Safety Science 68 (2014) 81–88

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Task analysis of transit bus drivers' left-turn maneuver: Potential countermeasures for the reduction of collisions with pedestrians

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ARTICLE INFO

Article history:
Received 20 April 2013
Received in revised form 5 January 2014
Accepted 23 February 2014
Available online 22 March 2014

Keywords:
Task analysis
Transit bus
Left-turn maneuver
Pedestrian

ABSTRACT

Left-turn maneuvers by transit buses are associated with a particularly high rate of collisions with pedestrians. The primary objective of the current study was, through task analysis, to gather a detailed outline of all mental and perceptual tasks that transit bus drivers complete when making a left turn at a signalized intersection. As a secondary objective, based on the task analysis examination, we proposed several countermeasures for the reduction of collision between transit buses and pedestrians. The task analysis revealed that transit bus drivers engage in various tasks during all stages of a left-turn maneuver. The results also showed that the task demand is at a peak during the performance of one of the most critical tasks – detecting pedestrians. Non-driving tasks that transit bus drivers are required to perform (e.g., collecting fares, providing directions to passengers) further increase the tasks demands. Based on the results of the task analysis, we proposed several potential solutions for the reduction of collisions between transit buses and pedestrians. The proposed countermeasures included a technology-based (collision warning system for both drivers and the pedestrians) and infrastructure-based (protected left turn signal for buses only) solutions, as well as examination of individual factors (e.g., stress coping ability) and the relationship with different aspects of driving performance.

1. Introduction

According to National Highway Traffic Safety Administration (NHTSA), there were 4280 fatalities and approximately 70,000 traffic-related injuries of pedestrians in 2010, resulting in an average of one pedestrian fatality every two hours and an injury event every 8 min (NHTSA, 2010). About a fifth of those pedestrian fatalities occurred at intersections (NHTSA, 2010), making them a particularly dangerous location. Intersections however, are not the only danger affecting pedestrians. In the United States, between 1999 and 2005, more than 40% of all fatal transit bus crashes involved a collision with a pedestrian (Blower et al., 2008). In light of this it is easy to postulate that intersections and transit buses represent a particularly dangerous combination for pedestrians. However, we can get even more specific regarding the danger that intersections represent to pedestrians. Compared to other maneuvers at intersections (e.g., driving straight), left-turn maneuvers are associated with a particularly high proportion of collisions with pedestrians (Almuina, 1989). Of the permissible maneuvers that occur at intersections, drivers making a 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 et al., 1998). In 2010, a transit bus driver in Portland, Oregon, collided with a group of pedestrians while making a left turn, which resulted in five fatalities (Rose, 2010). In 2009, one pedestrian was killed in Des Moines, Iowa, as a result of a collision with a transit bus making a left turn (Ryan, 2009). Between 2007 and 2010 Metro Transit (Minneapolis, Minnesota) bus drivers were involved in six collisions with pedestrians resulting from left turns. It is evident from these data and examples that crashes between transit buses and pedestrians represent a transportation safety concern in the United States.

The unacceptable frequency of collisions between buses and pedestrians led to various attempts by transit authorities across the country to implement measures to reduce those collisions. For example, Metro Transit (Minneapolis, Minnesota) implemented a *Look-and-See* campaign to remind drivers to visually scan their surroundings prior to making a turning maneuver. Other agencies including the Maryland Transit Authority incorporated external devices on transit buses that alerted nearby pedestrians when a bus was making a left turn at an intersection. Technological advancements allow for the consideration of additional countermeasures that may reduce the frequency of collisions between

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http://dx.doi.org/10.1016/j.ssci.2014.02.023
0925-7535/Published by Elsevier Ltd.

pedestrians and transit buses, especially during left turns. However, the development and deployment of these initiatives is most often based on a perception of what may be helpful as opposed to a directed scientific approach that examines the source of these collisions and proposes countermeasure based on those examinations. Since it is the transit, rather than regional or national buses (e.g., Greyhound) that are involved in these collisions with pedestrians, the current study examines the actions of the transit bus drivers and identifies the potential antecedents and situations that may lead to collisions with pedestrians. Moreover, the current study examines the actions of transit bus drivers during a left-turn maneuver, as this specific maneuver has shown to result in most collisions with pedestrians. A first step in understanding the source of the transit bus/pedestrian issue is to identify the underlying factors that contribute to these collisions. The present study accomplishes this by conducting task analysis, a detailed examination of transit bus drivers' actions when completing a left-turn maneuver. Addressing gaps in the literature and conducting a task analysis represents the initial goal of the current research. Based on the task analysis findings, the second goal includes proposing potential countermeasures for the reduction of the collisions between pedestrians and transit buses.

