Management and Production Engineering Review
Volume 4 • Number 1 • March 2013 • pp. 10–19
DOI: 10.2478/mper-2013-0002

A CONCEPTUAL ANALYSIS OF COGNITIVE DISTRACTION FOR TRANSIT BUS DRIVERS

Kelwyn A. D'Souza[1], Denise V. Siegfeldt[2], Alexa Hollinshead[3]

[1] *Eastern Seaboard Intermodal Transportation Applications Center (ESITAC), Hampton University, U.S.A.*
[2] *Extended Studies Department, Florida Institute of Technology, U.S.A.*
[3] *Department of Psychology, Hampton University, U.S.A.*

Corresponding author:
Kelwyn A. D'Souza
Eastern Seaboard Intermodal Transportation Applications Center (ESITAC)
Hampton University
Hampton, VA 23668, U. S. A.
phone: (757) 727-5037
e-mail: kelwyn.dsouza@hamptonu.edu

Received: 25 June 2012
Accepted: 5 January 2013

Abstract
The purpose of this paper is to analyze cognitive distraction data to determine its impact of transit bus drivers' capability. Much of the theory and results applied in this paper are from the work of researchers working on similar projects. In order to understand cognitive distraction and how it can be mitigated, a Cognitive Distraction Model is outlined. The model was analyzed to evaluate the correlation between driver capability, and demographics and driving patterns. A model that provides an understanding about cognitive workload and driver capability could provide better psychological solutions to mitigate the number of accidents due to cognitive distraction and develop relevant driver training programs. Through additional research from the neurological and behavioral sciences, regulators could develop a better understanding of the causal factors and ways to control cognitive distraction.

Keywords
Accident Risk Management, Driver Inattention, Driver Distraction, Physical Distraction, Mental Distraction, Driver Training, Cognitive Distraction, Multitasking, Behavioral Science.

Introduction

According to the National Highway Traffic Safety Administration (NHTSA), distracted driving claimed over 5,000 lives and nearly half a million injuries across the U.S [1]. The analysis of accident databases shows driver distraction to be a significant cause of accidents on the highways [2]. This growth in transit bus services coupled with proliferation of advanced in-vehicle technologies are causing more distractions. *Distraction occurs when a driver's attention is diverted away from driving by a secondary task that occurs approximately 30% of the vehicle movement time [3].* Government regulators have proposed policies such as the recent National Transportation Safety Board's (NTSB) recommendation ban all cell phone usage including hand-free devices while driving, except in emergency situations [4]. The hand-free devices have been included in the ban, since although they eliminate visual and physical distraction, their usage results in cognitive distraction [5].

Various studies have shown that visual and physical distractions are a major cause for automobile accidents mainly because such studies are easier to conduct as compared to cognitive distraction. There is a paucity of research reported in the literature [6] on cognitive-related distraction because identifying a way to properly obtain and analyze the data appears to be difficult. In an earlier study by D'Souza and Maheshwari [7], data collected on the driver's perception of each distracting activity revealed that cognitive distraction generally due to multitasking driving tasks with secondary tasks was perceived by drivers as the highest form of distraction. A more detail analysis of the relationship between the cognitive workload and driver capability and corresponding responses is necessary for a complete understanding of distracted driving.

This paper explores the problems of distracted driving from a behavioral point of view with an attempt to formulate a concept for investigating the role a driver's cognitive state plays on their driving effectiveness. In order to understand cognitive distraction and how it can be controlled is the development and analysis of a Cognitive Distraction Model (CDM) that describes the different components of the cognitive distraction processes. A cognitive distraction model is proposed consisting of four components: Driving Tasks, Distracting Activities, Cognitive Workload, and Driver Capability. The model analyzes the drivers' response to cognitive workload and driver capability due to multitasking of driving and distracting activities. It is one of only a few studies to examine the full range of distractions and associated risk due to cognitive factors. The reason for undertaking this research was to get a better understanding of distracting activities originating in the mind since most published research on distracted driving focus on physical and visual distractions.

