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Bus Driver Intersection Task Analysis: Investigation of Bus-Pedestrian Crashes

Final Report

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University of Minnesota

CTS 13-04

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
CTS 13-04		

4. Title and Subtitle	5. Report Date
Bus Driver Intersection Task Analysis: Investigation of Bus-Pedestrian Crashes	January 2013
	6.
7. Author(s)	8. Performing Organization Report No.
Chia Wei, Ensar Becic, Christopher Edwards, and Michael Manser	
9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
HumanFIRST Program University of Minnesota 111 Church Street SE Minneapolis, MN 55455	CTS Project #2012011
	11. Contract (C) or Grant (G) No.
12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
Intelligent Transportation Systems Institute Center for Transportation Studies University of Minnesota 200 Transportation and Safety Building 511 Washington Ave. SE Minneapolis, Minnesota 55455	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

http://www.its.umn.edu/Publications/ResearchReports/

16. Abstract (Limit: 250 words)

The current report includes two specific research efforts. The primary objective of the first research effort was to conduct a task analysis of a left-turn maneuver by a bus driver. The goal of this task analysis was to provide insight into the cognitive and perceptual processes that bus drivers complete while performing a left-turn maneuver. An additional goal of the first research effort included the development of potential countermeasures that could help reduce the frequency of bus-pedestrian collisions. The interviews conducted as part of the task analysis revealed that drivers engage in a large number of subtasks and cognitive/perceptual processes when completing a left-turn maneuver. We proposed two potential interventions for the reduction of bus/pedestrian collisions. One of the proposed interventions was designed to aid a driver in detection of pedestrians at a crosswalk. The second intervention was designed to remove a need to perform a particular attention-demanding subtask to reduce the cognitive and perceptual load that drivers experience during this maneuver. The second research effort was designed as a pilot simulator study in which we examined the potential effectiveness of proposed interventions. The second study uncovered unanticipated findings (i.e., high rate of collisions with pedestrians) that may be due to the nature of the simulator studies – lack of real-world consequences. The results of the pilot study provided sufficient data for further examination of different support tools for the reduction of the fatalities between left-turning buses, and also uncovered potential relationship between work-related stress and the impact on driving performance.

17. Document Analysis/Descriptors	18. Availability Statement
Bus drivers, Left turns, Pedestrians, Fatalities	No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	57	

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200 Transportation and Safety Building
511 Washington Ave. S.E.
Minneapolis, Minnesota 55455

ACKNOWLEDGMENTS

The authors wish to acknowledge those who made this research possible. The study was funded by the Intelligent Transportation Systems (ITS) Institute, a program of the University of Minnesota's Center for Transportation Studies (CTS). Financial support was provided by the United States Department of Transportation's Research and Innovative Technologies Administration (RITA).

The authors would also like to acknowledge the help of Peter Easterlund of the HumanFIRST Program for his substantial programming contributions. We also acknowledge Metro Transit for providing access to its bus drivers, as well as the bus drivers themselves for agreeing to participate. Their participation is greatly appreciated.

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EXECUTIVE SUMMARY

In the United States between 1999 and 2005, more than 40 percent of fatal transit bus crashes involved a collision with a pedestrian (Blower, Green & Matteson, 2008). Compared to other maneuvers at intersections (i.e., driving straight, turning right), left-turn maneuvers are associated with a particularly high proportion of collisions with pedestrians (Almunia, 1989). Pedestrian fatalities as a result of a collision with left-turning buses occur at intersections across the country. Bus drivers are frequently held accountable for such collisions; however, the factors that contribute to these collisions, as well as mechanisms of the left-turn maneuver by bus drivers have not been adequately researched.

The current report includes two specific research efforts. The primary objective of the first research effort was to conduct a task analysis of a left-turn maneuver by a bus driver. The goal of this task analysis was to provide insight into the cognitive and perceptual processes that bus drivers complete while performing a left-turn maneuver. An additional goal of the first research effort included the development of potential countermeasures that could help reduce the frequency of bus-pedestrian collisions. The interviews conducted as part of the task analysis revealed that drivers engage in a large number of subtasks and cognitive/perceptual processes when completing a left-turn maneuver. Some of those subtasks are performed at specific sections of an intersection or at a specific time, while other subtasks are performed continually. We proposed two potential interventions for the reduction of bus/pedestrian collisions. One of the proposed interventions was designed to aid a driver in detection of pedestrians at a crosswalk. The second intervention was designed to remove a need to perform a particular attention-demanding subtask to reduce the cognitive and perceptual load that drivers experience during this maneuver.

The second research effort was designed as a pilot simulator study. The primary objective of the simulator study was to examine the proposed countermeasures and uncover the potential concerns that would need to be addressed prior to the full evaluation of the proposed solutions. In this research effort we examined the potential effectiveness of technology- and infrastructure-based interventions. The technology-based intervention included a pedestrian detection system which would alert a driver prior to the potential collision with a pedestrian. The infrastructure-based intervention included a protected left-turn (i.e., green arrow) for buses. A secondary goal of the pilot simulator study included the examination of the impact of environmental factors (e.g., stress, weather conditions) on bus drivers' performance, as well as on the effectiveness of the proposed countermeasures. The second research effort uncovered unanticipated findings that may be due to the nature of the simulator studies – lack of real-world consequences. Bus drivers failed to make any response to more than half of the collision scenarios, resulting in a high rate of collisions with pedestrians. Although the results also show poorer left-turn driving performance under stressful driving conditions, the unexpected decreased pedestrian detection performance suggests the results of the current work should be accepted with significant caution.

Future simulator studies would need to address the unexpected findings encountered in the current work while a field study would benefit from focus groups and usability examinations of warnings used in systems that aid a bus driver in detection of critical pedestrians.

1. INTRODUCTION

According to National Highway Traffic Safety Administration, in 2009, there were 4,092 fatalities and approximately 59,000 traffic-related injuries of pedestrians, resulting in an average of one pedestrian fatality every two hours and an injury event every nine minutes (NHTSA, 2009). More specifically, 24% of pedestrian fatalities occurred at intersections (NHTSA, 2009), making them a particularly dangerous location. Pedestrian-vehicle collisions often result in serious injuries and fatalities due to the mass and speed of the vehicle involved. The severity of injury increases as vehicle size increases. For example, in the United States between 1999 and 2005, more than 40 percent of fatal transit bus crashes involved a collision with a pedestrian (Blower, Green & Matteson, 2008). In that period, a total of 778 persons were killed in traffic crashes involving transit buses, 315 (40.5%) of which were pedestrians (Blower et al.). Left-turns have been linked with many pedestrian fatalities; in April of 2010, a bus driver in Portland, OR, collided with a group of pedestrians while making a left turn; 5 pedestrians were killed. The driver was unharmed. In August of 2009, one pedestrian was killed in Des Moines, IA, as a result of a collision with a bus making a left turn.

Locally in Minneapolis, MN, between 2007 and 2010, there were six collisions between pedestrians and buses making a left-turn maneuver. In order to achieve the goal of zero collisions, Metro Transit implemented a *Look-and-See* campaign to remind drivers to visually scan their surroundings prior to making a left-turn maneuver. However, due to the complexity of left-turns, this has been a difficult position to maintain. Metro Transit expressed strong interest in investigating alternative solutions, some of which were examined by this research effort.

In support of Metro Transit's zero collisions policy, the end goal of this project includes the reduction of left turning collisions, in particular, investigating alternative solutions. This goal was accomplished by conducting two studies. The first study, Study One, consisted of a *Task Analysis* of bus driver's left-turn process. The goal of the task analysis was to identify how many various tasks bus drivers conduct, concurrently or sequentially, while driving and making a left turn and how they prioritize tasks during a turning maneuver. Further, the aim of the task analysis was to create a detailed analysis of various tasks that bus drivers complete (tangible and endogenous) and determine the cognitive and motor demands of each task. Study Two was a *Pilot Simulator Study* which was designed to examine the potential solutions for reducing the likelihood of a pedestrian-bus collision for left-turns. The potential solutions that were examined in the pilot simulator study were based on the task analysis results.

1.1 BACKGROUND AND LITERATURE

Left-turn vehicle maneuvers have been associated with a high rate of pedestrian-vehicle collisions at all types of intersections (e.g., two-way/two-way). Moreover, Almuina (1989) indicated that left-turns had the highest proportion of collisions involving pedestrians. Of the permissible maneuvers that occur at intersections, drivers who make left-turn have been reported to be four times more likely to collide with pedestrians compared to drivers who proceed straight through an intersection (Lord, Smiley, & Haroun, 1998). Left-turns at intersections are difficult for drivers of all types of vehicles, but they are especially challenging for large vehicles, such as buses. In addition to maneuvering a larger vehicle, bus drivers also complete a number of tasks that drivers of other vehicles do not, such as attending to passengers, bus schedules, traffic conditions, collecting fares, helping disabled passengers get on and off the bus, answering questions about directions, routes, schedules, and announcing stops. It would appear that driving represents only a small portion of all the tasks that bus drivers perform. The non-driving elements of operating a transit bus likely contribute to significant increase in mental effort which is an important consideration during attention demanding tasks, such as making a left turn at an intersection.

Independent of non-driving tasks, the amount of mental effort required to make a left turn at an intersection is substantial. Mental workload increases during turning maneuvers at intersections (Hancock, Wulf, Thom, Fassnacht, 1990). Compared to making a right-turn or driving straight through an intersection, making a left turn at an intersection requires a greater number of subtasks, such as examining oncoming traffic for an appropriate gap. Research has shown drivers' rate of blinking and head movements is much higher when making a turn compared to driving straight through an intersection (Hancock et al., 1990). However, if drivers increase their active scanning when making a left turn it does not necessarily imply a successful detection of obstacles. For example, when head position was statistically controlled, response times to simple probes, such as visual tasks, became significantly slower during turning maneuvers compared to straight maneuvers. This was likely due to an increase in attentional demand during turning maneuvers (Hancock et al., 1990). Object detection failures were more likely to occur when turning because more attentional resources were devoted to making a turning maneuver. It is possible that the high rate of pedestrian vehicle collisions when making a left turn is due to high task demands. In addition, the presence of left turn signals at intersections (i.e., green arrow) has reportedly led to increased detection of pedestrians in crosswalks. This was speculated to be a result of removing an attention demanding subtask (i.e., selecting an appropriate turning gap), which likely decreased the complexity of making a left turn (Lord et al. 1998). With reduced complexity, drivers were able devote more cognitive resources towards other driving-related tasks, such as detecting pedestrians in the crosswalk.

Driving behavior changes relative to the complexity of the concurrent driving task. Drivers adapt to task demands by strategically prioritizing their behavior to ensure that they complete their high-priority tasks. In situations when tasks are numerous and attentional resources limited, drivers prioritize one task at the expense of another. If a bus driver decides that keeping an accurate schedule has increased priority (arriving at planned destination on schedule), depending on the mental burden of other tasks, the driver may fail to provide sufficient attention to other tasks (e.g., scanning for bicycles and pedestrians). During rush-hour traffic or events that are accompanied by increased number of pedestrians, drivers may strategically reduce the amount of effort directed towards one of the driving tasks in order to focus on another (Cnossen and Meijman, 2004). When faced with a demanding traffic situation, such as one described above, a typical passenger car driver may abandon tasks that are irrelevant to driving, such as listening to a radio, in order to safely navigate an intersection. Driver adaption strategies for navigating through intersections have not been outlined for transit bus operators. One may speculate about the tasks that drivers complete when making a left-turn maneuver (e.g., scanning for the pedestrians, selecting appropriate gap between the oncoming vehicles), however, it is likely that bus drivers are required to complete numerous other tasks, discrete, as well as continuous. A thorough outline of tasks that a bus driver completes is needed to provide insight regarding future development of countermeasures to lessen pedestrian collisions resulting from left-turn maneuvers. Such an outline can be developed by conducting a task analysis, a method that would provide details of various subtasks, such as: complexity, frequency, impact of environmental and other extraneous conditions, as well as behavioral aspects of the bus drivers.