1.1. Etiology of the left-turn maneuvers performed by transit bus drivers

Left turns at intersections can be challenging for drivers of all types of vehicles, but are especially challenging for drivers of large vehicles, such as buses. In addition to the complex physical characteristics of maneuvering a larger vehicle, transit bus drivers are also asked to concurrently perform numerous non-driving tasks, such as answering passengers' questions about directions, collecting fares, and announcing stops. While some of the tasks do not ordinarily occur at the time when a driver is making a turn, unplanned distractions that cannot be controlled by a driver (e.g., commotion in the back of the bus, passenger asking questions) can occur at any time, on a straightaway or at an intersection. It is clear that driving represents only a portion of all the tasks that transit bus drivers perform. The non-driving elements of operating a transit bus likely contribute to a significant increase in mental effort, which is an important consideration during attention demanding tasks, such as making a left turn at an intersection. Performing a left-turn maneuver at a busy intersection is likely to strain driver's cognitive resources and additional engagement in non-driving tasks may result in shifting of cognitive resources away from the primary task of driving.

Independent of non-driving tasks, the amount of mental effort required to make a left turn at an intersection is substantial (Hancock et al., 1990). Hancock and colleagues have shown that drivers' rate of blinking and head movements is much higher when turning compared to driving straight through an intersection. However, more active scanning (i.e., more frequent eye movements) when making a turn does not necessarily imply a successful detection of obstacles (also see Boot et al., 2006). For example, when head position was statistically controlled, response times to simple visual probes became significantly slower during turning maneuvers compared to straight maneuvers (Hancock et al.). The response impediment is likely due to increased attentional demands. The findings by Hancock and colleagues were not specific to left turns as they are applied to both left and right turns. However, the higher rate of collision when making a left turn compared to the right would indicate a more dangerous maneuver, and we would argue, a more attention-demanding maneuver, as well. Compared to making a right turn or driving straight through, the increased attentional demand for left-turn maneuvers is due to greater number of subtasks performed by the transit bus driver, such as examining oncoming traffic for an appropriate turning gap, monitoring the stop light, and monitoring the pedestrians on the roadway as well as the sidewalks. It is possible that the high rate of pedestrian vehicle collisions when making a left turn is due to high task demands, a notion supported by increased detection of pedestrians at crosswalks with presence of left-turn signals (Lord et al., 1998). The inclusion of a left-turn signal removes a particular attention-demanding task (e.g., selecting appropriate turning gap). With the reduced complexity of the left-turn maneuver, a driver may be able to devote more cognitive resources towards other driving-related tasks, such as detecting pedestrians at a crosswalk.

Drivers adapt to high task demands by strategically prioritizing their behavior to ensure successful completion of high-priority tasks (Cnossen et al., 2004). In situations when tasks are numerous and attentional resources are limited, drivers prioritize one task at the expense of another (Kramer et al., 2007; Becic et al., 2013). For example, relative to the current work, if a transit bus driver decides that keeping an accurate schedule has increased priority (arriving at the planned destination on schedule), depending on the attentional demands of other tasks, the driver may fail to provide sufficient attention to the most important tasks – detecting pedestrians and bicyclists. During rush-hour traffic or events that are accompanied by increased number of pedestrians, drivers may strategically reduce the attentional effort directed towards one of the driving tasks in order to focus on another (Cnossen et al.). When faced with a demanding traffic situation 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 in general complete when making a left-turn maneuver (e.g., scanning for the pedestrians, selecting an appropriate gap between the oncoming vehicles, etc.), however, it is likely that transit bus drivers complete additional discrete and continuous tasks, most of which represent standard components of transit bus driver's responsibilities.