Research results [3, 5, 8, 9] on multitasking limitations of the brain are utilized in this paper to develop the CDM. By understanding the correlation between cognitive distraction and location, driving pattern, and driver demographics better psychological solutions can be put into place to mitigate the number of accidents due to cognitive distraction. The results anticipated from this research will provide a better understanding about cognitive distractions and how they can be avoided.

Literature review

Driver distraction represents a significant problem in the personal and public transport sector, and has been studied by several researchers [6]. The analysis of accident databases in the City of Perth, Western Australia found driver distraction to be responsible for 13.6% of all crashes on the highways [2]. A study funded by the AAA Foundation [10] identified the major sources of distraction for personal vehicles contributing to crashes, developed taxonomy of driver distractions for the U.S. driving population, and examined the potential consequences of these distractions on driving performance. The source of bus driver distractions at a major Australian public transport company was investigated using ergonomics methods through which, a taxonomy of the sources of bus driver distraction was developed, along with countermeasures to remove/mitigate their effects on driver performance [11].

Research on cognitive distraction is limited [5, 12]. Harbluk and Eizenman [5] conducted a study on 21 drivers under conditions of cognitive distraction caused by the usage of hand-free and speech recognition devices and reported changes in driver visual behavior, vehicle control, and *subjective assessment of workload, safety, and distraction.* Multi-tasking and using a cell phone with hand-free and speech recognition devices may eliminate visual and physical distraction but cognitive distraction is still prevalent.

Transit bus drivers are required to perform multiple tasks in addition to driving such as attending to passengers in addition to their primary activity of driving by multitasking. A white paper by the National Safety Council states that *multitasking is a myth* since the human brain can only perform one task at a time sequentially and cannot perform multiple tasks simultaneously [8] although, some researchers [13] have concluded that drivers can meet specific performance criteria by controlled multitasking. The accident reports filed by law enforcement officials rarely document cognitive distraction as the cause of accidents. Such accidents are possibly recorded in Virginia Traffic Crash Facts under the category of *No Violation* [14]. Yang [15] analyzed trends in transit bus accidents and related factors such as road design, weather, lighting condition, etc, recorded by the National Transit Database (NTD), but no analysis was reported on cognitive driver distraction. Driver cognitive status is normally not known for a large number of accidents but it is estimated that 10.5 % of drivers were distracted at the time of the accident [3]. Due to lack of reporting cognitive distractions by drivers, the associated risks and impact on performance is difficult to study and hence, not been well-understood.

Factors such as location, driving hours/week; and driver age, gender, and experience have an impact on public bus driver distraction [16]. A driving route running through a densely populated area servicing a greater number of passengers accompanied by higher external sources of distraction due to more frequent stops and more other road users or pedestrians [10]. A driver less familiar with the driving routes is more likely to be involved in rear-end accidents at signalized intersections [17]. Studies on the impact of age, gender, driving experience, and driving demands on driving performance suggests that younger (below 25 years) and older (above 70 years) drivers tend to be more vulnerable to the effects of distraction than middle-aged drivers [1, 18]. Older female drivers had increased risk of crash due to poor attention, cognitive, executive, and motor skills [18]. The age group > 75 years presented the highest risk due to age-related problems with physical and cognitive abilities [18]. Blower et al. [19] reported that age, sex, hours driving, trip type, method of compensation, and previous driving records are related to driver errors. The impact of age and cognitive functions on driving performance has been studied extensively to predict cognitive distraction with a computational cognitive model and validating the results through simulation [20]. O'Connors [6] has proposed a relationship between odds ratio and complexity of secondary tasks where the computed odds ratios were 3.1 for complex secondary tasks, 2.1 for moderate secondary tasks, and 1.0 for simple secondary tasks. From the odds ratio, O'Connors [6] has computed the risk of involvement in a crash or near crash

Researchers have discussed driver's cognitive interaction while driving to understand the occurrence of accidents. Wong and Huang, [12] have proposed a research framework for studying driver's mental process in order to determine how accidents occur which includes a conceptual framework of driving mental process that is a step towards development of a workable model to study accident causality. Trick et al. [21] have provided a conceptual framework that combines the two fundamental dimensions of attention selection in order to have a more comprehensive driving theory. Although the work of Wong and Huang [12] and Trick et al. [21] are not directly related to driver distraction, their framework provides useful inputs for development of the cognitive distraction model in this paper.

