

**EVALUATION OF DRIVER PERFORMANCE WHILE  
MAKING UNPROTECTED INTERSECTION TURN  
UTILIZING NATURALISTIC DATA INTEGRATION METHODS**

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**ABSTRACT**

Within the set of all vehicle crashes that occur annually, intersection-related crashes are over-represented. The research conducted here uses an empirical approach to study driver behavior at intersections, in a naturalistic paradigm. A data-mining algorithm was used to aggregate the data from two different naturalistic databases to obtain instances of unprotected turns at the same intersection. Several dependent variables were analyzed which included visual entropy, mean-duration of glances to locations in the driver's view, gap-acceptance/rejection time. Kinematic dependent variables include peak/average speed, and peak longitudinal and lateral acceleration. Results indicated that visual entropy and peak speed differs amongst drivers of the three age-groups (older, middle-age, teens) in the presence of traffic in the intersecting streams while negotiating a left turn. Although not significant, but approaching significance, were differences in gap acceptance times, with the older driver accepting larger gaps compared to the younger teen drivers. Significant differences were observed for peak speed and average speed during a left turn, with younger drivers exhibiting higher values for both. Overall, this research has resulted in contribution towards two types of engineering application. Firstly, the analyses of traffic levels, gap acceptance, and gap non-acceptance represented exploratory efforts, ones that ventured into new areas of technical content, using newly available naturalistic driving data. Secondly, the findings from this thesis are among the few that can be used to inform the further development, refinement, and testing of technology (and training) solutions intended to assist drivers in making successful turns and avoiding crashes at intersections.

*This work is a tribute to my late grandfather Pramatha. My biggest regret remains that he was not there to see me pursue and succeed in this academic endeavor, which he always wanted to live vicariously through me. He was a true advocate for me and in my heart I will always carry his spirit and the wonderful memories we shared.*

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## 1. Introduction

In 2007, 2.4 million vehicle crashes were intersection-related. This was 40 percent of the total number of reported crashes and thus this over-representation of intersection crashes, relative to the total number of crashes makes driving behavior at intersections a traffic safety issue (FHWA, 2009). Considering that intersections constitute only a small part of our entire roadway system this overrepresentation is of greater concern.

Vehicle crash fatalities are a major cause for fatalities for the overall population, but two driver groups are at an elevated crash risk (i.e., the older driver and the younger driver group). In 2009, intersection fatalities for older drivers were 21 percent of the total fatalities at intersections (NHTSA, 2010). Yet older drivers represent only 12.4 percent of the overall population, so their intersection fatality contribution is nearly twice than their contribution to total population, further Federal Highway Administration (FHWA) estimates the same intersection fatality at 25.5 percent (FHWA, 2009). The population of older drivers has increased over the past decade and projections indicate it is to increase by almost two-fold in the next decade. Such a demographic shift has provided impetus for understanding and creating a transportation environment that aids this age group, especially in negotiating intersection scenarios.

Aging entails a variety of physical and mental changes that can affect and impair driving ability and driving related decision making. These changes can create difficulties for the older driver. But age differences are not restricted to the older end of the lifespan. Young drivers also faces challenges.

Younger teens compared to the older population face a different sort of challenge; they lack experience and have an elevated risk-taking attitude. The teen population (15 -19 years) in the United States is about 7 percent of the total population and the percentage of licensed drivers for the same age group is about 4.9 percent (Census Bureau, 2009) (National Safety Council, 2007). Interestingly, however, the contribution of teens to total vehicle crash fatalities is almost 4 times that of the licensed driver contribution and almost 3 times that of the total population contribution by this age group at 19 percent (NHTSA, 2009) (National Safety Council, 2007).

Younger driver fatalities are also due to co-occurring contributing factors such as alcohol involvement, speeding, not wearing seat belts among others which make places them at a higher crash risk. Inattention is also a major concern and research has shown how the younger drivers are more prone to engage in secondary tasks while driving than other age groups.

Intersection turns comprise of variety of challenges to the driving population. Previous research has shown the importance of visual glances used for gathering driving information and making following driving related decisions. The research will try to understand driver differences using visual glance patterns while making the same unprotected intersection turns.