In the current study we conduct a task analysis of transit bus drivers making a left-turn maneuver at intersections. The goal was to gather a detailed outline of all mental and perceptual tasks that transit bus drivers perform at various points of a left-turn maneuver. Furthermore, based on the findings from the task analysis, we propose potential countermeasures that may help reduce the frequency of collisions between pedestrians and transit buses, especially left-turning buses.

2. Methods

2.1. Participants

Six transit bus drivers and driver trainers (including one female and five male operators) employed by the Minneapolis, Minnesota based public transportation operator Metro Transit, participated in the study. The Metro Transit service area covers seven counties in Minneapolis/St. Paul metropolitan area. Each participant interview lasted approximately two hours. The participants were not compensated for their participation; rather their time was donated by Metro Transit. All of the interviewees were experienced transit bus drivers with a minimum of 10 years and maximum of 20 years at the job.

2.2. Materials and apparatus

Participants were presented with several large laminated posters depicting various intersections within the Minneapolis/St. Paul area at which bus/pedestrian collisions occurred in the past (an example of a poster is shown in Fig. 1). The purpose of the posters was to provide an environment that would allow the participants to readily recall their experiences when driving through known intersections. To encourage discussions and interactions between participants and the researchers, participants were asked to physically draw on the posters when explaining different tasks they performed while making a left turn. The participants were asked about the intersections presented on the posters, but also about any other intersections in the Minneapolis/St. Paul area. Moreover, in order to examine full task demands of a complex left-turn maneuver, we focused on an open-left turn (i.e., unprotected left-turn lanes without a green arrow) intersection where opposite direction traffic is not required to left-turning traffic.

2.3. Procedure

Before the start of the interviews, the experimenter described a number of collisions between left-turning buses and pedestrians that occurred in the state as well as nationally. This review was designed to elicit experiential knowledge from the transit bus drivers and provide guidance as to the type of information that was of interest to the experimenters. Participants were asked open-ended questions about the left-turn maneuver and tasks leading up to, during, and after the maneuver. Participants were then free to describe what elements they felt contributed to crashes, at the previous crash locations, based on their experience. Additional probe questions were asked depending on the context and content of their answers. The interview process used an iterative approach, such that subsequent interviews not only confirmed material discussed with previous participants, but also uncovered new and insightful information.

The interviews that we carried out were modeled to be similar to the intersection segmentation process used by Richard et al. (2006). The subsequent task analysis was expected to define and describe drivers' mental effort at various points of the left-turn maneuver in order to identify driver needs and deficits. All of the subtasks and mental processes that transit bus drivers reported completing during a left-turn maneuver were classified into five categories: *visual processes*, *working memory tasks*, *executive tasks*, *motor tasks* and *unplanned events*. The primary purpose of the categories was to organize the input from the interviews. The categories were created such that they encompass observable (e.g., steering, head movement to scan side mirrors), as well as unobservable actions (e.g., making judgments about turning gap), actions that require attentional resources.

Visual processes included any processes or tasks that required transit bus drivers to visually observe the surrounding environment, read symbols/traffic signs, monitor mirrors and detect motion. 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, while focused visual search included pre-planned visual search of the known high-risk areas (e.g., traffic lights and mirrors) to assess 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 a driver's visual field (e.g., in the side mirrors). *Executive tasks* were characterized as those tasks that required drivers to make evaluations, determinations or a decision. Typical executive tasks included evaluating the gaps in the oncoming traffic, determining the state of the traffic signal/light (whether green cycle has just started or nearing its end), judging the distance from a curb and/or determining the number of turn lanes, and deciding to turn. *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. 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 distract the driver during any one of the previously defined segments. It is necessary to determine a transit bus driver's ability to deal with such situations such that if a driver's cognitive resources are overburdened when making a left turn, any additional tasks may result in a failure to