Analysis of cognitive driver distractions

A self-administered survey was used to collect drivers' current perception of cognitive distraction. The region covered by the transit agency was divided into two locations: the Northside and Southside due to the difference in population density, street layouts, and accident rates. The Southside is more commercialized and densely populated with a higher accident rate of 62 accidents/million miles compared to the Northside's rate of 54 accidents/million miles.

Potential Sources and Duration of Distraction

The transit bus drivers rated how distracting they found listed activities and the approximate duration they experienced these activities in a typical eight-hour shift. The ratings and durations for each activity was averaged and ranked from highest to lowest [22]. The top five distracting activities shown in Table 1 are mostly passenger-related.

Table 1
Top Five Distracting Rating Activities.

Rank	Activity	Average Distraction Rating	Related Category
1	Passengers using a mobile phone	2.48	Passenger
2	Passengers not following etiquette (eating, drinking, smoking, noisy)	2.35	Passenger
3	Passengers trying to talk to you	2.23	Passenger
4	Fatigue/Sickness	2.1	Personal
5	Passengers	2.08	Passenger

The survey collected the time drivers spend per shift on various distracting activities while driving a bus. The average time for each activity was computed and sorted from highest to lowest average times. The top five activities are listed in Table 2. The bus drivers reported that much of their distracted time was on passenger-related activities.

Table 2
Top Five Distracting Duration Activities.

Rank	Activity	Average Distraction Duration (Hrs)	Related Category
1	Passengers using a mobile phone	2.66	Passenger
2	Other Road Users	2.24	External
3	Passengers	2.23	Passenger
4	Passengers trying to talk to you	1.96	Passenger
5	Passengers not following etiquette (eating, drinking, smoking, noisy)	1.84	Passenger

Driver Perception of Impact of Distracting Activities

The U.S. DOT [23] has categorized distractions as Visual, Manual, and Cognitive and reported that the severity of distractions increases as it involves more than one category. In an earlier study by D'Souza and Maheshwari [7], a driver distraction survey collected information on the three categories of distraction: visual, physical and cognitive. Around 90% of the distracting activities were perceived by the drivers as caused by Mind/Attention off the Road (cognitive). The activities were sorted by number of drivers and the top five for each category of effects are summarized in Table 3. Around 80% of the top five distracting activities were passenger-related which are caused by cognitive distraction. An Australian study [2] found that distracting activities that contributed most to a crash were conversing with passengers (11.3%), lack of concentration (10.8%) and outside factors (8.9%) [2]. Table 4 shows that cognitive distraction has the highest mean, median and mode values.

Classification of High Risk Distracting Activities

Although subjective approaches are applied for classification of distracting activities [24], this study developed an objective approach using an index. The Distraction Risk Index (DRI) estimates the potential risk associated with each Risk Zone activity. The DRI for the seven Risk Zones I, II, and III activities are shown in Table 5.

Table 3
Top Five Ranking of Distraction Categories as Perceived by Driver.

Activity	Distraction Category	Visual Effects of Distraction	Physical Effects of Distraction	Cognitive Effects of Distraction
Passengers using a mobile phone	Passenger	–		1
Reading (eg Route Sheet)	Operational	1	–	–
Ticket Machine	Technology	2	3	–
Climate Control	Technology	3	4	–
Passengers	Passenger	4	–	3
Disabled Passengers	Passenger	5	5	5
Fatigue/Sickness	Personal	–	1	–
Pedestrians	Infrastructure	–	2	–
Passengers not following etiquette (eating, drinking, smoking, noisy)	Passenger	–	–	5
Passengers trying to talk to driver	Passenger	–		2
General Broadcast	Operational	–	–	4

Table 4
Statistical Comparison of Driver Perception of Distraction.

Parameters	Visual	Physical	Cognitive
Mean	7.21	4.79	22.11
Median	6	5	21
Mode	4	7	21
Std. Dev.	4.84	2.37	6.39
Minimum	1	1	9
Maximum	19	18.11	33
Range	18	10	24

Table 5
Distraction Risk Index.