From a systematic approach, visual glances provide information about the driving environment to the driver, but it is upto the driver to process that information to make the necessary driving relevant decisions. In the case of making an unprotected turn, the driver needs to make the turn while there is through traffic condition flowing across in the neighboring streams of traffic stopping him from making the turn as dictated by their right of way. Hence, all drivers in the aforementioned driving situation are presented with Gaps in flowing traffic, and it is upto them to accept that gap in the flowing traffic and proceed to make the turn. It is this decision of gap-acceptance across drivers and driver groups that this research will explore in better hope to understand the problem.

Further, not all drivers are the same as they vary in experience or age-dependent ability. Crash statistics points out how the older driver age-group and the younger driver age-group are critical driving population due to their significantly elevated crash risk. The proposed research will also attempt to analyze the various kinematic measures associated with driving; more so while making intersection turns and compare them across these diverse driver groups.

Driving is a complex psychomotor task and the most of these visual glancing, decision-making and task execution happens instantaneously. A breakdown of the task i.e. completing an intersection turn will provide us with a better understanding of why intersections are a high crash risk for drivers. In the past decade, most of the research conducted for driving related research has been in a driving simulator. More recently, there has been a shift to a real car, but still the

driving environment has been constrained with the use of a closed test track with simulated driving environment.

This research will utilize a naturalistic approach to driving studies, where driver's personal vehicle was instrumented for longer durations and data collected as they drive around unsupervised in the natural driving environment. This methodology provides researcher to observe drivers true behavior and is not skewed by experimenter bias.

## **1.1 Purpose and Objectives**

The purpose of this research was to assess and understand the importance of driver behavior across different age groups while negotiating different intersection types – and to gain insight into whether the presence of traffic at an intersection interacts with age effects in determining turning behavior at intersections. The study uses an empirically-based naturalistic approach to study driver behavior, where each driver's vehicle is instrumented with a data acquisition system and then returned to its owner to drive out on public roads (as they normally would) for an extended period of time (e.g., up to a year or more). This approach allows observing drivers while they engage in their true driving behavior, rather than in behaviors adopted to try to satisfy experimenters in traditional driving experimentation. This research will provide findings that can lead in the future to the development of technology countermeasures and/or training recommendations and to support drivers as they negotiate turns at intersections.

Before providing a review of the literature, the research questions to be examined in this thesis are introduced next (in a preliminary way), along with the hypotheses to be tested. This upfront presentation of the research questions will serve as a preview of where the research is headed, and foreshadow the development of methods later in the proposal.

## **1.2 Research Questions**

Key questions, which were identified as important ones to be answered with new research on driving behavior at intersections, are framed below. (These emerged from a review of the

literature that is provided in the next section). In brief, previous research work has used controlled experimental studies to examine age-related differences between older and younger drivers at intersections – and has identified differences in visual scanning and other selected measures of behavior. Further, the aspect of making intersection turns, where drivers do not have the right of way but have to decide when to turn into flowing traffic conditions is an even greater concern. This, research will try to explore this particular intersection turn scenario where the drivers have to make unprotected (not having the right-of-way) turns.

Currently limited research exists that has tried to use naturalistic driving data to examine age-related differences during intersection turns. In addition, whether the presence or quantity of other vehicles at an intersection affects visual scanning or other aspects of driver behavior at the intersection has not yet been examined - nor has the issue of whether traffic density interacts with age effects. Finally, gap acceptance judgments (i.e., the acceptance of a time interval by a driver between passage of one vehicle and the arrival of the next vehicle to complete a turn) by age have not been studied in natural driving, nor have their consequences on time to initiate and complete turns been studied. Learning more about these key areas would push the state of understanding forward about drivers negotiating intersections – and it is therefore upon three questions that this thesis will focus:

**Research Question 1: How do drivers regulate their visual glances while making unprotected turns?**

**1.2.1.1 Hypothesis 1**

*The presence of traffic at the intersection increases the amount of visual scanning that driver's exhibit prior to initiation of their turns for all age groups.*

**1.2.1.2 Hypothesis 2**

*Older drivers will have longer fixated glance durations in comparison to the teen driver*