1.2 AN OVERVIEW OF RESEARCH STUDIES

This project included two specific research efforts: a *Task Analysis* and a *Pilot Simulator Study*. The primary objective of *Task Analysis* study was to conduct detailed task analysis of a left-turn maneuver by bus drivers. An additional objective included proposing potential countermeasures, based on the findings of task analysis that may help reduce the frequency of left-turn bus/pedestrian collisions. The primary objective of *Pilot Simulator Study* was to examine the proposed countermeasures and uncover potential concerns that would need to be addressed prior to full evaluation of the proposed solutions. The secondary goal of the *Pilot Simulator Study* included examination of the impact of environmental factors on bus driver's left-turning performance, as well as on the effectiveness of the proposed countermeasures.

2. STUDY ONE: TASK AANALYSIS OF BUS DRIVER LEFT-TURN MANEUVERS THROUGH SIGNALIZED INTERSECTIONS

2.1 INTRODUCTION

Task analyses for driving tasks have previously been conducted to create driver training programs (Mcknight and Adams, 1970) and identify cognitive bottlenecks that occur at intersections for drivers of passengers vehicles (Richard, Campbell and Brown, 2006). Fastebneier and Gstalter (2007) provided a method for conducting task analysis for vehicle driving and further uncovered potential problems and opportunities for training, technology and highway design solutions. In general, task analyses of different driving procedures are expected to define driver information needs. These needs should be the basis for the development of any driver assist system. Most task analyses begin by expanding on previous work. Mcknight and Adams' task analysis (1970) contained a large catalogue of driver behavioral requirements; approximately 1,700 different items were organized into a heterogeneous structure of 45 major driving tasks, but those did not include many critical elements for turning at intersections. Richard et al. (2006) expanded on McKnight and Adams' work (1970) to generate a detailed task analysis of intersection maneuvers. They modeled how well driver capabilities match the demands of driver's tasks; however, additional work is needed to define the information needs and tasks held by transit bus drivers.

2.2 STUDY ONE OBJECTIVE

Pedestrian fatalities that result from left turning buses at intersections occur nationwide. Although the bus drivers are often held accountable for such collisions, the factors that contribute to these collisions have not been well researched. The primary objective of Study One was to conduct a task analysis of a left-turn maneuver by a bus driver. The task analysis was carried out based on the procedures established by Fastenmeir and Gstalter (2007). The goal of this task analysis was to provide insight into the mental and perceptual tasks that bus drivers perform when completing the left-turn maneuver. A better understanding of these tasks will facilitate the development of concepts for support tools that help lessen left-turn bus–pedestrian collisions.

2.3 METHODS

2.3.1 Participants

Six bus drivers and driver trainers employed by Metro Transit, Minneapolis, MN participated in first study. All the drivers completed an informed consent form prior to participation in the interviews. Each interview was conducted at a bus depot location (i.e., in a private office) and lasted approximately one and half hours. There was no compensation for participation in the interview process; however the participant's time was donated by Metro Transit. All of the interviewees were experienced bus drivers with a minimum of 10 years and maximum of 20 years on the job.

2.3.2 Materials and Apparatus

A total of three interviews were completed each of which included two bus drivers or driver trainers. Participants were presented with several large laminated posters depicting different intersections at which bus/pedestrian collisions occurred in the past (see Figure 1). The interviews were conducted in an open-ended manner, such that the participants were asked to describe all the various tasks, observable (e.g., checking the mirrors) and non-observable (e.g., determining the next bus stop) that they performed during a left-turn maneuver.

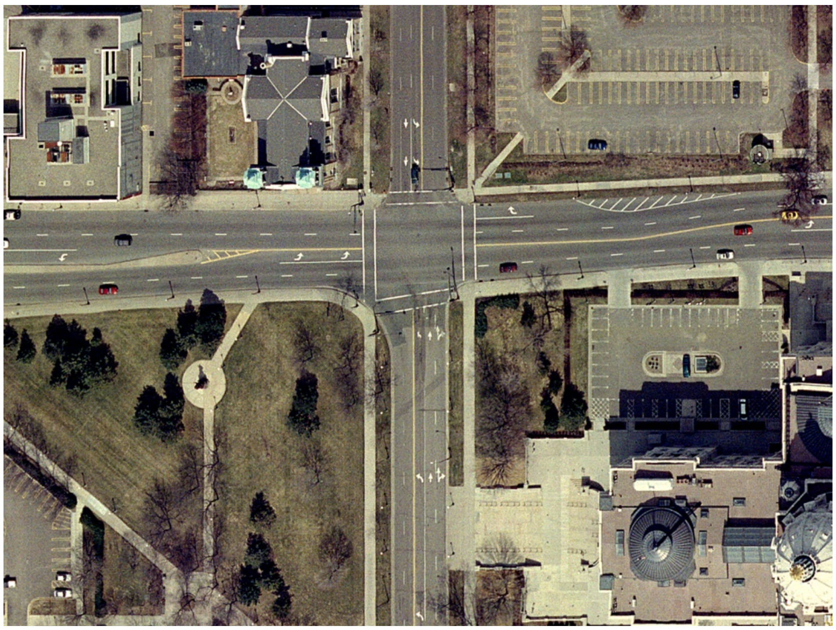

Figure 1: Depiction of an intersection presented to participants in Study One.

2.3.3 Study Procedure and Design

The task analysis was conducted at Metro Transit facilities using an open interview format. To begin, participants were asked open-ended questions about the left-turn maneuver and tasks leading up to, during, and after the maneuver. Additional probe questions were asked depending on the context and content of the answers. The interview process used an iterative approach, such that subsequent interviews not only confirmed the already discussed material, but also uncovered new and useful information.

Before the start of the interviews, experimenters described a number of left turn bus-pedestrian collisions that occurred in the state, as well as nationally. This review was designed to elicit experiential knowledge from the participants and provide guidance as to the type of information that was of interest to the experimenters. Participants were then free to describe what elements they felt contributed to the crash based on their experiences. To encourage discussions and interactions between participants and the researchers, several large laminated posters were shown of specific intersection locations where collisions had occurred (see Figure 1). Participants were encouraged to draw on these posters when they explained different subtasks they perform while making a left turn.

As part of the task analysis goal the researchers divided the intersections into six defined stages that bus drivers encountered when performing a left turn maneuver. The six segments were developed from a task analysis report in terms of intersection driving scenarios (Richard et al., 2006). Each segment had different driving objectives: approach and deceleration represented the segment of the intersection at which the transit bus approaches the intersection and determines the upcoming location of the turn; deceleration/acceleration represented the location at which the bus operator determines the traffic light state and makes preparation to stop or drive through the intersection; intersection entry was characterized as the part of the intersection at which the bus enters the position of turning; prepare for turn/execute turn represented the segment of the intersection in which the bus driver completes the tasks that relate to gap acceptance decision and the start of the turning; and post turn was characterized as the part of the intersection after turning (see Figure 2). It should be noted that these segments were not present (i.e., visible) on the posters that were shown to the participants during the interviews. However, keeping these stages in mind the researchers would identify tasks from interviewee's and make note of them. Specifically, the task analysis was performed for each of those segments to determine the level and the frequency of each of the subtasks that bus drivers perform.

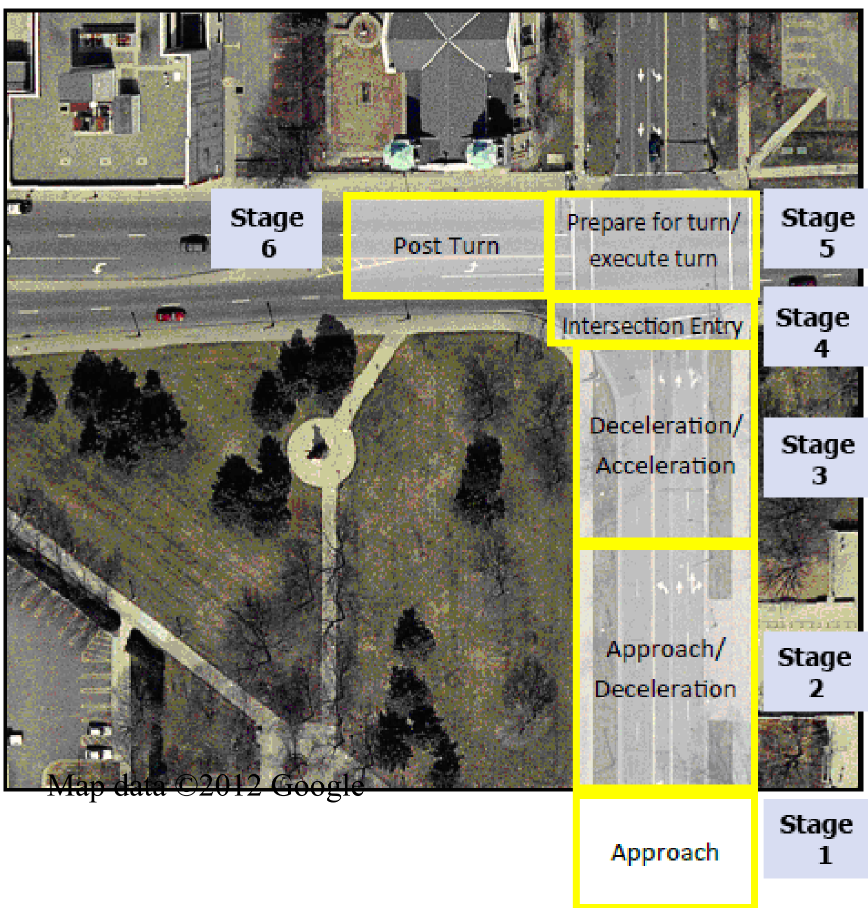

Figure 2: Depiction of six stages of a left-turn maneuver at the examined intersection.

2.4 RESULTS

Information from the interviews was reviewed and categorized based on the various tasks and subtasks that bus drivers reported completing at different stages of an intersection.

The following are the overall or "general" tasks and mental processes that most drivers reported completing during the initial segment (see Figure 3 for graphical depiction of task analysis for this segment):

- Looking up ahead to receive a "big picture" – inspecting traffic environment, road condition, status of the bus (i.e., external, internal).
- Determining how many, if any, lanes to cross to in order to get into the turning lane.
- Determining how much time, based on the traffic conditions, is needed to merge from right to left.
- Determining the number of left-turning lanes. Bus driver would need to choose the outer-most lane, in order to stop at the next bus stop.
- Inspecting the traffic light. The status of the traffic light affects the bus driver's decision regarding the acceleration or deceleration. When drivers observe the light change from red to green (a fresh green light), they may try to speed up in a safe manner try to reach the intersection before the light turns red.