	Passenger using mobile phone	Passenger talk to driver	Fatigue/sick	Passengers	Ticket machine	Non-etiquette passenger	Climate control
Rating	90	90	90	70	50	90	50
Duration	90	70	50	70	50	50	30
Visual	30	30	30	50	70	30	50
Manual	30	30	90	30	50	30	50
Cognitive	90	90	50	70	50	70	50
Risk index	66%	62%	62%	58%	54%	54%	46%
Risk zone	I	I	II	II	III	III	III

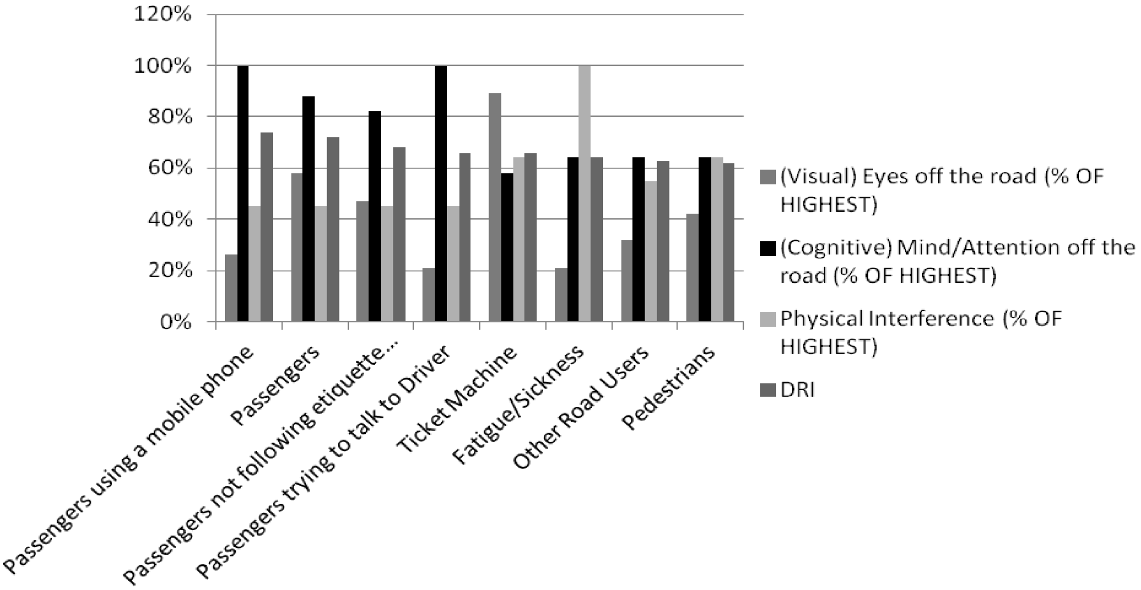

Fig. 1. Comparison of Cognitive with Physical and Visual for High Risk Distracting Activities.

Figure 1 shows the comparison of cognitive distraction with physical and visual distractions for the high risk distracting activities classified in Zones I, II, and III. Cognitive distraction is higher for most passenger-related distracting activities. Ranney [3] also identified conversation with passengers as the most common secondary task compared to eating, smoking, manipulating controls, reaching inside the vehicle, and cell phone use.

Cognitive distraction model results

An analysis of historical bus accident data for the past three years (2008–2011) was conducted at a regional transit agency to identify causes of accidents (Table 6). The monthly accidents are classified as being either *preventable* or *non-preventable*. A more detail analysis of incidents within the agency property and off-property could determine whether it was driver distraction, driver inattention, or day time/weather conditions that played a role in the accident.

Cognitive Distraction Model

Numerous factors interact with one another when a driver is on the road, creating driver distraction. Research has clearly shown that driver distraction is largely a cognitive function and it diverts a driver's attention away from the road, producing a threat to safety. The Cognitive Distraction Model [CDM] shown in Fig. 2 comprises of four processes that contribute to driver distraction and influence driver performance. These four processes are: Driving Tasks, Distraction Activities, Cognitive Workload, and Driver Capability. These four processes interact, and they are influenced by factors such as age, driving experience, location of routes, and gender.