**Research Question 2: How do drivers manipulate their gap acceptance levels across age groups?**

**1.2.1.3 Hypothesis 3**

*The younger driver group will accept lesser gaps in traffic to make unprotected turns when compared to other age groups*

**1.2.1.4 Hypothesis 4**

*Older driver group need significantly larger gaps to make unprotected turns and will reject smaller gaps available compared to other drivers.*

**Research Question 3: Are there age-related differences in driving kinematics while making turns at the intersections?**

**1.2.1.5 Hypothesis 5**

*The Younger Driver group will exhibit higher kinematic values (lateral & longitudinal accelerations, mean speed etc.) in their initiation, execution, and completion of their turns compared to the other driver groups*

**1.2.1.6 Hypothesis 6**

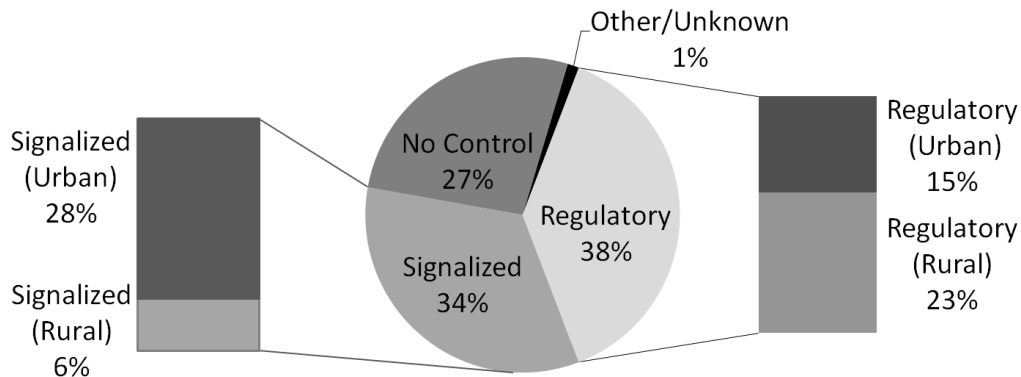
*Older driver group will exhibit more cautious and lower kinematic values in their initiation, execution, and completion of their turns (e.g., taking more time to be certain of decisions) – and this tendency toward slow responding will be amplified in the presence of other traffic.*

## 2. Literature Review

### 2.1 Intersections - A Crash Risk

Intersection crashes are overrepresented amongst total number of crashes, relative to their overall contribution to the transportation system. In 2007, there were 2.4 million vehicle intersection related crashes and their contribution to total number of reported crashes were 40 percent (FHWA, 2009). Further, using the General Estimates System (GES) the National Center for Statistics and Analysis (NCSA) found how 21 % of total fatalities were at the intersection (TRB, 2003)

Figure 1 illustrates the contribution of each intersection type to the total fatalities adapted from the Federal Highway Administration report on the Intersection Safety Problem (FHWA, 2009). From figure 1, the total fatality seems to be equally distributed between intersections controlled by signals (34%) and stop, yield and other regulatory signals (38%) (FHWA, 2009).



**Figure 1:** Fatalities at Intersection by Traffic Control Device in 2007

*Source:* Adapted from FHWA. (2009). *The National Intersection Safety Problem. Intersection Safety Issue Briefs*, U.S. Department of Transportation, Federal Highway Administration, Washington D.C. available in Public Domain ,

