bus to help cyclist use bike rack, if needed.	This task consists of using the kneeling device on the bus.
Original	3.2.3.3	Make a clear line of sight	Ask bikers to remove anything that creates a visual barrier or obstruction (e.g., bike bags).
Original	3.2.3.4	Alert cyclist to reset bike rack by honking horn, if needed after bike is taken off the rack.	This task consists of alerting cyclists after they remove their bike from the rack. This task may be infrequent.
Original	3.2.4	Monitor fare payments for correct amount and provide transfers if needed.	This task consists of monitoring fares, and ensuring that boarding riders are paying the appropriate fare. It includes handing out transfers to riders as necessary.
Original	3.2.4.1	Follow “No Fare Paid” procedure for fare dodgers.	This task consists of inputting into the Integrated Fare and Dispatch Messaging System that a rider on the bus did not pay the fare.
Original	3.2.5	Apply Fare Discounts	This task consists of deciding if the rider is eligible for a fare discount and then administering the appropriate fare discount to the rider. Fare discounts are not as common as regular fares. Use of integrated fare and dispatch messaging system.
FG 4	3.2.5.x	Ask Passenger to show proof of eligibility for discount	
Original	3.3	Message Dispatch	This task consists of sending a message to dispatch using the onboard system, if needed. The operator must remember if the message is available, and then press the system buttons to find it. Sending a message may occur the moment before departure. There may be dozens of message options, but only use a few may be useful. For example, “Running a few minutes late” and “Beyond recovery”.
FG 4	3.3.x	Select Message Priority (RTT or PRTT)	RTT = Right to Talk, PRTT = Priority Right to Talk.
Original	3.4	Message Riders	This task consists of activating an auditory message to onboard riders using the onboard system, if needed. Example messages to riders include, “Please step back to the rear”, “make room for more passengers” or “this is the last stop, lease disembark the bus.”
FG 1	3.4	Message Riders	Another message is "lower volume" to tell people to quiet down.
Original	4	Departure	This task consists of driving away from the bus stop.
Original	4.1	Visual Scan	Visual scanning consists of searching for hazards, glancing at mirrors and through the front passenger door.

Status	Task Number	Task Name	Task Description
Original	4.2	Depart from stop	This task consists of deciding that the bus is ready for departure, closing the door, and accelerating away from the stop.
Original	4.1	Visual Scanning	Visual scanning consists of searching for hazards, glancing at mirrors and through the front passenger door.
Original	4.1.1	Rock-and-Roll	The “rock-and-roll” technique requires rotating the head and torso. These rotations are for glancing at the door, the mirrors, and through the front window
Original	4.1.2	Check for late riders	During departure there is an additional glance through the window behind the front passenger-entry door to scan for late riders arriving after the door has been closed. Onboard customers/riders may block this view.
FG 4	4.1.x	Check for any movement	Look for bikers kids animals, etc.
Original	4.1.3	Check for rear traffic.	Bus operators check for traffic coming from behind the bus.
Original	4.1.4	Check for bikers	This task consists of checking mirrors for cyclists.
FG 4	4.1.x	Watch for Tail Sweep	Don't want to take out a telephone pole or fire hydrant
Original	4.2	Depart from stop.	This task consists of deciding that the bus is ready for departure, closing the door, and accelerating away from the stop.