Table 6
Bus Accident Data (2008–2011).

Location of accident	Non-preventable	Driver distraction	Other preventable	Total
Northside	553	105	110	768
Southside	1124	227	318	1669
Total	1677	332	428	2437
% of total accidents	68%	14%	18%	100%

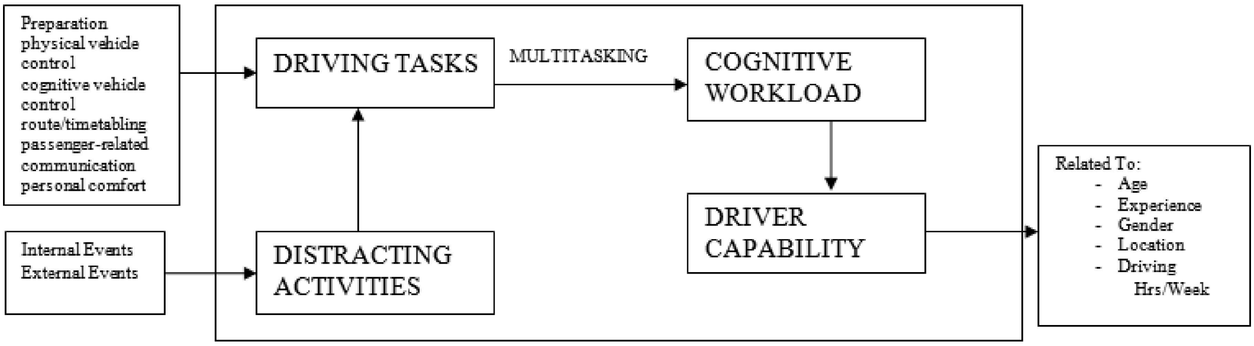

Fig. 2. Cognitive Distraction Model (CDM).

Driving Task

Driving tasks can be defined as everything that is needed to operate the transit vehicle. These driving tasks are divided into primary driving tasks and secondary driving tasks. Common examples of primary driving tasks for a transit driver are steering, using the accelerator, applying the brakes, changing lanes, determining what speed to use, and communicating to other drivers by using the turn signal and turning on the headlights. Salmon et al. [25] has presented a Hierarchical Task Analysis (HTA) which list seven categories of tasks a bus driver needs to perform while driving the bus: preparation tasks, physical vehicle control tasks, cognitive vehicle control tasks, route/timetabling tasks, passenger-related tasks, communication tasks, and personal comfort tasks.

In contract, secondary driving tasks are non-driving activities occurring approximately 30 percent (%) of moving time causing driver distraction [3]. The types of non-driving distractions reported by Wong and Huang [12] include *in-vehicle distraction, external distraction, and the acquisition of information.* Secondary driving tasks conducted internally generally include conversing with passengers, tending to passengers with infants, collecting tickets, making announcements, using a navigation system or other wireless device and managing climate control. The transit drivers are also distracted by external events such as other road users, pedestrians, weather conditions, etc. When transit drivers focus their attention on secondary driving tasks, their attention is diverted from the primary driving tasks causing distractions.

Distracting Activities

Transit drivers are confronted by numerous distracting activities as they go through their daily occupational routine. Some of these distracting activities come from external events to include navigating through road construction and flashing digital road signs indicating which route to take. Other distracting activities relate to internal events including things associated with the driver, such as daydreaming, fatigue or illness, or hunger. Internal events within the transit vehicle also present distractions for the driver, to include conversations with the passengers, passengers using mobile cell phones, and passenger distractions due to conversations with other passengers. The culmination of these events results in cognitive overload. The driver can only focus on one thing at a time. Research has demonstrated that *multitasking is a myth* [8] and that driver's attention can only be directed to one activity at a time. Therefore, even the use of voice-operated and hands-free devices represents distractions that can present a safety hazard to the driver and passengers.