2.4.1 Components of the Left-Turn Maneuver

As a next step, the various tasks and processes that the drivers reported completing were binned into specific concepts that can be defined and that are broad enough to fit other similar tasks and processes found in the remaining segments of the intersection. All of the subtasks and mental processes that bus drivers reported completing during a left-turn maneuver were classified into the following categories: visual, working memory, executive, motor tasks and unplanned events.

- *Visual processes:* included any process or task which required drivers to visually observe surrounding conditions, read symbols/traffic signs, track mirrors, detect motions and perform broad scanning. The visual processes were further separated into two distinct types: broad visual inspection and focused visual search. Broad visual inspection was characterized as general scanning of the environment to determine potential dangers (e.g. the big picture) while focused visual search included pre-planned visual search of the known high-risk areas (e.g., traffic lights and mirrors) to assess the safety conditions.
- *Working memory tasks* were considered those tasks and situations that required drivers to hold information in their memory, information that may be recalled or manipulated at a later time. These included tasks such as monitoring a bicyclist that may disappear/reappear from driver's visual field.
- *Executive tasks* were characterized as those tasks that required drivers to make evaluations, determinations, or a decision. Typical executive tasks included determining the gap of oncoming traffic, traffic signal/light (fresh green or stale green) recognition, judging the distance from a curb, or determining the number of turn lanes.
- *Motor tasks* were defined as any tasks that required drivers to make physical responses. Some of these tasks were continuous, such as minor corrections of the steering wheel,

while others occurred at specific locations, such as departing from a previous stop or turning at an intersection.

- *Unplanned events* included tasks that were not part of a typical turning maneuver. Bus operators are frequently required to cope with unplanned events, which may include passengers asking for directions, an unexpected noise from passengers in the busy, or other unexpected events that may distract the driver. It is necessary to determine driver's ability to deal with such situations. If driver's cognitive resources are already taxed when making a left turn, any additional tasks may result in the failure to accurately complete the primary task during a left-turn maneuver; the failure that may result in the bus-pedestrian collision.

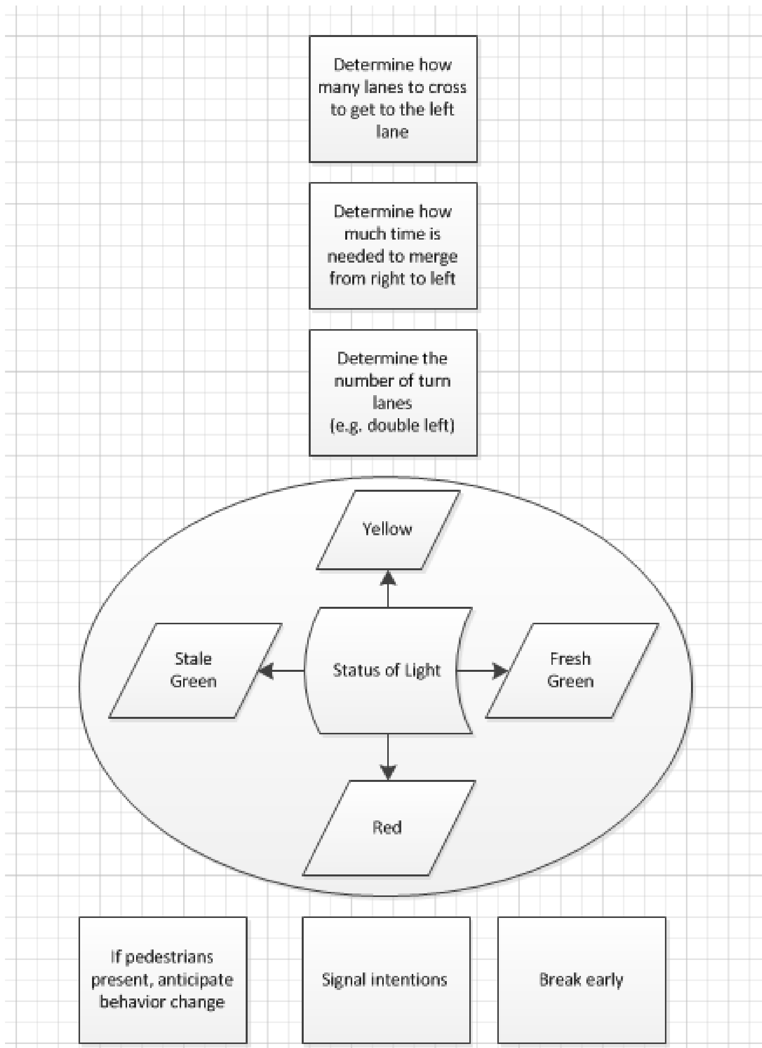

Figure 3: A graphical illustration of the task analysis that relates to the bus driver's initial approach to an intersection before making a left turn.

Following the interviews, the experimenters in a collaborative fashion categorized the reported subtasks and processes into the pre-designed bins. This was not an exact process, but rather subjective categorization by the experimenters. Table 1 lists all the subtasks and processes that bus drivers reported completing in Segments 1 and 5 and classifies them into one of the concepts. Full task analysis for the remaining stages can be found in Appendix A. Each of the tasks and processes was associated with a specific concept and in some cases more than one.

Table 1: Left-turn task analysis for Segments 1 and 5.

Segment 1	Approach	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Plan bus departure				x		
1.1	Determine how many lanes will have to be crossed				x		
1.2	Determine how much time/space there is to merge from right to left				x		
1.3	Changing lane (Four lanes/ triple lanes/ two lane)					x	
2	Assess tail-swing to ensure tail end clearance from curb and pedestrians near curb				x	x	
2.1	Maintain lane position					x	
3	Check for surrounding situation	x					
3.1	Scan for unsafe situations or obstacles	x					
4	Look up at the intersection	x					
5	Observe the traffic light	x					
5.1	If the light is red, try to speed up so they can make the left turn when it turns green				x	x	
6	Check for road features	x					
Segment 5	**Prepare to turn/Execute turn**	**Broad Visual**	**Focused Visual**	**Working Memory**	**Executive**	**Motor**	**Unplanned events**
1	Observe road features	x					
1.1	Double back scan down sidewalk	x	x				
1.2	Triple glance - forward, left sidewalk, then back through right mirror		x				
2	Maintain wheel position as straight (to prevent collision with oncoming traffic from accidental acceleration of the bus)					x	
3	Determine entrance lane (money lane, or right lane)		x		x		
4	Determine angle of turn		x		x		
5	Select Gap in on-coming traffic	x			x		
6	Wait until light times out while in the intersection if a traffic gap does not appear that allows for a left turn		x		x	x	

2.4.2 Summary of Leftt-Turn Components

As Figure 3 and Table 1 show, bus drivers were primarily engaged in *Broad Visual*, *Executive*, and *Motor* subtasks in the first segment (Approach).

The second segment (Approach/Deceleration) started after a bus departed from a bus stop. In this segment, drivers continued to be engaged in primarily *Motor* (e.g. changing lanes when there are more than one lane to across), *Executive* (e.g. determine the distance to the intersection), and *Broad Visual* (e.g. inspecting the conditions of the surroundings) subtasks. Table 2 presents detailed reported subtasks and processes that bus drivers completed in the second segment.

Table 2: Left-turn task analysis for the second segment.

Stage 2	Approach/ Deceleration	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Complete lane changing (if more than 2 lanes)					x	
2	Maintain lane position					x	
3	Check for surrounding situation	x					
3.1	Scan for unsafe situations or obstacles	x					
3.2	Keep eye on bikers		x	x			
4	Look up at the intersection, observe the distance to intersection	x			x		
5	Observe the traffic light (fresh green or stale green)	x					
5.1	Fresh green (saw the light change from red to green), once passenger boarding is complete determine if there is enough time to make it to the intersection to complete the left turn				x	x	
5.2	Stale green (e.g. did not see the light change)				x	x	
6	Determine the location of the next bus stop		x		x	x	
7	Break early (easy on brakes - smooth stop)					x	

The third segment (Deceleration/Acceleration) started after the bus has completed the lane change. Most of the subtasks and processes that drivers reported completing in this segment can be classified as *Broad Visual* (e.g. scan for surrounding situation and observe the traffic light) and *Motor* (e.g. maintain lane position) subtasks. Table 3 presents detailed reported subtasks and processes that bus drivers completed in the third segment.

Table 3: Left-turn task analysis for the third segment.

Stage 3	Deceleration/ Acceleration	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Maintain lane position					x	
2	Check for surrounding situation	x					
2.1	Scan for unsafe situations or obstacles	x					
3	Observe road feature	x					
3.1	If there is a median, keep close to the curb to make sure that no bike can fit in the space	x				x	
4	Look up at the intersection, observe the distance to intersection		x				
5	Observe the traffic light	x			x		
6	Stop 1 car length behind crosswalk	x				x	
7	Leave 1 car length between bus and lead vehicle at intersection (leave an out)	x				x	

The fourth segment (Intersection Entry) represented the smallest portion of an intersection, but not necessarily the section at which drivers spend the least amount of time. When entering an intersection where they were about to make a left turn, bus drivers reported engaging in *Focused Visual* (e.g. follow the movements of pedestrians and bicyclists; scan the sides) and *Executive* subtasks (e.g. determining how many vehicles are making the left turn, number of vehicles in front of the bus; determine the optimal gap between the oncoming vehicles to complete the left-turn maneuver). They also reported significant engagement in *Broad Visual subtask as well* (e.g.

observe the pedestrians crossing the intersection and bicyclists who may prepare to turn left). Table 4 presents detailed reported subtasks and processes that bus drivers completed in the fourth segment.

Table 4: Left-turn task analysis for the fourth segment.

Stage 4	Intersection Entry	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Observe surrounding situation	x					
1.1	Figure out what vehicles will turn with the bus at the intersection (especially truck, bicycle)	x			x		
1.2	Be aware of oncoming traffic	x			x		
1.3	Keep eye on pedestrians		x	x			
1.4	Look into the mirror if there is a noise in the back		x				x
2	Waiting for the lead car turn left	x			x		
2.1	Allow for a 4 second pause before proceeding	x		x	x		
2.2	Align bus parallel with current lane (i.e. straighten to ensure bus is not encroached on adjacent lane)					x	
3	Big pictures	x					
3.1	Scan to the right (for red light violators; e.g. cars that may run the light)		x				
3.2	Scan to the left	x	x				
3.3	Scan on-coming traffic for gaps	x	x				
3.4	Scan for pedestrians and bicyclists	x	x				
3.5	Last look is down crosswalk to the left	x	x				
4	Turn the wheel					x	
4.1	Check for height of curb on to the right of the bus, approach slowly, if curb is high there is risk of collision with curb	x			x		

The fifth segment (Prepare to turn/Execute turn) contained the entire inside of an intersection, from entrance to an exit. As can be noted from Table 1, drivers engaged in substantial number of subtasks at this section. Drivers reported performing multiple subtasks, including *Focused Visual* (e.g. double check the sidewalk, make sure the gap is clear), *Executive* (e.g. determine the entrance lane; determine the angel of turn; select gap in on-coming traffic), and *Motor* (e.g. maintain wheel position as straight at the intersection; execute the turn) subtasks. In general, intersection Entry (segment 4) and Prepare to turn stage (segment 5) represented the most important and difficult stages in the left-turning maneuver. The most demanding because of the high number of subtasks that bus drivers performed which strained their attentional, perceptual and cognitive resources. In short, drivers were overtaxed during this period of a left-turn maneuver. At the same time, these segments also contained the most important subtask – detecting pedestrians.