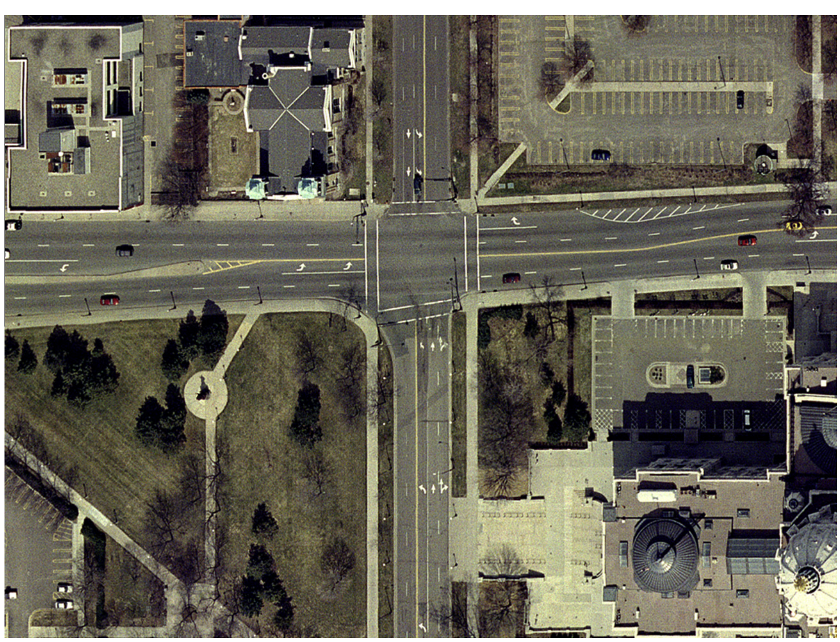

Fig. 1. Depiction of an intersection presented to the participants.

accurately complete the primary task. A failure during driving and specifically during the turning phase may result in a bus-pedestrian collision.

The experimenters divided each intersection into six defined stages that transit bus drivers navigated when performing a left-turn maneuver (Fig. 2). This segmentation process was used to map-out where tasks could occur and uncover changes in task demands at different sections of an intersection. For example, such segmentation may reveal a bottleneck (e.g., multiple tasks performed with insufficient cognitive resources) at specific section that may not be present at others. The six segments were developed based on driving objectives in terms of intersection navigation (Richard et al., 2006). To begin, each segment had different driving objectives. The first segment was defined as the "*Approach*", which included leaving the bus stop before entering the intersection. The second segment was defined as "*Approach and deceleration*" which represented the area within which the transit bus approached the intersection. The "*Deceleration/acceleration*" segment represented the section at which the bus operator determined the traffic light state and initiated preparation to stop or drive through the intersection; "*Intersection entry*" was characterized as the part of the intersection at which the bus entered the position of turning; "*Prepare for turn/execute turn*" represented the segment of the intersection in which the bus driver initiated and completed the tasks encompassed by the turning decision and the start of the turn and finally, "*Post turn*" was characterized as the part of the intersection after turning. It should be noted that these segments were not present (i.e., visible) on the posters shown to the participants during the interviews.

The task analysis method was tailored toward vehicle driving and can be used for uncovering potential problems, as well as identifying opportunities for training, the development of assistive technologies, and highway design solutions.

3. Results

Information from the interviews was reviewed and categorized based on the various tasks and subtasks that transit bus drivers

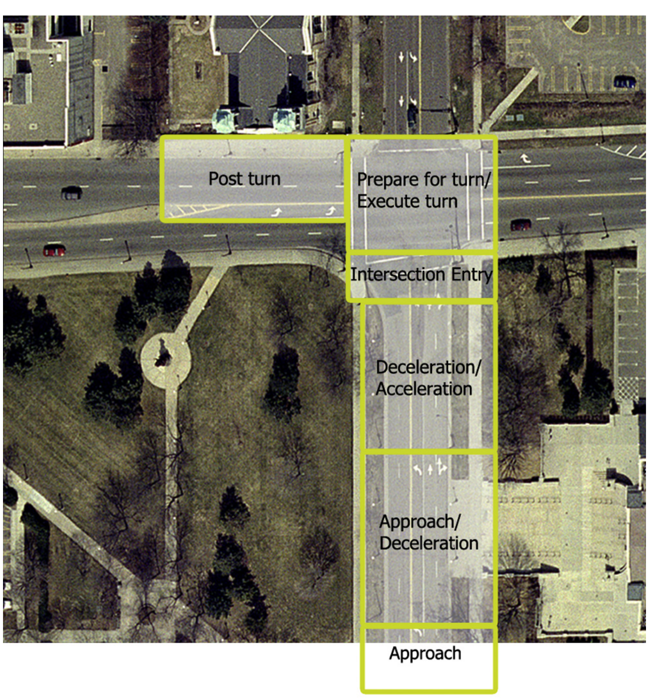

Fig. 2. Depiction of six segments of a left-turn maneuver at one of the examined intersections.