Distracted drivers experience inattention blindness. They are looking out the windshield, but do not process everything in the roadway environment necessary to effectively monitor their surroundings, seek and identify potential hazards, and to respond to unexpected situations The danger of inattention blindness is that when a driver fails to notice events in the driving environment, either at all or too late, it's impossible to execute a safe response such as a steering maneuver or braking to avoid a crash [9].

Cognitive Workload

Cognitive workload refers to the amount of information that a transit driver must process while driving. The brain controls visual, manual and cognitive driving functions as shown in functional magnetic resonance imaging (fMRI) [8]. A Carnegie Mellon University study produced fMRI pictures of the brain during a simulator run shows that cognitive distraction decreased activity by 37 percent in the brain's parietal lobe which controls driving providing a biological reason for driving risks [8]. To complicate the situation, the transit driver must use their cognitive capabilities to not only concentrate on primary and secondary driving tasks, but to focus on routes and abide by agency regulations pertaining to issues like vehicle speed and required amount of time to get from point of departure to the scheduled destination. Dealing with passenger issues adds to the cognitive workload. Research has shown that when talking on a mobile phone, drivers tend to slow down, which demonstrates their distractedness. Cognitive workload varies according to additional factors including amount of traffic on the road, day of the week and time of day (Figs. 3 and 4). The number of accidents gradually rise between Monday and Friday and then decreases.

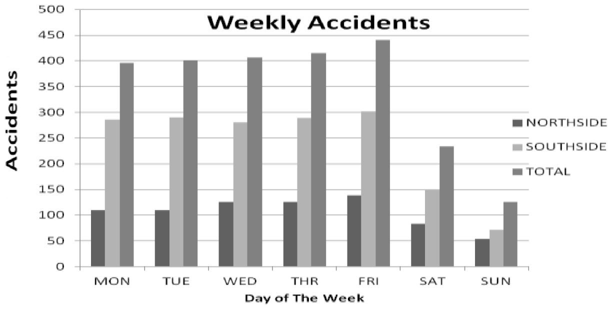

Fig. 3. Accidents on Days of the Week.

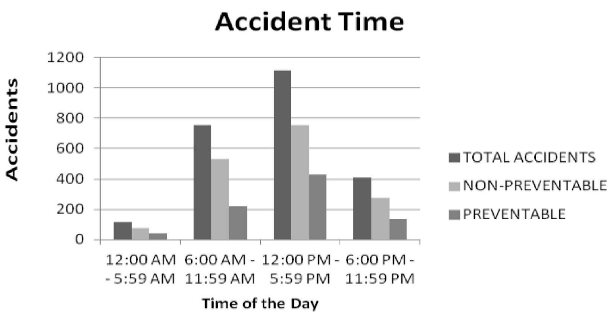

Fig. 4. Accident Time of the Day.

Distracting activities such as carrying on a conversation with a passenger or listening to a passenger's mobile cell phone conversation leads to multitasking while driving. The transit driver attempts to distribute his or her attention to both the secondary driving tasks as well as the primary tasks associated with operating the vehicle. Mental inattention begins to take place, particularly as additional secondary driving tasks are factored in. This mental inattention increases the amount of time that it takes for the driver to fully process information that being taken in and to formulate and act upon decisions made, based on such information. A threshold is reached, particularly as additional tasks are added, due to limited mental capacity, thereby strengthening mental inattention due to being overtaxed by a heavy mental workload. At this point, it becomes impossible to multitask and the mental inattention towards the primary driving tasks produces a major crash risk.

Humans have limited mental load capability which often leads to brain "bottleneck" in which the brain is straining to secure resources for non-driving (distracting) activities which competes with the primary driving tasks. Driving experience plays a role in driving performance (Fig. 5). Experienced drivers perform common driving tasks without thinking (for example slowing down before making a turn) thus thinking that they have the cognitive capability under all driving conditions until an accident shows otherwise. When the brain's limits are stretched and information processing slows down reducing the driver's reaction time, thus increasing the risk of an accident. Figure 5 reveals that novice drivers have a higher accident rate than the more experienced drivers. Since, novice drivers are generally young, it is clear that young, inexperienced drivers are at increased risk to themselves and are also a major hazard for other road users.