The last segment (Post turn) started after a driver exited the intersection. In this segment, drivers reported focusing on *Motor* (e.g. reduce the speed; move to right lane; locate the bus to the stop sign) as well as *Executive* (e.g. determine how much space to merging to the bus stop) subtasks. Table 5 presents detailed reported subtasks and processes that bus drivers completed in the last segment.

Table 5: Left-turn task analysis for the last segment.

Stage 6	Post turn	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Reduce speed					X	
2	Signal and move to the right lane					X	
3	Locate bus stop position				X	X	
4	Observe road feature	X			X		
4.1	If in the left lane, determine how much time/space for merging right to prepare for bus stop	X			X	X	
5	Check for pedestrians running for the bus at the last minute		X	X			

The information included in Figure 3 and Tables 1-5 provides detailed descriptions of the subtasks and processes that bus drivers completed during a left-turn maneuver, however it may be challenging to compare the predominant tasks in which drivers engaged at different segments of the intersection. Figure 4 shows another method of viewing this information. Each task (concept) is represented by a specific color with hue illustrating the prevalence of each of the tasks. Darker hue indicates driver's increased engagement in that particular task (multiple subtasks that relate to the same concept) while a lighter hue indicates only a minimal effort for a particular task. For example, the *Motor task* was the most prevalent task in stage 2 (Approach/Deceleration) and stage 6 (Post Turn), while the *focused visual* was the most prevalent in preparing for the turn stage (Prepare to turn/Execute turn). Broad Visual component was the most prevalent in stages 3 and 4 (Deceleration/ Acceleration, Intersection Entry).

2.4.3 Left-Turning Buses: Other Relevant Factors

The interviews with the bus drivers and their trainers produced a detailed task analysis of a left-turn maneuver. The interviews revealed the extent of attentional demands, but also other factors that may impact driver's ability to successfully complete this task. The interviewees mentioned stress as a causal factor for engaging in risky driving practices (e.g., increasing velocity), thereby increasing the potential for a collision with a pedestrian. Sources of stress are multiple, but some of them stem from a need to maintain strict schedules, deal with the passengers and operate the bus safely in inclement weather. The interviews revealed that experienced bus drivers have developed a stress coping tactic; they tend to be less concerned with maintaining the schedule, unlike the novice drivers. Moreover, the concern about the schedule may frequently lead novice drivers to engage in risky driving behaviors (e.g., increasing velocity, taking smaller turning gaps) in order to reach the next bus stop on time. We were not able to verify these comments with novice drivers since all of the participants in Study One had at least 10 years of experience.

Weather and visibility were other issues brought up in the interviews as potential factors that may impact drivers' ability to drive safely, in general, and make a left turn at an intersection, in particular. Snow banks, night driving, fog and sun glare were some of the issues discussed, all of which place additional perceptual demands on bus drivers, making it more challenging to detect pedestrians or even other vehicles.

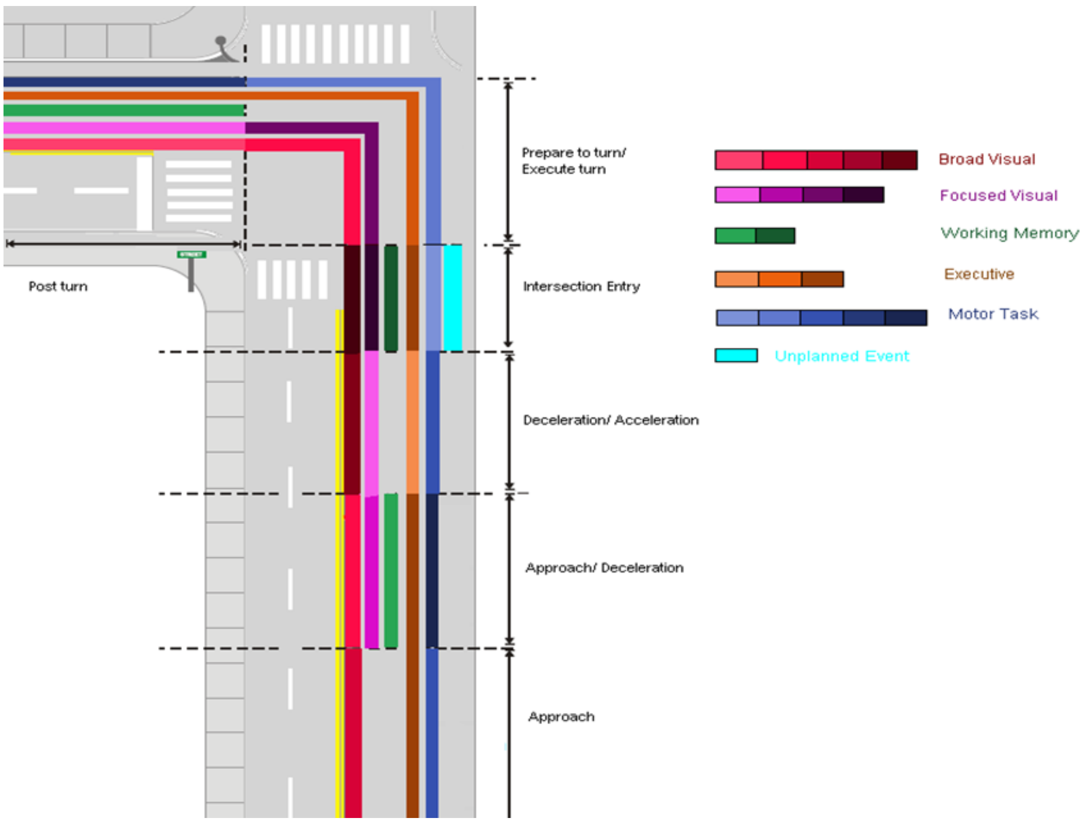

Figure 4: The prevalence of various subtasks at different point of an intersection during a left-turn maneuver.

2.5 DISCUSSION

The results of the interviews contributed to the creation of a comprehensive task analysis for bus drivers performing left turn maneuvers at open left turn (i.e., no green arrow) intersections. The task analysis findings led to the creation of relevant concepts that the bus drivers complete when making a left-turn maneuver. The interviews revealed an immediately apparent issue – bus drivers engage in a large amount of different subtasks during such maneuvers, some of which are performed at specific points of the turning procedure while others are more pervasive. An obvious concern relates to the amount of mental resources required for completion of those tasks compared to the resources available. That is, are bus drivers overburdened? The solutions that we propose are based on two principles: aiding drivers in performing a particular subtask, or completely removing a need to perform a particular subtask. Since the primary goal of this research includes reduction in the frequency of bus/pedestrian collisions, the first proposed solution is to aid drivers in detecting potentially critical pedestrians. We propose a technology-based solution which would track the movement of targets of interest (e.g., pedestrians, bicyclists) and alert the driver if a target becomes an imminent danger. One of the main subtasks in Segment 5 includes tracking the oncoming traffic and determining the optimal gap between the vehicles. This is a perceptually demanding task that occurs concurrently with the most important subtask overall – detecting pedestrians and bicyclists while starting to execute a turn.

The Figure 5 shows an overview of a left-turn diagram. The pink shaded area represents the region of interest (ROI) in which potential targets would be tracked and detected. Based on the results of task analysis, we proposed a support tool that would provide an auditory cue to the driver when a pedestrian enters a collision proximity zone. A visual display, such as the one presented in Figure 5 was considered and rejected, based on the interviews with the drivers. A visual display would have a high potential to act as a distractor. A display that drivers had to view would increase an already high attentional and perceptual task demands. This represented a technology-based solution which was examined in *Pilot Simulator Study*.

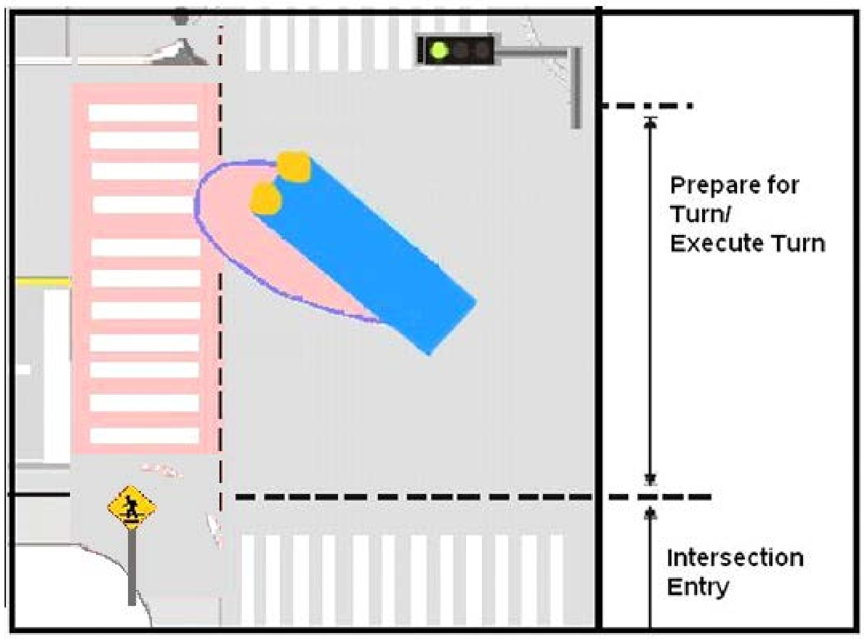

Figure 5: Proposed pedestrian detection system. The shaded pink areas represent the areas of interest in which pedestrians would be tracked and detected.

Our second proposed solution involved completely removing a need for performing a particular subtask; therefore, we developed an infrastructure based solution — a protective left-turn for buses. The primary goal of this proposed solution would be to reduce the bus driver's perceptual and cognitive load during the critical portion of the left turn. This represented an infrastructure-based solution which was examined in Study Two.

The interviews revealed stress and visibility as factors requiring further consideration. As part of the environmentally-based support tool, in Study Two we examined the impact of stressful driving conditions on driving performance. The proposed stressful conditions included factors such as background noise, strict schedule, as well as limited visibility.

2.6 LIMITATIONS

One potential limitation of the task analysis method we used in Study One related to recall bias, a potential confound in self-reported study design. We ameliorated this concern by confirming participants' reports with subsequent drivers in order to achieve consistency of responses. In addition, all the drivers in this study were experienced, with a minimum of 10 years of bus driving. Task analysis, concepts, and actions by novice bus drivers may rank differently in importance compared to more experienced drivers. Furthermore, the interviews used an open forum format which may fail to ask relevant questions during the interview. However, the iterative approach was used for interviews, such that subsequent interviews not only confirmed the already discussed material, but also uncovered new information, that is, we completed three interviews and reviewed the information from previous interview in the next. This process minimized the potential concerns.

3. STUDY TWO: PILOT SIMULATOR TESTING

3.1 INTRODUCTION

The results of the task analysis conducted in Study One highlighted the degree of perceptual and mental effort required of bus drivers to successfully complete a left turn at intersections. The primary goal of Study Two was to examine the potential effectiveness of the two proposed interventions on bus drivers' driving performance during left turns, and more specifically drivers' ability to detect pedestrians (on the crosswalk who may cross the path of the left-turning bus) at intersections. While the two interventions focused on different subtasks that bus drivers perform while making a left turn, the goal was the same – improved detection of pedestrians and reduction of bus/pedestrian collisions.