reported completing along the task analysis stages of an intersection. These tasks and mental processes were then binned into specific concepts that were defined and that were broad enough to fit other similar tasks and processes transit bus drivers reported completing in the remaining segments of the intersection. As mentioned earlier, the interview process used an iterative approach; all of the subtasks and processes that transit bus drivers reported completing during a left-turn maneuver were reviewed several times across different drivers assuring consistency of response.

3.1. Components of the left-turn maneuver

Following the interviews, the experimenters subjectively categorized the reported subtasks and processes into task categories. Tables 1–3 list all the subtasks and processes that transit bus drivers reported completing in all six segments and classified them into one of the pre-designated bins, each representing a particular concept. Each of the tasks and processes was associated with a specific concept and in some cases more than one.

As Table 1 shows, transit bus drivers reported being primarily engaged in broad visual, executive, and motor subtasks in the first segment (approach). During the second segment (approach/deceleration), transit bus drivers continued to be engaged in performing primarily motor (e.g. changing lanes when there are more than one lane to across), executive (e.g. determining the distance to the intersection), and broad visual (e.g. inspecting the conditions of the surroundings) subtasks. The third segment (deceleration/acceleration) started at time when a transit bus driver made determination of whether to accelerate too catch the green light and turn or decelerate in the anticipation of the red light. Most of the subtasks and processes that transit bus drivers reported completing in this segment (see Table 2) can be classified as broad visual (e.g. scanning for surrounding situation and observing the traffic light) and motor (e.g. maintaining lane position) subtasks. These initial three segments can be considered as *pre-intersection*.

The next two segments contained the most important subtask that transit bus drivers were required to complete and occur within the *intersection* box. The fourth segment (intersection entry) represented the smallest portion of an intersection, but not necessarily the section at which transit bus drivers spend the least amount of time. When entering an intersection where they are about to make a left turn, transit bus drivers reported engaging in focused visual (e.g. following the movements of pedestrians and bicyclists; scanning both sides of the road) and executive subtasks (e.g. determining how many vehicles are making the left turn, number of vehicles in front of the bus; determining the optimal gap between the oncoming vehicles to complete the left-turn maneuver). As Table 2 shows, they also reported significant engagement in the Broad Visual subtask (e.g., observing the pedestrians crossing the intersection and bicyclists who may prepare to turn left). 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 3, transit bus drivers engaged in substantial number of subtasks at this section. Drivers reported performing multiple subtasks, including focused visual (e.g. double checking the sidewalk), executive (e.g. determining the entrance lane; determining the angle of a turn; selecting gap in the on-coming traffic), and motor (e.g. maintaining straight wheel position at the intersection; executing the turn) subtasks. In general, intersection entry (segment 4) and the prepare to turn stage (segment 5) represented the most important and difficult stages in the left-turn maneuver. The fourth and fifth segment were also the most demanding because of the high number of subtasks that transit bus drivers performed, the demand that strained their cognitive resources. At the same time, these segments also contained the most important subtask – detecting pedestrians.

Table 1
Task analysis for a left-turn maneuver for segments 1 and 2.

Segment 1	Approach	Broad visual	Focused visual	Working memory	Executive	Motor
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 2	Approach/deceleration					
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

Table 2
Task analysis for a left-turn maneuver for segments 3 and 4.

Segment 3	Deceleration/acceleration	Broad visual	Focused visual	Working memory	Executive	Motor
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
Segment 4	Intersection entry					
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			
2	Waiting for the lead car turn left	x			x	
2.1	Allow for a 4 s 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 last segment (post turn) started after a driver exited the intersection. In this segment (see Table 3), drivers reported focusing on motor (e.g. reducing the speed; moving to right lane), as well as executive (e.g. determining how much space to merging to the bus stop) subtasks.