APPENDIX S. TASKS FOR NAVIGATING THROUGH AN INTERSECTION

Status	Task Number	Task Name	Task Description
Original	1	Monitor Safety	This task consists of performing the necessary checks and actions to make sure the bus and other road users are safe. This task is continuously repeated through the intersection.
Original	1.1	Visual Scanning	This task consists of searching for hazards and glances at mirrors and through the front passenger door. This task requires rotating the head and torso. These rotations are for glancing at the door, mirrors, and through the front window.
Original	1.1.1	Check left side of intersection for potential hazards	This task consists of checking the left side of the intersection for any potential hazards.
Original	1.1.1.1	Check left side of intersection for other vehicles.	This task consists of checking the left side of the intersection for other vehicles that could potentially be in the bus path of travel.
Original	1.1.1.2	Check left side of intersection for pedestrians.	This task consists of checking the left side of the intersection for any pedestrians that could potentially be in the bus path of travel.
FG 2	1.1.1.2	Check left side of intersection for pedestrians.	Add children and pets to the description.
Original	1.1.1.3	Check left side of intersection for cyclists.	This task consists of checking the left side of the intersection for any cyclists that could potentially be in the bus path of travel.
FG 2	1.1.1.4	Check sidewalk on left side of intersection for movement.	This task consists of checking the sidewalk on the left side of the intersection any pedestrians, children, or pets that may eventually be a hazard.
Original	1.1.2	Check right side of intersection for potential hazards.	This task consists of checking the right side of the intersection for any potential hazards.
Original	1.1.2.1	Check right side of intersection for other vehicles.	This task consists of checking the right side of the intersection for other vehicles that could potentially be in the bus path of travel.
Original	1.1.2.2	Check right side of intersection for pedestrians.	This task consists of checking the right side of the intersection for any pedestrians that could potentially be in the bus path of travel.
Original	1.1.2.3	Check right side of intersection for cyclists.	This task consists of checking the right side of the intersection for any cyclists that could potentially be in the bus path of travel.
FG 2	1.1.2.4	Check sidewalk on right side of intersection for movement.	This task consists of checking the sidewalk on the right side of the intersection any pedestrians, children, or pets that may eventually be a hazard.
FG 3	1.1.3	Look for Traffic trying to overtake the bus	Look in rear view mirrors, left then right, for motorists, cyclists, or EMS, that may try to overtake the bus.
Original	1.2	Maintain Look Ahead Time.	This task consists of glancing forward and scanning the forward view approximately 15 seconds or one-city block ahead of the bus.
FG 2	1.2	Maintain Look Ahead Time.	Also known as, "Read the road ahead"

Original	1.2.1	Maintain visual awareness of other vehicles, pedestrians, and cyclists.	This task consists of maintaining visual awareness of where surrounding vehicles, pedestrians, and cyclists are or could be in relation to the bus.
Original	1.3	Clearing the intersection.	This task consists of deciding that the intersection is clear of potential hazards after a visual scan is completed and no hazards were identified.
Original	1.4	Conduct Scheduled Mirror Checks.	This task consists of checking the bus mirrors for the appropriate duration and at the appropriate intervals.
Original	1.4.1	Count to seven.	This task consists of counting to seven to achieve the appropriate interval between scheduled mirror checks.
FG 2	1.4.1	Count to seven.	This is provided during training by not done in reality.
Original	1.4.2	Look at mirrors.	This task consists of looking at the mirrors as part of scheduled mirror checks. Any glance longer than 2 seconds is considered a fixed stare.
Original	1.4.3	Repeat previous tasks.	This task consists of repeating Tasks 1.4.1 and 1.4.2 and looking at the other mirror.
FG 2	1.5	Look at the mirror to make sure it does not hit anything.	This task consists of making sure that bus mirrors clear/will not hit any pedestrians or infrastructure.
Original	2	Approach the Intersection.	This task consists of approaching the intersection.
FG 2	2.x	Awareness of occupancy in the bus	This task consists of being aware of the occupancy of the bus and if there are passengers standing.
FG 2	2.x	Awareness of equipment	Different buses can brake or accelerate differently.
Original	2.1	Choose Approach Lane.	This task consists of choosing the lane that the bus will be in before entering the intersection.
Original	2.1.1	Decide approach lane given the bus route and the location of the next stop.	This task consists of deciding which lane the bus should be in given the bus route and the location of the next stop.
FG 3	2.1.1	Decide approach lane given the bus route and the location of the next stop.	Other bus agency routes affect deciding what lane to use. Bus operators check their mental map of the transit network and the current time to decide if any buses ahead may cause a slowdown in their lane.
Original	2.1.2	Choose Bus Maneuver for Intersection.	This task consists of choosing the maneuver the bus will make at the intersection given the bus route and the location of the next stop.
Original	2.1.2.1	Lane Changing Safety Measures.	This task consists of using the left or right turn signal and checking the appropriate mirror prior to and when making a lane change.
Original	2.1.3	Move to appropriate lane given the bus route and location of the next stop.	This task consists of moving the bus into the appropriate approach lane given the bus route and location of the next stop.
Original	2.2	Decided to proceed through/stop at intersection.	This task consists of deciding if the bus driver can proceed through the intersection or must stop at the intersection based on the traffic signals.
Original	2.2.1	Check the status of the intersection.	This task consists of checking the status of the intersection to help inform the decision of whether the bus driver must slow down, stop, or can proceed with the bus maneuver.
FG 3	2.2.1.x	Decide if intersection is clean or dirty	Assess the amount of traffic. Dirty intersections have a lot of pedestrian and vehicle traffic. Certain areas need