One of the proposed interventions was a technology-based solution that included an auditory warning system that alerted bus drivers before a potential collision with a pedestrian. This was a direct intervention method in that it aided a driver in performance of the most critical task (i.e., detecting critical pedestrians), rather than reducing the overall attentional demand of the driving task. More accurate and faster detection of pedestrians, exhibited in quicker braking or steering away from the potential collision, would indicate a beneficial impact of such system.

We also proposed an infrastructure-based solution that was considered an indirect intervention or an intervention that may reduce the required attentional demand during a critical segment of a left-turn maneuver. This intervention would include a protected left turn at intersections (i.e., green arrow) either for all vehicles or for buses only. Depending on the traffic volume at a particular intersection, a dedicated left-turn arrow for all vehicles may not be a possibility. Alternatively, a 'smart' intersection may receive a signal from a bus about to make a left turn prompting activation of a dedicated green arrow until that bus completes the turn. Monitoring oncoming traffic and determining an optimal gap between the vehicles is a demanding perceptual task and this intervention would completely remove a need to perform such task. We hypothesized that the additional available cognitive resources would be used by the bus drivers to monitor for pedestrians, increasing the potential for successful detection, thereby reducing bus/pedestrian collisions. Indeed, signals at intersections that indicate when a bus can make a left turn have reportedly led to increased detection of pedestrians in crosswalks. This was likely the result of removing the requirement for the driver to decide when it was appropriate to turn, which decreased the complexity of making a left turn (Lord et al., 1998), thus allowing greater attention toward detecting pedestrians. Adding a dedicated left turn signal has another important consequence – pedestrians are prohibited from crossing the street, thereby substantially removing the likelihood of a pedestrian in the roadway. In a way, this represents a confound for the current work as it would be difficult to untangle the impact of the reduced number of pedestrians (or even absence of pedestrians) with the reduced cognitive load, resulting from removing a need to perform a difficult perceptual task. Any potential impact of this particular intervention would need to be explained as an interactive effect of these two factors.

In addition to the primary goal of examining the potential usefulness of the proposed interventions, Study Two also had a secondary goal which included investigating the environmental factors that may impact bus driver's performance. The interviews conducted in

Study One revealed that stress, for which one of antecedents may be adherence to strict schedules, may have an impact on bus driver's driving performance, especially on novice drivers' performance. For example, arriving at a planned destination on schedule can become a high-priority task for a driver which can lead to an increase in risky driving behavior (i.e., accepting smaller gaps when turning). Increasing an amount of effort in order to adhere to the schedule may also reduce the effort directed to other tasks, such as scanning for pedestrians (Cnossen, Meijman, & Rothengatter, 2004). Other factors, such as unruly passengers may also increase stress while lower visibility in inclement weather (e.g., fog, snow banks) may increase the perceptual difficulty of the critical task (i.e., detecting pedestrians at crosswalks). Furthermore, individual differences between the bus drivers may exist; some drivers may be more affected by stressful conditions than others. Understanding the impact of the various environmental factors on bus driver's driving performance would be beneficial when designing the potential interventions; the interventions should be designed in such a manner as to address the impact of the environmental factors.

To accomplish these goals, Study Two was conducted in the Minnesota Valley Transit Authority (MVTA) bus simulator. Two different groups of participants were asked to complete the same route under two different driving environments, Normal and Stressful.

The following are the main research issues examined in Study Two:

- Evaluation of the effectiveness of the two interventions on bus driver's ability to avoid collisions with pedestrians when making a left turn.
    - Driving performance in the Control condition (i.e., no intervention) was compared to the Treatment condition in which drivers were exposed to one of the two proposed interventions.
- Examination of the impact of stressful driving conditions on the effectiveness of the two interventions and bus driver's left-turn driving performance.
    - Driving performance of drivers in Stressful driving environments was compared to the performance of the drivers in Normal driving environments.

3.2 METHODS

3.2.1 Participants

A total of 31 bus drivers participated in this study. All of the participants were employees of Metro Transit, Minneapolis, MN. All of the participants had a valid driver's license, normal or corrected-to-normal vision (visual acuity of at least 20/40) and no previous history of disorders predisposing them for motion sickness (e.g., epilepsy). Table 6 presents demographic information of the bus drivers who participated in Study Two.

Table 6: Characteristics of the participants in Study Two.

	Driving Environment	
	Normal	Stressful
Total Participants	17	14
Gender		
Male	12	12
Female	5	2
Age (mean)	45.1	45.8
Experience (mean years)	15.4	10

3.2.2 Materials and Apparatus

3.2.2.1 MVTA Bus Driving Simulator

Study Two was conducted in the MVTA bus simulator (see Figure 6). This simulator was manufactured by Realtime Technologies, Inc. and offered support for the integration of advanced safety technologies. It featured realistic control operation and instrumentation including power assist for the brakes, force feedback for the steering and full startup procedure for the buses (e.g., buttons for engine, hand brake, doors). The driving environment was projected to a five-channel, 210-degree forward visual field screen (2.5 arc-minutes per pixel) with rear and side mirror views provided by a rear screen and vehicle-mounted LCD panels, respectively. The simulator software generated a replica of several blocks of 46th Street and an intersection of Minnehaha Ave and 46th Street in Minneapolis, Minnesota.

Figure 6: MVTA driving simulator where Study Two was conducted.

3.2.2.2 Questionnaires

At the beginning of the study participants completed the Driving History (Appendix B) and Job Satisfaction (Appendix C) questionnaires. The Driving History questionnaire was designed to collect participants' demographic information and work-related characteristics. The Job Satisfaction questionnaire was designed to evaluate degree to which participants experience work-related stress. Higher scores on this questionnare (overall range of 15-60) indicated higher work-related stress.

3.2.2.3 Secondary Task

In all of the experimental trials, participants completed a concurrent secondary task while driving. Participants were asked to press a button whenever a light, located next to 'start engine' button, turned red. The red light would turn on at random intervals, within 20-40 seconds following the previous onset of the red light. The secondary task was designed to examine the bus drivers' situational awareness. Greater probability of detecting the onset of the red light would indicate greater situational awareness. Low detection accuracy would indicate a decreased situational awareness, but also possible prioritization. A bus driver exposed to high levels of perceptual and cognitive demand may forego the secondary task in order to retain the high level of performance on the primary task of driving. If the implementation of a particular intervention (e.g., infrastructure-based) results in a reduction of bus driver's cognitive workload, we may see improved performance on the secondary task. Drivers may use the newly available cognitive resources, which were freed up as the result of a particular intervention, to improve their situational awareness, and thus the performance on the secondary task.

3.2.2.4 Collision Events

In some of the route trips, bus drivers were presented with potential collision scenarios with pedestrians. In each of these events, a pedestrian located on a sidewalk, at different locations, would start crossing the intersection in front of the bus (see Figure 7). For the collision events that were accompanied by a warning, the warning occurred at 2.5 seconds time-to-contact (period of time until a potential collision; TTC). The initiation of the critical maneuver of a pedestrian was visible for all events except one. Three of the events were head on collisions (pedestrian stepping in front of the bus) while in one of the events, a pedestrian walked towad the side of the bus. All of the events were avoidable, but a successful avoidance of the collision required a driver to initiate an avoidance maneuver within 2.5 seconds following the pedestrian's encroachment onto the sidewalk.

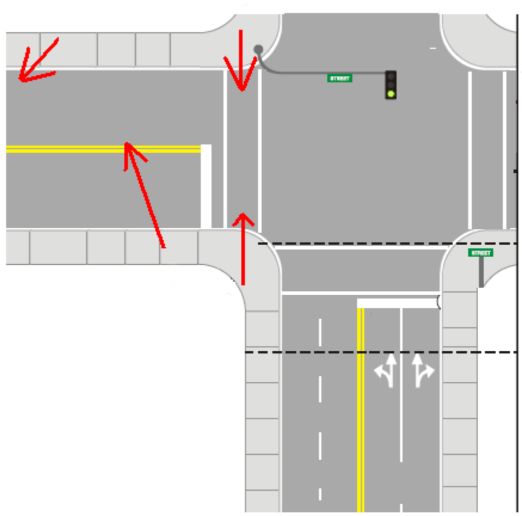

Figure 7: Pedestrian collision events in Study Two. The beginning of the arrow represents the staring position of the pedestrians crossing the intersection.

3.2.2.5 *Pedestrian Detection System*

In some of the route trips, participants were presented with a Pedestrian Detection System (PDS). The PDS was designed to track the movement of targets of interest (e.g., pedestrians, bicyclists) and alert a driver if the target requires a response by drivers. Based on the results of the task analysis, this intervention was designed to provide an auditory cue to the driver when a pedestrian entered the collision proximity zone. A visual display, that would graphically track the movements of the pedestrians and bicyclists was considered but later rejected because it could have a high potential to act as a distractor, especially at times when a driver is exposed to high levels of attentional and perceptual task demands.

3.2.3 Procedure

After participants completed the consent form and the two questionnaires, participants completed a block of practice trials in which they acclimated to the dynamics of the bus simulator and familiarized themselves with the starting procedures. Furthermore, participants were given a demonstration of the secondary task and an opportunity to practice. Following the practice drive, participants proceeded with the experimental portion of the study. In each of the trials, the participants completed two tasks, driving and the secondary task.

Driving performance was examined through a trial-based driving task in which participants were asked to complete a short route. The starting position was the same for each trial (the right lane of the road). Participants were asked to make a stop at the first bus stop, make a left turn at the intersection and finally, make a stop at the second bus stop (see Figure 9 for the route). Participants completed multiple trips on the same route under different driving conditions. They were instructed to drive in the same manner as they would their regular bus routes, including following the *Safety Keys*[1] information and observing the traffic laws.

The performance on the secondary task, which was present at every trial, was represented through the probability of detection of the red light. Participants were asked to respond by pushing a button, as soon as they detected the red light. They were also instructed that the performance on the secondary task should not endanger their driving performance. In essence, driving was their primary task.

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[1] Safety Keys, developed by Metro Transit, represent a guideline that bus drivers are encouraged to follow during the completion of a left-turn maneuver. It consists of visually inspecting specific locations at an intersection as well as bus mirrors in a specified order and at specified times.

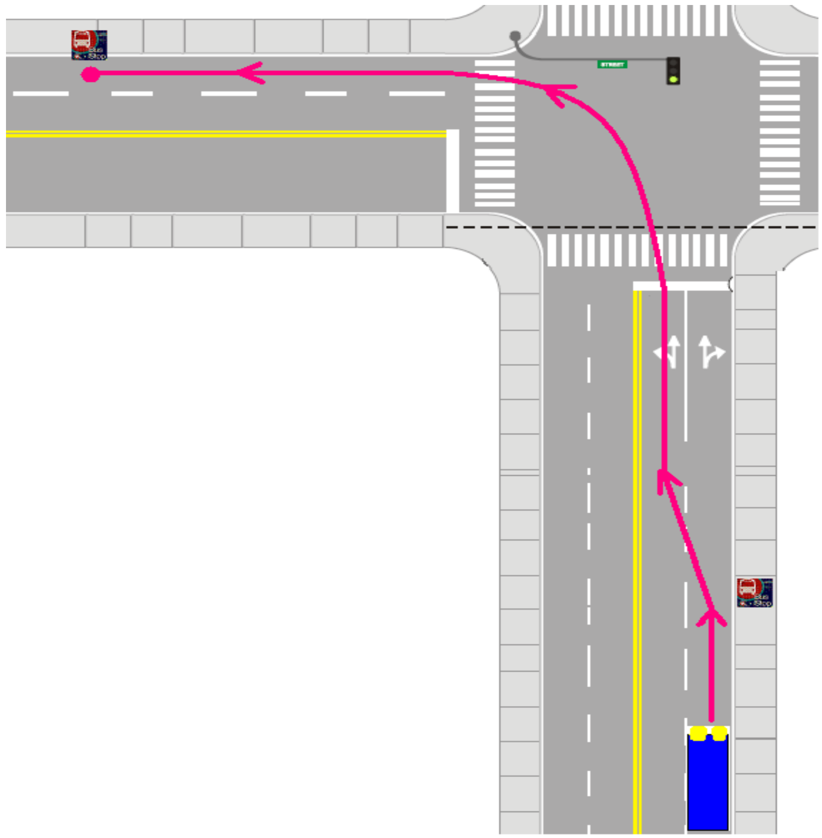

Figure 8: Representation of the route participants completed in Study Two.