3.2. Left-turning buses: other relevant factors

The interviews with the transit 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

Table 3
Task analysis for a left-turn maneuver for segments 5 and 6.

Segment 5	Prepare to turn/execute turn	Broad visual	Focused visual	Working memory	Executive	Motor
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
Segment 6	Post turn					
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		

other factors that may impact driver's ability to successfully complete the 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. There are multiple sources of stress but some of them stem from the need to maintain strict schedules, interact with the passengers, and operate the bus safely in inclement weather. The interviews revealed that experienced transit bus drivers have developed a stress coping tactic; they tend to be less concerned with maintaining the schedule, unlike the novice transit bus drivers. Moreover, the concern about the schedule may lead novice transit bus 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 had at least 10 years of experience.

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

4. Discussion

The results of the interviews contributed to the creation of a comprehensive task analysis for transit bus drivers performing left-turn maneuvers at open left turn (i.e., no green arrow) intersections. The task analysis findings identified specific subtasks that the transit bus drivers complete when making a left-turn maneuver. The information included in Tables 1–3 provides detailed descriptions of the subtasks and processes that transit bus drivers reported when completing a left-turn maneuver. However, it may be challenging to compare the predominant tasks transit bus drivers performed at different segments of an intersection. Fig. 3 shows another method of viewing this information. Each concept is represented by a specific color with shade/hue illustrating the prevalence. A darker shade indicates a transit bus driver's increased engagement in that particular concept (multiple tasks that relate to the same concept) while a lighter shade indicates only a minimal effort for a particular concept. For example, the motor task was the most prevalent concept in approach/deceleration and post turn segments, while the focused visual was the most prevalent in the preparing to turn segment. The interviews revealed an immediately apparent and important issue – transit bus drivers engage in a significant amount of varied subtasks during left-turn 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 transit bus drivers overburdened? What countermeasures can be taken to aid transit bus drivers, especially in situations when the available cognitive resources are insufficient to perform the task?

4.1. Potential countermeasures for reduction of fatalities

The primary goal of the current research was to develop a detailed outline of the tasks transit bus drivers complete when making a left turn. The findings from the task analysis allowed us to identify important factors that can inform the development of potential solutions for the reduction of the bus/pedestrian collisions. In addition to the findings uncovered from the interviews, we also examined currently employed modification factors aimed at reducing general crashes at intersections. In a way, the currently deployed countermeasures for the reduction of crashes at intersections (e.g., protected left-turn) served as a top-down approach to the solution for the crashes between pedestrians and left-turning buses. The interviews and the generated task analysis served a dual purpose. First, to examine the feasibility and uncover potential issues with the implementation of some of the general countermeasures for the reduction of crashes at intersections. The second purpose was to act as a bottom-up approach, uncovering new factors specific to the left-turning bus drivers that require a specialized countermeasure.

The solutions that we propose are based on two approaches. The first approach is to aid drivers in performing a particular subtask. The second approach is to completely remove that subtask.

Since the ultimate goal of the current research is to reduce the frequency of bus/pedestrian collisions, the first proposed solution is to aid drivers in detecting critical pedestrians (i.e., pedestrians that may be on a collision path). One of the main subtasks in the two intersection segments included 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 initiating a left turn. We propose a technology-based solution that would track the movement of targets of interest