			more attention than others. These are called awareness zones - e.g., near stadiums when games are over.
FG 3	2.2.1.x	Landing zone monitoring	Makes sure the target lane that precedes the intersection is clear and has enough room for the whole bus.
FG 2	2.2.1.x	Determine if there is there room for the bus through the intersection	Makes sure that the bus will be able to clear the intersection and that no part of the bus will be blocking the intersection.
FG 3	2.2.1.x	Check for on-coming EMS	Makes sure the bus does not become an obstacle. As soon as sirens are noticed, stop the bus.
Original	2.2.1.1	Check the stoplight status.	This task consists of checking the status of the stoplight to help inform the decision of whether the bus driver must slow down, top, or can proceed with the bus maneuver.
Original	2.2.1.2	Check the crosswalk status.	This task consists of checking the status of the crosswalk to determine if the bus operator will have to slow down, stop, or can proceed with the bus maneuver.
Original	2.2.1.3	Decide if green light is fresh or stale.	This task consists of determining how long the light has been green.
Original	2.3	Accelerate/Coast/Decelerate the bus	This task consists of accelerating/coasting/decelerating the bus based on the status of the stoplight in preparation for entering the intersection. The age of the bus and the equipment (e.g., retarder, transmission, etc.) may affect conducting this task.
FG 3	2.3	Accelerate/Coast/Decelerate the bus	Add "driver covers the brake" to the task definition.
Original	2.4	Prepare for intersection entry.	This task consists of preparing the bus to enter the intersection.
Original	2.4.1	Prepare the bus to stop.	This task consists of preparing the bus to stop at the intersection based on the state of the stoplight, crosswalk, and whether the green light is fresh or stale.
Original	2.4.2	Prepare the bus to proceed through the intersection.	This task consists of preparing the bus to proceed through the intersection based on the status of the stoplight, crosswalk, and whether the green light was fresh or stale.
Original	3	Intersection Entry.	This task consists of entering the intersection.
Original	3.1	Scan visual field using the “rock – and-roll” technique.	This task consists of scanning the area around the bus by having the bus operator pivot their body and head to peer around fixed visual obstructions.
Original	3.2	Choose appropriate speed for bus maneuver.	This task consists of choosing the appropriate speed for the bus maneuver given the maneuver the bus will make through the intersection.
FG 2	3.2	Choose appropriate speed for bus maneuver.	Turn speed is supposed to be 3 to 5 mph
Original	4	Execute Maneuver.	This task consists of executing the bus maneuver through the intersection given the bus route and the location of the next stop.
Original	4.1	Turn the corner.	This task consists of making a turn through the intersection give that this is the appropriate maneuver for the bus given the bus route and the location of the next stop.

Original	4.1.1	Square off the turn/sweep the turn.	This task consists of making a turn in either two phases (squaring off the turn) or one phase (sweeping the turn).
Original	4.1.2	Check bus clearance (e.g., glace to right mirror to check curb clearance).	This task consists of checking the clearance between the bus wheels and the curb to make sure the wheels do not strike the curb.
FG 3	4.1.x	Evasive Maneuvers	If someone gets in the way, stops the intersection, the bus operator must choose a maneuver, legal or not, to get the bus through the intersection.
Original	4.2	Go straight through the intersection.	This task consists of going straight through the intersection given that this is the appropriate maneuver for the bus route and the location of the next bus stop.

DOT HS 812 652
May 2019

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

13932-052019-v3