While the driving task and the route (intersection and the location of the bus stops) were the same for both driving environment groups, drivers in the Stressful driving group performed the driving task under more challenging conditions: foggy weather designed to reduce visibility, noisy background designed to mimic unruly passengers, a time limit designed to increase driver's stress. Participants in the Stressful group were given a specific time limit within which they were asked to complete the route, the limit differed based on the state of the left turn signal (during the protected left-turn drives, participants received extra 30 seconds to complete the route). All of the participants were provided with a detailed explanation prior to the start of each block of trials, including the time in which they were supposed to complete the route (for the Stressful group).

Table 7 represents experimental conditions that participants completed in Study Two. Each participant was randomly assigned to one of the two driving environments. The Stressful driving condition consisted of 14 participants, while the Normal condition had 17 participants. The discrepancy in the number of the participants is due to several occurrences of motion sickness which resulted in some participants withdrawing from the study. Participants in each of the driving environment groups completed 4 blocks of trials, each consisting of three route trips. In half of the blocks participants completed the route with the protected left turn (i.e., green arrow) while the rest of the experimental blocks consisted of an open left turn (i.e., no green arrow). Furthermore, half of the protected and open left-turn blocks were completed with the presence of a Pedestrian Detection System while the other half of the blocks did not include this system. To reduce the anticipatory responses to the potential collisions, only one of the three route trips in each block of trials included a collision event.

Table 7: Experimental conditions the participants completed in Study Two.

Driving Environment	Blocks of drives
Normal	No PDS, Open left turn
	No PDS, Protected left turn
	With PDS, Open left turn
	With PDS, Protected left turn
Stressful	No PDS, Open left turn
	No PDS, Protected left turn
	With PDS, Open left turn
	With PDS, Protected left turn

3.3 EXPERIMENTAL DESIGN

3.3.1 Independent Variables

The independent variable that examined the impact of the direct intervention was *Pedestrian Detection System (PDS)*, consisting of PDS Control (PDS Off) and PDS Treatment (PDS On) conditions. The independent variable that examined the impact of the intervention was *Left Turn Signal (LTS)*, consisting of LTS Control (LTS Off) and LTS Treatment (LTS On) conditions. The examination of the effectiveness of the two interventions was examined across different *Driving Environments* (with *Stressful* and *Normal* levels), exploring whether stress impacts the efficacy of two proposed interventions.

3.3.2 Dependent Variables

To determine the effectiveness of the proposed interventions to reduce the frequency of bus/pedestrian collisions when making a left turn we collected data within three measurement constructs: work-related stress, situational awareness, and driving performance. The work-related stress construct was collected through the Job Satisfaction questionnaire. The situational awareness construct was examined through the performance on the secondary task. Secondary task performance was defined as the proportion of accurate responses to the red light flashing inside the simulator. Accurate response was characterized as pressing a button within three seconds following the onset of the light. The driving performance construct was examined through the following measures:

- *Response to potential collisions (accuracy and response time)*. Since braking was the appropriate response for each of the four potential collision events, response time was measured from the time a critical pedestrian entered the crosswalk until driver's initiation of a response. The response was defined as a reduction in velocity by 25%. The typical upper limit of velocity at the time of the potential collision was about 10 m/h. Tapping a brake was considered to fall within the parameters of normal operational procedure during the turning of the bus and as such not an adequate measure. Reduction in velocity was viewed as a direct response to the movements of the critical pedestrian. Failing to make a complete stop within four seconds always resulted in a collision. Furthermore, the response time measure was collected only for the accurate responses. Failing to initiate any response within four seconds (i.e., response time > 4 seconds) was characterized as an inaccurate/missed response.

- *Wait time* was defined as the time it took a driver to make a left turn after the stop light changed to green. This measure was collected only for the open left-turn blocks of drives. Wait time corresponded to the size of the gap between the oncoming vehicles. The gaps between the vehicles progressively increased from the beginning of the stream (2 seconds) to the later sections of the same stream (> 10 seconds). A longer time to turn equated to accepting a great gap between the oncoming vehicles.

3.4 RESULTS

The results section is divided into three parts: an examination of driving performance measures, analysis of the work-related stress measure, and examination of the secondary task performance. Given the limited number of trials in which a pedestrian/bus collision could potentially occur (only one per block), we did not analyze data for significant effects, but rather only present descriptive statistics. Dependent measures were examined and reported such that they present the impact of the two interventions separately, as well as in interaction with each other. Moreover, the results are presented separately for the two Driving Environment groups. The analyses did not reveal different responses for the four different collisions, so the reported results represent the combined scores across the four collisions.

3.4.1 Driving Performance Measures

3.4.1.1 Accuracy of Response

The accuracy of response arguably, is the most important measure in Study Two. It indicates not only the frequency of collisions, but whether the bus drivers initiated an avoidance maneuver in the first place. A collision event was additionally characterized as an inaccurate/missed response if a bus driver failed to reduce velocity within four seconds following pedestrian's encroachment onto the crosswalk. Moreover, failing to make a complete stop within that time always resulted in the collision. We expected bus drivers to initiate late braking in some trials; however, we did expect them to respond. The results are rather surprising, in that they indicate a high rate of no responses. Although one of the collision events was more difficult to avoid (pedestrian appeared to the side), three of the events involved a pedestrian stepping in front of the bus, an event which was possible to perceive. An overall average accuracy of response was .46, indicating that drivers did not respond on 54 percent of all events.

Figure 10 depicts the accuracy of response for the technology and infrastructure-based interventions, separately for the two driving environments. The data indicates a lack of clear main effect of the Pedestrian Detection System (.47 and .46 for the PDS On and PDS Off, respectively), and an unexpected difference between the status of the Left Turn Signal in Normal driving environment (.47 and .62 for the LTS On and LTS Off, respectively).

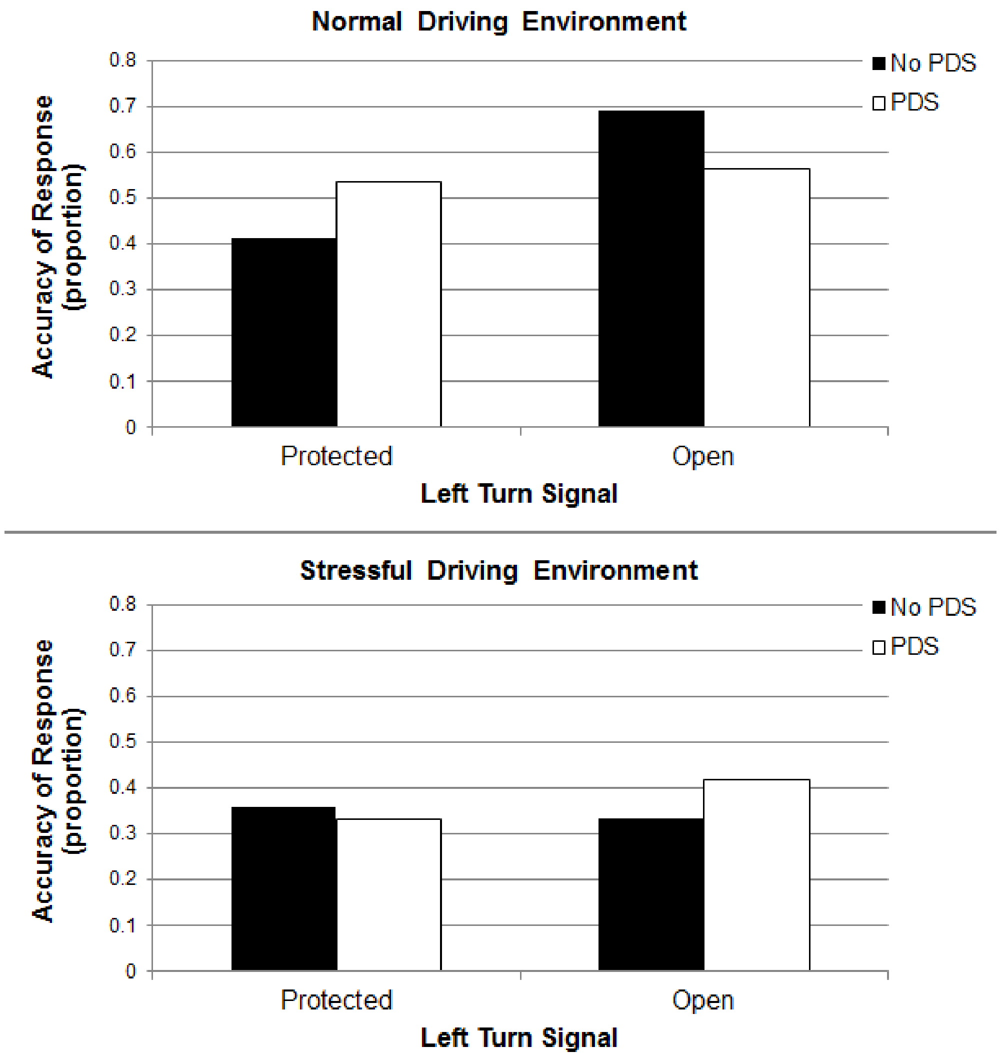

Figure 9: Accuracy of response as a function of left-turn signal and pedestrian detection system factors for normal (top panel) and stressful (bottom panel) driving environments.

Contrary to expectations, the presence of the PDS did not reduce the number of collisions. Additionally, the protected left-turn signal (i.e., green arrow). Table 8 suggests a possible interaction between the PDS and LTS for the Normal Driving environment. PDS showed a beneficial trend in the Protected left turn condition (53% and 41% for PDS On and PDS Off, respectively), but an opposite trend in the Open left turn condition (56% and 68% for PDS On and PDS Off, respectively). Due to increased variability and error, a limited number of trials represent a challenge for the interpretation of data. However, the high occurrence of collisions represents an even greater challenge for interpretation of the current data. Data indicated that bus drivers did not brake for approximately five out of eight potential collisions with the pedestrians. The drivers did not start braking late, but rather collided with the pedestrians without responding. These findings are quite perplexing and, because one of the stated priorities of the drivers is pedestrian safety, we have to question aspects of performance within the simulated environment that may have biased the study results. For example, all driving simulators lack some degree of realism because they cannot account fully for all stimuli experienced in normal driving. This lack of realism is a potential drawback of all simulation-based research. The potential lack of realism can influence driver responses because such that drivers may not respond to safety critical events similarly to real-world situations. Because drivers did not respond to collisions in this study it suggests their behavior may have been biased in the current work and, as a result, any interpretation of results must be accepted with significant caution. Drivers in the Stressful driving environment were more likely to be involved in a collision with a pedestrian compared to drivers in the Normal driving environment, the finding that supports our hypothesis; however, since drivers responded to two out of four (in Normal) and three out of four (in Stressful) collisions, and this may indicate potential bias, this finding should also accepted with caution.