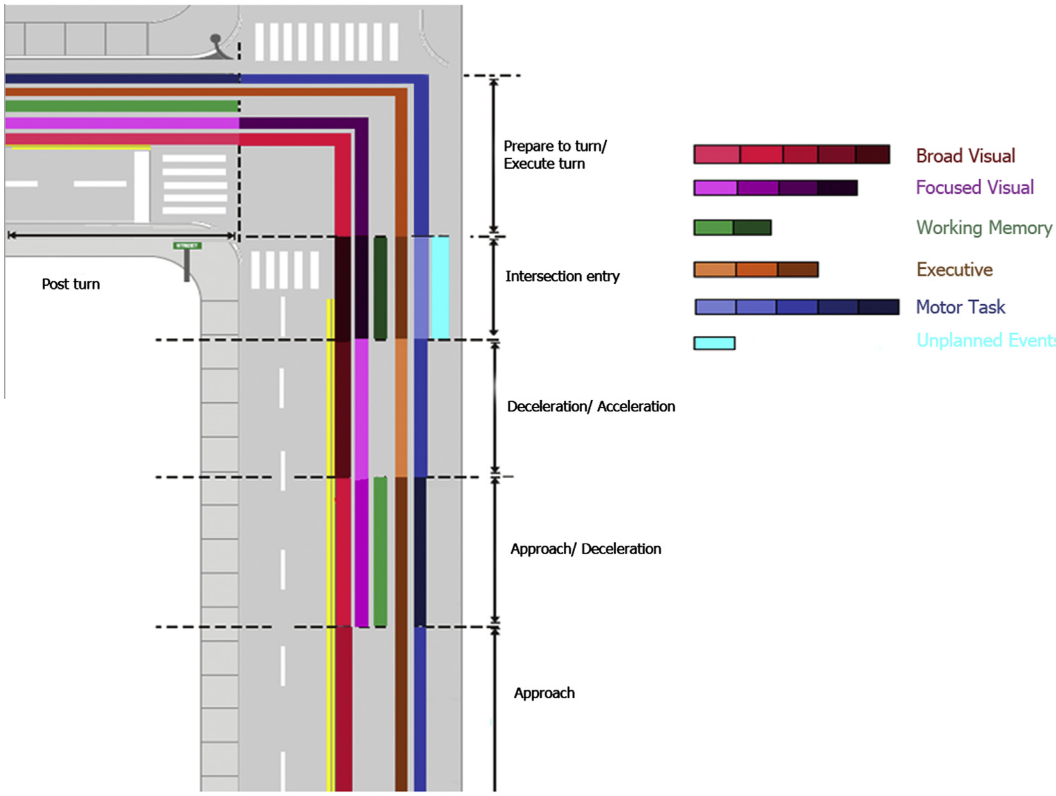

Fig. 3. The prevalence of various subtasks at different points of an intersection during a left-turn maneuver.

(e.g., pedestrians, bicyclists) and alert a transit bus driver if the target becomes an imminent danger. This support tool would provide an auditory cue to a transit bus driver when a pedestrian enters a collision proximity zone. Based on the interviews with the transit bus drivers, it is important for the assist system not to include a visual component (i.e., display). A visual alert system that required drivers to view it in order to detect pedestrians would increase already high attentional and perceptual task demands. This pedestrian detection system could be considered a direct intervention method in that it would aid a driver in the performance of the most critical task (i.e., detecting critical pedestrians), rather than reduce 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.

For the second solution, we propose an infrastructure-based turning aid. This intervention would include a protected left turn at intersections (i.e., green arrow) either for all vehicles turning left or for buses only. However, this recommendation is tempered by the notion that a protected left turn for all vehicles may not be possible at critical intersections when considering appropriate traffic flow and other transportation engineering approaches. 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. This countermeasure could be considered an indirect intervention or an intervention that may reduce attentional demand during a critical segment of a left-turn maneuver. The infrastructure solution completely removes the need for transit bus drivers to judge an optimal gap in traffic and allows them to attend to other critical and unexpected hazards such as pedestrians and bicyclists. Previous research that employed dedicated signals at intersections indicating to transit bus drivers when to make a left turn has reportedly led to increased detection of pedestrians in crosswalks (Lord et al., 1998). This was likely the result of removing the requirement for a transit bus driver to judge the appropriate turning gap, which decreased the complexity of the left turn (Lord et al.), thus allowing greater attention toward detecting pedestrians. Adding a dedicated left turn signal has another important consequence – pedestrians are prohibited from crossing the street when a bus is turning, thereby substantially reducing the likelihood of a pedestrian in the roadway. However, the infrastructure solution represents a potential confound for the future evaluations as it would be difficult to untangle the impact of the reduced number of pedestrians in crosswalks (i.e., reduced perceptual load) with the removal of turning gap judgment subtask (i.e., reduced cognitive load). Any potential impact of this particular intervention would need to be explained as an interactive effect of these two factors.