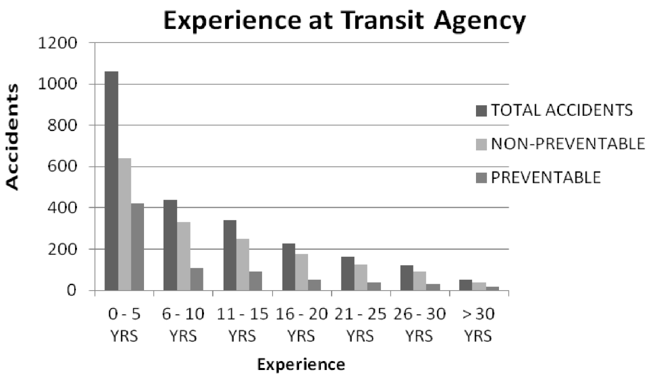

Fig. 5. Impact of Driving Experience.

There are factors that play a mediating role on driver distraction, and performance to include driver capability, number of passengers in the vehicle, and driver's age.

Cognitive distractions exist. For example, research has shown that older drivers tend to have more vehicle accidents when entering intersections [26]. In this study, passengers, passengers talking with driver, and passengers using mobile phone devices were the most prevalent reported cognitive distractions. McEvoy [2] and Ranney [3] have also reported conversation with passengers as the most common form of distraction.

Driver Capability

Driver capability depends to a great extent on the level of multitasking the driver can perform while executing the primary driving tasks and the secondary tasks. The brain must do attention switching", when it deals with multitasking [9]. When a driver is driving and attempts to perform a secondary task such as talking to a passenger, the brain shifts its focus and the driver develop "inattention blindness" [9] which may lead to running a red signal and a crash.

According to National Safety Council [9] multitasking impairs performance since the brain has capacity limits. According to brain researchers, "reaction-time switching costs", is a time the brain takes to switch its attention and focus from one task to another [9]. Hence, driver capability is affected which slows the reaction time to potential hazards supporting the major reason for an accident. Although the switching time is very small, repeatedly switching adds up the time.

Figure 6 shows the location of accidents and the type of accident. The non-preventable accidents are not caused by the bus driver. For example, the bus maybe hit by another vehicle. The preventable accidents could have been avoided (for example the bus hit another vehicle) if the bus driver had exerted more caution. It appears that the number of accidents is dependent on the location (Northside and Southside) and day of the week. The number of accidents in the Southside is more than double that of the Northside.

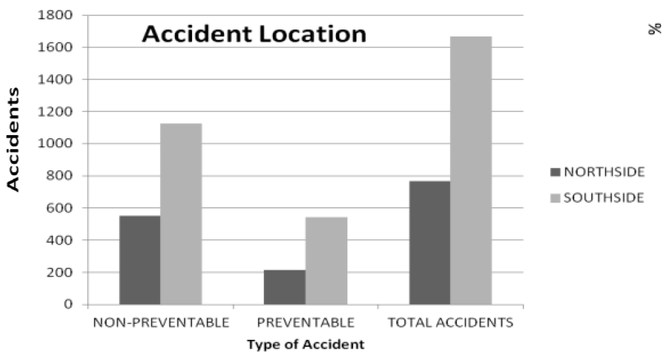

Fig. 6. Location of Accidents.

Some of the preventable accidents have been caused by driver distraction but the proportion is unknown. Researchers have reported that 13.6% of all accidents were caused by distracted driving [2]. The Table 6 has been restructured to reflect the 13.6% distracting activities that caused accudents from 2008–2011:

The factors of the transit bus drivers consisting of demographics and driving pattern data collected through the survey were compared with factors of other studies to determine their applicability and significance to the current study. The results discussed in the following paragraphs are based on the responses of drivers that participated in the survey, observation on selected routes, and discussion with agency staff members.