Table 8: Accuracy of response as a function of left-turn signal, pedestrian detection System and driving environment.

Driving Environments	Protected Left Turn			Open Left Turn		
	PDS	No PDS	Overall	PDS	No PDS	Overall
Normal	.533	.412	.469	.563	.68.8	.625
Stressful	.333	.357	.346	.417	.333	.375
Overall	.444	.387		.5	.536	

3.4.1.2 Response Time

The response time measure was collected only for accurate responses, trials in which drivers made an attempt to avoid a collision with a pedestrian. Figure 11 depicts the average response time for the two types of interventions across the two driving environments. However, given the low accuracy of drivers' response, the response time measure included a small data sample, the factor which makes the interpretation of the response time measure tentative.

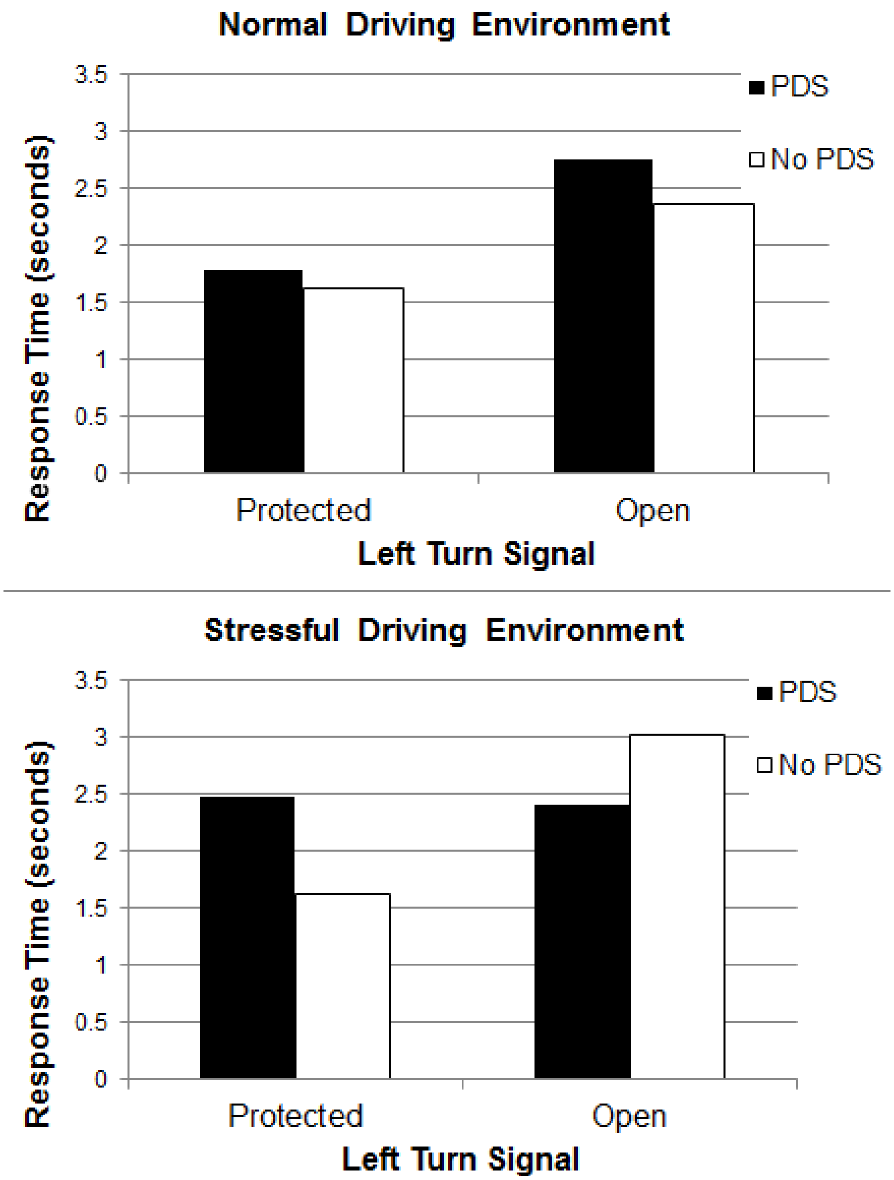

Figure 10: Response time as a function of pedestrian detection system and left-turn signal for normal (top panel) and stressful (bottom panel) driving environments.

3.4.1.3 Wait Time

The wait time measure was collected for blocks of trials that included an Open Left turn intersection (i.e., no green arrow was present). As shown in Figure 12, participants in the Stressful driving environment waited less time before making a left turn at the intersection (39.9 seconds) compared to the drivers in the Normal driving environment (54.2 seconds). This is an expected finding, since the participants in the Stressful environment were given a time limit within which to complete the route. The wait time measure for the two driving environments corresponded to acceptance gap of 6.5 seconds (time-to-contact) for drivers in the Stressful and 7.5 seconds (time-to-contact) for the drivers in the Normal driving environment. The findings for the wait time measure did not reveal a trending effect of the PDS; the presence of the system did not affect bus drivers' turning gap.

Figure 11: Wait time as a function of driving environment and pedestrian detection system.

3.4.1.4 Stress and Experience

An overall average score on the Job Satisfaction questionnaire was 38.6 (sd = 6.1) across the two Driving Environment groups. The average scores for drivers in the Normal and Stressful driving environments were 38 and 39.3, respectively, revealing similar distributions between the drivers in the two groups. Based on the interviews conducted in Study One, we hypothesized that experienced drivers may be less likely to be negatively affected by the stressful driving conditions and possibly experience smaller degree of work-related stress. We performed a Pearson correlational analysis between the scores on the Job Satisfaction questionnaire and the years of experience driving a bus, revealing a moderate positive relationship ($r = .4$). Bus drivers with greater experience driving a bus scored higher on the Job Satisfaction questionnaire, that is, more experienced bus drivers also reported greater level of work-related stress, contrary to our expectations. However, correlations between the scores on the Job Satisfaction questionnaire and overall accuracy or response ($r = .12$), as well as wait time ($r = -.11$) did not reveal any relationships. Because of the different years of experience between drivers in the Normal and Stressful group, we performed a correlational analysis between years of experience and overall accuracy of response, revealing a moderate positive relationship ($r = .33$). Bus drivers with greater experience driving a bus were more likely to brake in order to avoid a collision with a pedestrian. This moderate relationship in addition to different years of experience between the drivers in the two driving environment groups suggests a potential confound. Differences between the Normal and Stressful driving conditions may be due to driving experience, rather than due to stressful conditions. It is possible that both factors play a role, but the low number of participants and collision events do not allow us to decouple this potential confound.

3.4.1.5 *Secondary Task Performance*

Bus drivers' performance on the secondary task, in a way, was similar to their accuracy of response performance. An overall average accuracy score on the secondary task was only .105 proportion of accurate responses. That is, drivers detected and responded to only 10.5 % of red lights. The average accuracy proportion for drivers in the Normal and Stressful driving environment were .08 and .13, respectively. Due to floor-level performance, interpretation of any differences is not possible. Such low accuracy of detection could be an indication of a very low situational awareness of the bus drivers, or perhaps more significantly, indicate the prioritization of the primary task of driving. One potential strategy for a good secondary task performance would require bus drivers to attend to the locations inside the cabin (i.e., location of the red light), while another may have the drivers rely on the peripheral detection of the red light to achieve good performance. Drivers with a wider functional field of view would be more likely to detect the presence of the light, but since we did not examine participants' functional field of view, we are unable to confirm this hypothesis. Regardless of the strategy, devoting attentional resources to the secondary task while completing a very attention-demanding primary task, as shown in Study One, would reduce the available resources and drivers' ability to detect pedestrians at the crosswalk. It is likely that the bus drivers prioritized the driving task at the expense of the secondary task performance. The difficulty of the primary task has shown to affect the level of prioritization. Different levels of driving demands (crossing an intersection vs. uneventful straightaway driving) have shown to affect drivers' speech production, as well as encoding and recollection (Becic, Dell, Bock, Garnsey, Kubose & Kramer, 2010).

3.5 DISCUSSION

Study Two was designed as a pilot investigation to uncover the potential issues with the implementation and examination of the proposed interventions for the reduction of bus/pedestrian collisions. Due to the low number of potential collision trials in which we collected various measures, the results were presented as descriptive statistics. The most important measure found in Study Two relates to the high proportion of times that driver did not respond to a potential collision with a pedestrian. Since the collision events were easily visible, and because one of the stated priorities of the drivers includes pedestrian safety, we have to acknowledge that such unexpected results were likely due to a potential confounds associated with simulation research. Lack of realism and especially lack of real-world consequences is a potential drawback of simulation research, the lack which can affect the participants' responses. As a result, any interpretation of results must be tentative and be accepted with significant caution.

The data did not reveal a trend supporting either benefits or costs of the Pedestrian Detection System. The initial concerns regarding the possibility of the system acting as a distractor did not come to fruition, however, nor did the hypothesis of the benefits of such a system. Descriptive data showed an unexpected cost of the protected left turn; drivers in the normal driving conditions exhibited a trend of increased number of collisions, contrary to our expectations. The lack of realism of simulators in general offers a reasonable explanation for this result, but another possibility should be considered. A protected left turn (i.e., green arrow) may in some situations reduce the high state of attentional preparedness (i.e., lull drivers into a false sense of security) rather than, as we hypothesize, allow drivers to redirect their attentional resources towards the task of detecting pedestrians at the crosswalk.

The floor-level performance exhibited secondary task performance indicated that high mental effort was required for the performance of the primary task, but also indicated prioritization. Prioritizing the driving task is a good strategy, but this finding is important for another reason. Due to the resource-depleting difficulty of the left-turn task, drivers simply may not be able to perform an additional task. If that indeed is the case, bus drivers should not be burdened with additional responsibilities, especially those that require immediate attentional resources at that time. Moreover, any potential interventions should be designed such that they do not impose additional task demands on the drivers.

The descriptive statistics of Study Two revealed one consistent finding. Drivers in the Stressful Driving Environment exhibited trends towards being less likely to respond to potential collisions and more likely to accept a smaller gap when turning. These findings would suggest that stressful driving conditions can impact drivers' performance and their ability to detect pedestrians, findings that should be considered when developing potential interventions. This finding may potentially be confounded with years of experience driving a bus, a confound that should be addressed in future research.

3.6 LIMITATIONS AND FUTURE DIRECTIONS

Since Study Two was designed as a pilot study, the lack of inferential statistics is an expected limitation. A low number of data points (i.e., collision events), which would increase the variability of the results, was the reason why only descriptive statistics were presented. The primary limitation of the current work was the level of realism offered by the simulation platform (all simulators possess this limitation). In particular, simulation environments cannot account fully for the normal stimuli presented to drivers, thus, driver behaviors in a simulator may not be identical to those in the real-world. As such, the interpretation of the results of Study Two needs to be mindful of this limitation. Another potential confound is that participants were not monetarily remunerated by the experimenters; rather their time was donated graciously by Metro Transit. Bus drivers' participation in this study, in a way, was part of their work day and perhaps viewed as a break/rest, a stress-relieving pause. As a result participants may not have responded exactly as they would in a work (i.e., on-road driving) situation. Future studies should consider recruiting the drivers outside their work hours and offer performance-based monetary remuneration to address this possible confound.