The interviews revealed stress and driving conditions as factors with potential to impact transit bus drivers' performance. Adherence to strict schedules has been identified as one of the antecedents of stress, a factor that can potentially have a negative impact on novice transit bus drivers' driving performance. For example, if arriving at a planned destination on schedule becomes a high-priority task for a transit bus driver, in order to meet demands of that task, the driver may increase engagement 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 et al., 2004). Other factors, such as unruly passengers have a potential to increase stress while lower visibility in inclement weather (e.g., fog, snow banks) may also increase the perceptual difficulty of the critical task (i.e., detecting pedestrians at crosswalks). These factors become especially relevant when considering individual differences; some transit bus drivers may be more affected by stressful conditions than others. This can play an important role when assigning routes to drivers. For example, as a perk of seniority more experienced drivers may have an opportunity to choose their own routes, presumably those associated with lower level of stress leaving novice drivers with more challenging route options. Transit authorities across the country have various methods for assigning routes, but the findings from the interviews conducted in the present study would suggest that both experience and transit bus driver's individual ability to handle stressful situations should be considered when assigning routes to the drivers. Although assigning specific routes may not be a possibility for all transit authorities, providing support regarding stress-coping techniques should be considered.

Notifying pedestrians about the actions of a large vehicle has been a topic of interest for numerous commercial vehicle fleets and transit authorities. The number of fatalities involving transit busses suggests the necessity of collision warning devices to aid either drivers or pedestrians about the action of the transit vehicle. Alerting pedestrians is a rather novel approach for the solution of bus/pedestrian collisions, with several methods already being employed by a number of transit authorities and districts. These devices initiate an external auditory warning for pedestrians when the bus is turning (Maryland Transit Administration, 2011; Tri-County Metropolitan Transportation District of Oregon, 2011). However, the auditory warning competes with other environmental noises (e.g., bus engine). More importantly, this is a static technology, that is, it does not actively monitor objects of interest (i.e., pedestrians, bicyclists), but rather provides a warning only at very specific situations (e.g., when turning), regardless of the need. This can easily lead to habituation, especially when the auditory warning is not paired with a near collision event. This warning could also include a visual component, such as flashing lights on the side of the transit bus that onset concurrently with the auditory warning. Bi-modal warnings have shown to be more effective than unimodal when part of an in-vehicle collision warning system (Ho et al., 2007; Kramer et al., 2007) and we would expect the same benefits of the bi-modal warning to occur when alerting pedestrians of a potential collision with a transit bus. Detection technology, such as one described in the technology-based countermeasure, equipped with both internal and external warning mechanisms would alert both elements of the potential collision. This warning system would need to be tempered with operator input and detection algorithms that need to take into account proximity of objects and predicting likely collision situations (Mertz et al., 2000). When this system detects a potential collision it would alert both the driver and nearby pedestrians through speakers and/or lights located on the exterior of the bus.

The task analysis method used in the current study (i.e., self-reported) has a recall bias as a possible confound. We ameliorated this concern by confirming transit bus driver reports with subsequent drivers in order to achieve consistency between responses. Additionally, all transit bus drivers in this study were experienced, with a minimum of 10 years of bus driving. Task analysis, concepts, and actions by novice transit bus drivers may rank differently in importance compared to more experienced drivers.

5. Conclusions

Independent of non-driving tasks, the amount of mental effort required of transit bus drivers to make a left turn at an intersection is substantial. However, the demands of the left-turn maneuver by transit bus drivers do not end with driving-specific tasks. Non-driving tasks, such as monitoring the passengers and maintaining timely schedule, collecting fares and providing directions are also considered as standard components of transit bus driver's responsibilities. The task analysis revealed that transit bus drivers are engaged in a substantial number of driving-related subtasks when performing a left-turn maneuver. The addition of non-driving tasks may present attentional demands that cannot be met by the drivers. Based on the findings from task analysis and interviews with the transit bus drivers, we proposed several countermeasures that may reduce the frequency of collisions between pedestrians and transit busses.

Acknowledgements

The study was funded by the Intelligent Transportation Systems (ITS) Institute, a program of the University of Minnesota's Center for Transportation Studies (CTS). We also acknowledge Metro Transit for providing access to its bus drivers, as well as the bus drivers themselves for agreeing to participate.

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