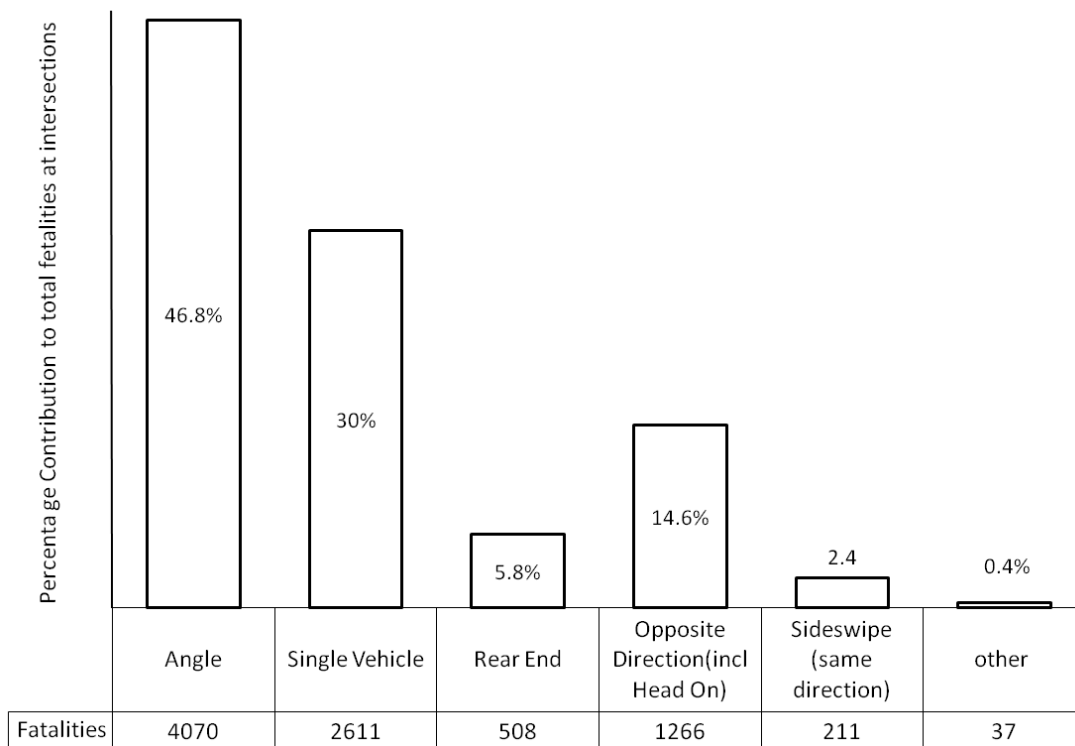
*Used under FAIRUSE guidelines(2011)*

For regulatory controlled intersections the fatalities seems slightly weighed towards rural intersections but this gap is not as wide as in the case of signalized intersection where almost a majority of the fatalities were in the urban areas (figure 1).



Intersections are a roadway feature where driver age-related differences are highlighted more than any other roadway feature. A controlled study of all driver age groups showed the difficulty of making right & left turns at intersections and responding to traffic signals (Brainin, 1980). On further analysis, the study revealed that the older driver turn problem was due to a lack of caution, poor positioning during the turn, result of failing to signal, and their difficulty in coming to a stop at an intersection.

Figure 2, depicts the total fatality distribution by crash type, and angular crashes have the highest contribution. Together with crashes from opposite direction, we can see how most fatal crashes at the intersection occur due to multiple vehicle crashes with the two vehicles coming together from different directional stream of traffic.



**Figure 2:** Fatalities at intersection by Crash Type in 2007,

*Source:* Graph plotted using Data from FHWA. (2009). *The National Intersection Safety Problem. Intersection Safety Issue Briefs*, U.S. Department of Transportation, Federal Highway Administration, Washington D.C. available in Public Domain. Used under FAIRUSE guidelines(2011)

Other studies conducted state wide in the states of California, Maine, Texas, Michigan and Connecticut yielded similar results and found that for older driver, intersection crashes result from a failure to yield the right-of-way (Aizenberg & McKenzie, 1997) (Finison & Dubrow, 2002) (Griffin, 2004) (Kostyniuk, Eby, & Miller, 2003) (Zuckier, Jacobs, & Thibeault, 1999). Hauer (1998) revealed the extent of the relationship between the incidents at intersections and their relationship with age. The study found that for the 65 and above age group over 60% of injury, related incidents occur at intersection, and of the total fatalities almost 40% fatalities result at intersection for 65 and above adults and around half of the fatalities for 80 and above adults occur at intersections.

Overall, intersections are a complex traffic system where different streams of traffic come together, and probably require drivers of all age groups to make key decisions. The older driver population is the driver group which is at a higher crash risk at the intersection than any other age group, and together with the teen drivers constitute as driver groups with the highest crash risk. The following sections will specifically discuss in further details about these two critical driver groups (Older and Younger Drivers) with respect to their intersection driving behavior.