Based on experiences gained in this study several future directions are recommended. In future simulation-based studies a post study questionnaire will be useful in determining the source of confounds identified earlier. Future simulator studies should also address the issue of promoting drivers to exhibit behaviors in a simulator that are more reflective of real-world behaviors. Based on the limitations identified in this report it seems reasonable to conduct future research endeavors in real-world settings. However, examining how drivers respond to various new and untested driver support systems relative to safety-critical events is not prudent due to the potential for harm to pedestrians. It is for this reason that we recommended addressing the simulator-based limitations and conducting future studies in a simulator, where both drivers and pedestrians are safe. Furthermore, future studies should go beyond the simplistic nature of the potential collision scenarios examined in the present simulator pilot study. Specifically, scenarios with multiple pedestrians walking in different directions would offer a more realistic examination of left turns at busy intersections. Finally, future research should examine the incorporation of other assist and warning systems and the potential for transitioning *Connected Vehicles* to a bus platform.

4. CONCLUSION

The results of the interviews with the bus drivers revealed an immediately apparent issue – bus drivers engage in a large amount of various cognitive, perceptual and physical tasks during the completion of a left-turn maneuver. Moreover, the completion of the most critical subtask of all (i.e., detecting pedestrians and bicyclists) occurs at the time when bus driver's cognitive resources are strained due to completion of other perceptually demanding tasks, such as tracking the oncoming traffic and determining the optimal gap between the vehicles. The results of the task analysis informed the potential countermeasures for the reduction of fatalities between left-turning buses and pedestrians. As a pilot study, in a simulated setting, we examined the efficacy of a pedestrian detection system that aided a bus driver in detecting pedestrians, a protected left-turn signal that removed a perceptually demanding task (i.e., selecting a turning gap) and the impact of stress on bus driver's performance, especially in perceptually (e.g., limited visibility due to weather) and environmentally (e.g., passengers asking questions, commotion in the back of the bus) demanding conditions. The results of the pilot study provided sufficient data for further examination of different support tools for the reduction of the fatalities between left-turning buses, as well as continuous examination of the impact of work-related stress on driving performance.

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APPENDIX A: TASK ANALYSIS FOR FIVE INTERSECTION SEGMENTS

Stage 1	Approach	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Plan bus departure				x		
1.1	Determine how many lanes will have to be crossed				x		
1.2	Determine how much time/space there is to merge from right to left				x		
1.3	Changing lane (Four lanes/ triple lanes/ two lane)					x	
2	Assess tail-swing to ensure tail end clearance from curb and pedestrians near curb				x	x	
2.1	Maintain lane position					x	
3	Check for surrounding situation	x					
3.1	Scan for unsafe situations or obstacles	x					
4	Look up at the intersection	x					
5	Observe the traffic light	x					
5.1	If the light is red, try to speed up so they can make the left turn when it turns green				x	x	
6	Check for road features	x					
Stage 2	**Approach/ Deceleration**	**Broad Visual**	**Focused Visual**	**Working Memory**	**Executive**	**Motor**	**Unplanned events**
1	Complete lane changing (if more than 2 lanes)					x	
2	Maintain lane position					x	
3	Check for surrounding situation	x					
3.1	Scan for unsafe situations or obstacles	x					
3.2	Keep eye on bikers		x	x			
4	Look up at the intersection, observe the distance to intersection	x			x		
5	Observe the traffic light (fresh green or stale green)	x					
5.1	Fresh green (saw the light change from red to green), once passenger boarding is complete determine if there is enough time to make it to the intersection to complete the left turn				x	x	
5.2	Stale green (e.g. did not see the light change)				x	x	
6	Determine the location of the next bus stop		x		x	x	
7	Break early (easy on brakes - smooth stop)					x	
Stage 3	**Deceleration/ Acceleration**	**Broad Visual**	**Focused Visual**	**Working Memory**	**Executive**	**Motor**	**Unplanned events**
1	Maintain lane position					x	
2	Check for surrounding situation	x					
2.1	Scan for unsafe situations or obstacles	x					
3	Observe road feature	x					
3.1	If there is a median, keep close to the curb to make sure that no bike can fit in the space	x				x	
4	Look up at the intersection, observe the distance to intersection		x				
5	Observe the traffic light	x			x		
6	Stop 1 car length behind crosswalk	x				x	
7	Leave 1 car length between bus and lead vehicle at intersection (leave an out)	x				x	

Stage 4	Intersection Entry	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Observe surrounding situation	x					
1.1	Figure out what vehicles will turn with the bus at the intersection (especially truck, bicycle)	x			x		
1.2	Be aware of oncoming traffic	x			x		
1.3	Keep eye on pedestrians		x	x			
1.4	Look into the mirror if there is a noise in the back		x				x
2	Waiting for the lead car turn left	x			x		
2.1	Allow for a 4 second pause before proceeding	x		x	x		
2.2	Align bus parallel with current lane (i.e. straighten to ensure bus is not encroached on adjacent lane)					x	
3	Big pictures	x					
3.1	Scan to the right (for red light violators; e.g. cars that may run the light)		x				
3.2	Scan to the left	x	x				
3.3	Scan on-coming traffic for gaps	x	x				
3.4	Scan for pedestrians and bicyclists	x	x				
3.5	Last look is down crosswalk to the left	x	x				
4	Turn the wheel					x	
4.1	Check for height of curb on to the right of the bus, approach slowly, if curb is high there is risk of collision with curb	x			x		

Stage 5	Prepare to turn/Execute turn	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Observe road features	x					
1.1	Double back scan down sidewalk	x	x				
1.2	Triple glance - forward, left sidewalk, then back through right mirror		x				
2	Maintain wheel position as straight (to prevent collision with oncoming traffic from accidental acceleration of the bus)					x	
3	Determine entrance lane (money lane, or right lane)		x		x		
4	Determine angle of turn		x		x		
5	Select Gap in on-coming traffic	x			x		
6	Wait until light times out while in the intersection if a traffic gap does not appear that allows for a left turn		x		x	x	

Stage 6	Post turn	Broad Visual	Focused Visual	Working Memory	Executive	Motor	Unplanned events
1	Reduce speed					X	
2	Signal and move to the right lane					X	
3	Locate bus stop position				X	X	
4	Observe road feature	X			X		
4.1	If in the left lane, determine how much time/space for merging right to prepare for bus stop	X			X	X	
5	Check for pedestrians running for the bus at the last minute		X	X			

APPENDIX B: DRIVING HISTORY QUESTIONAIRE

This questionnaire asks you to indicate some details about your driving history and related information. Please tick one box for each question.

1. Today's date _______/(Month)/______ (Day)/ ______ (Year)

2. Have you worked today (as the bus driver)?

   ☐ No

   ☐ Yes.

   If yes, how many hours have you worked?

   ☐0-3 ☐ 3-6 ☐6-9 ☐9-12 hours

3. What is your date of birth?

   _________ (Month) / 19___ ___ (Year)

4. What is your gender?

   ☐ Male

   ☐ Female

5. What is your highest level of education completed?

   ☐ Elementary School

   ☐ Middle School

   ☐ High School / Vocational School

   ☐ Associates Degree

   ☐ Bachelor of Arts / Bachelor of Science

   ☐ Masters

   ☐ PhD

6. About how often do you drive to and from your place of work?

   ☐ ======= ☐ ======= ☐ ======= ☐ ======= ☐

Never	Hardly Ever	Sometimes	Most Days	Every Day

Working History/Experience

7. a. How long have you been working as a bus driver (at any company)?

☐0-5 years ☐ 6-10 years ☐11-15 years ☐16-20 years

☐21-30 years ☐ 31-40 years ☐ >40 years

b. How many years have you worked at your current place of employment?

________ years

8. Which routes have you driven in the past 12 months? (See route list)

Please list the top five bus routes, from the most to least frequently driven

(1) _________
(2) _________
(3) _________
(4) _________
(5) _________

9. When you are driving a bus, what kind of roads do you drive on frequently?

(check all that apply)

☐Highways

☐Main Roads other than Highways

☐Urban Roads

☐Country/Rural Roads

10. What kind of contract did you have at your current place of employment for the last 12 months?

☐ Full-Time

☐ Part-time

☐ Other, please specify: ________________

11. Were you previously employed as one of the following (check all that apply; leave blank if none apply)?

☐ Bus driver – Not a school or coach driver

(other than your current place of employment)

☐ School bus driver

☐ Coach bus driver

☐ Any other transportation that is designed to transport 15 or more passengers

☐ Other kind of commercial vehicle transportation (i.e. a truck driver)

12. Which class of commercial driver license do you currently have?

☐ Class A truck

☐ Class B truck

☐ Class C truck

13. Please state the **year** when you obtained your full driving license:

____

14. During the last three years, how many minor road accidents have you been involved in where you were at fault? A minor accident is one in which no-one required medical treatment, AND costs of damage to vehicles and property were less than $4000.

Number of minor accidents ____ (if none, write 0)

15. During the last three years, how many major road accidents have you been involved in where you were at fault? A major accident is one in which EITHER someone required medical treatment, OR costs of damage to vehicles and property were greater than $4000, or both.

Number of major accidents ____ (if none, write 0)

16. During the last three years, have you ever been convicted for:

	Yes	No
a. Speeding	☐	☐
b. Careless or dangerous driving	☐	☐
c. Driving under the influence of alcohol/drugs	☐	☐

17. What type of vehicle do you drive most while not at work:

- ☐ Motorcycle
- ☐ Passenger Car
- ☐ Pick-Up Truck
- ☐ Sport utility vehicle
- ☐ Van or Minivan
- ☐ Other, briefly describe: ____________________________

APPENDIX C: JOB CONTENT QUESTIONAIRE

1. My job involves a lot of repetitive work

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree	Disagree	Agree	Strongly Agree

2. My job does not require a high level of skill

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree	Disagree	Agree	Strongly Agree

3. My job requires me to work at a fast pace

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree	Disagree	Agree	Strongly Agree

4. I feel that I do not receive sufficient number of breaks at work

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree	Disagree	Agree	Strongly Agree

5. My job requires substantial physical effort

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree	Disagree	Agree	Strongly Agree

6. I feel my input is valued

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

7. I feel that my supervisors do not demand conflicting things of me

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

8. I feel work pressure affects my health and body

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

9. I feel my work interferes with my personal life

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

10. I feel I have to deal with unrealistic time-delivery pressure

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

11. I have opportunities to develop my own special skills (e.g. driving, time management, other)

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

12. I have enough time to get the job done

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

13. I am asked to do an excessive amount of work

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

14. My supervisor provides support that helps me complete my job

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

15. My supervisor expects me to volunteer for or accept extra shifts

☐ ========= ☐ ========= ☐ ========= ☐

Strongly Disagree | Disagree | Agree | Strongly Agree

16. What do you perceive as the primary reason for work stress (mark all that apply)

☐ Low pay

☐ Too much responsibility

☐ No oppurtunities for professional growth or promotions

☐ Long working hours

☐ Lack of involvement in decision making

☐ Repetitive work

☐ Other, specify: ______________________________

☐ None

17. How does the job stress affect you (mark all that apply)?

☐ Loss of focus or concentration

☐ Lethargic

☐ Frustrated

☐ Other, specify: ____

☐ None