The average age of the bus driver was 49 years. The Northside drivers' average age was 47 years and the Southside driver was 51 years. There are a higher proportion of female drivers (54%) compared to male drivers (46%). The average age of male drivers was 50 years and female drivers were 49 years of age. Most of the drivers fall in the 46–55 age groups (Fig. 7). Age is a significant factor related to accidents with younger drivers more prone to accidents and distracted driving [1]. According to the NHTSA [1], in 2008 28% of drivers involved in fatal crashes were under 30 years while only 10% drivers in the 40–49 age groups were involved in fatal crashes. In a study of truck-involved rear-end crash. Yan et al. [26] found younger car or truck drivers (<25 years) are less likely to get involved in a truck crashes compared to middle age drivers (26–55 years), but older drivers (>56 years), are more likely to be involved in a crash as compared to a middle age driver.

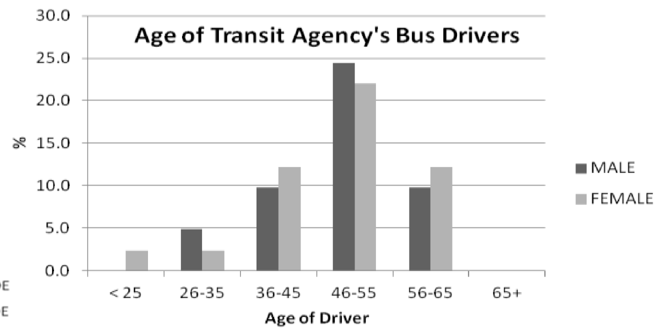

Fig. 7. Age Distribution of Drivers.

A t-test was conducted to determine if the differences in age, experience, and driving hours were significantly different for the Location or Gender. There is a significant difference in driving experience for both locations with drivers on the Southside being more experienced. There is no significant difference in age and driving hours/week between drivers from the Northside or Southside although Southside had slightly older drivers with significantly more driving experience. The drivers reported that they drive a bus for an average of 43 hours per week and that they typically drive the buses mostly during the day (65%) peak and non-peak times and during the night (35%).

Conclusions and recommendations

Developing effective policies and legislation to control cognitive distraction is difficult to implement due to non availability of proper measuring processes [3]. Laws enacted for alcohol consumption and red light running is not as effective for distracted driving since it is more of a societal issue [3].

Policies are needed that limit the distractions that transit driver's experience, including exposure to unnecessary passenger activities on buses. Research is needed to determine the best ways to train drivers to manage and control cognitive distractions in order to avoid reaching the threshold at which mental inattention occurs due to multitasking. This research needs to concentrate on the training of certain populations that tend to have the greatest crash risk. For example, research should be directed towards experienced drivers who may become distracted by secondary activities due to over-confidence in one's driving abilities, or may let their mind wander due to mental or physical fatigue or boredom after driving too many hours in a given week. The need for research also applies to younger drivers who may lack the primary driving skills needed to be able to divert attention to secondary tasks, and older drivers who make take longer to process cognitive information required to drive.

One of the reasons for the high accident rates of inexperienced drivers shown in Fig. 5 are deficits especially in relevant cognitive driving skills [27]. Petzoldt et al. [27] have recommended inexpensive computer based training (CBT) where young inexperienced drivers can experience various forms of cognitive distraction without harming themselves or others.

There was a wide range of distracting activities in the study of the transit agency [7]. This makes communications and outreach programs for the drivers difficult to implement [3].

Distracted driving causes the vehicle to veer outside the lane. In order to circumvent this impact of distraction, researchers have suggested broader shoulders and rumble strips [3]. Fatigue and sickness was noted in the top five distracting rated activity (Table 1). Having rest areas closer apart will allow fatigued/sick drivers to have more frequent stops.

Ranney [3] has proposed *guidelines for Interface Design Vehicular strategies* which focus on internal layout of vehicle systems that could cause distraction such as controls, broadcasting, ticket machine etc. The auto industry in North America and Europe has taken note of such guidelines and are devoting resources *to optimize the interface characteristics associated with in-vehicle technologies* [3].

This is a concept paper on cognitive distraction. The data collected by D'Souza and Maheshwari [7] on the drivers' perception of distraction indicated that cognitive distraction was a major cause. The concepts of cognitive distraction and the modular approach for gaining a better understanding were developed from the works of several researchers [3, 5, 8, 9]. The authors have plans to validate these results using a driving simulator which is planned to be installed on the University Campus.

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