## **2.2 Driver Age Group at Risk**

### **2.2.1 Older Drivers**

#### **2.2.1.1 Rapid increase in Older Population**

The population of older drivers has increased over the past decade and such a demographic shift has increased the importance of understanding and creating a transportation environment that aids this age group. More so the decline in fertility and mortality has made population aging a prominent demographic feature. According to a report by the Administration on Aging, there has been an increase of 13 percent (4.5 million) of the older population (65+) from 1998 to 2008 (A Profile of Older Americans:2009). The study also highlighted that the number of Americans aged 45-64, who will reach 65 over the next two decades – increased by 31 percent during this decade. This said it is not only the aging of the population alone but its combination with an increased life expectancy of an additional 18.6 years, which creates this larger elderly population.

A child born in 2007 would expect to live about 30 years longer than a child born in 1990 did. The U.S Census Bureau in their 2005 brief projected that there is going to be a substantial increase in the number of older people that will occur during the 2010 to 2030 period, after the first baby boomers turn 65 in 2011. The older population in 2030 is projected to be twice as large as in 2000 i.e. growing from 35 million to 72 million (He, Sengupta, Velkoff, & DeBarros, 2005).

The Top-Three fastest growing age groups according to the 2000 Census were the 50-54 age group (55% increase), and the 45-49 age group (45% increase, and the 90-94% (45% increase) between 1990-2000 (Meyer, 2001). This alone sums up the two substantial changes in the aging demographics, firstly a rapid increase in the middle age population who are on the cusp of old age come 2010 and secondly the increase in life expectancy for the older population, which is only going to increase as time progresses. In other words there will soon be more number of older people, and they will live longer than any other time historically. This overrepresentation of the older population will make their driving behavior important for maintaining and improving roadway safety.

#### **2.2.1.2 Fatalities and Injuries**

Over the past decade where the overall number of licensed drivers has increased from 183 million in 1997, to 206 million in 2007 i.e., an increase of 13 percent, the older driver licensed population increased by 19 percent (NHTSA, 2008). In 2008, 183,000 older individuals were injured in traffic crashes, accounting for 8 percent of all the people injured in traffic crashes during the year (NHTSA, 2008).

Though the number of licensed older drivers has increased, the number of overall fatalities has decreased for the 65 and older population by 19 percent (FARS Data Table). A similar news release by the Insurance Institute for Highway Safety (IIHS) reported the number of crash deaths among drivers 70 and older fell 21 percent during the period, even when the population of drivers 70+ rose 10 percent during the period of 1997-2006 (IIHS, 2008). These reductions, while encouraging from a safety-point-of-view – have various interpretations. One of them being that more older drivers now are aware of their limitations and self-regulate by refraining from driving in risky conditions (e.g., at night, or in heavy traffic) – or by refraining from driving

altogether. In addition, it is important to note that the older drivers as a group are involved in different types of crashes than younger teen drivers. When compared to younger drivers, drivers age 65 and older, and particularly drivers age 75 and older, have more vehicle-to-vehicle collisions, more intersection crashes, and fewer alcohol-involved crashes (Dulisse, 1997) (Hauer, 1988)

Of key importance for this research is that a major concern for older drivers is intersections. In 2009, intersection fatalities for older drivers were 21 percent of the total fatalities at intersections (NHTSA, 2010). Older driver's contribution to the overall population is 12.4 percent, but their intersection fatality contribution is twice that at 25.5 percent (FHWA, 2009).

A statewide survey of 664 senior drivers revealed that near half the respondents had placed importance on features like lighting at intersections, pavement markings at intersections, number of left turn lanes, width of travel lanes, size of traffic signals, concrete lane guides, need for more time to react (Benekohal, Resende, Shim, Michaels, & Weeks, 1992). They also indicated that older drivers found turning left to be a complex driving task. A corollary to the findings by Benekohal et.al (1992), was the study conducted by Staplin et.al (1997) which found that the most challenging aspect of intersection negotiation for the older driver age group is performing left turns during the permitted Yield-Signal (Steady circular green indication) condition. A focus group response from 81 older drivers also reported problems like difficulty in turning their heads at skewed angles, smoothly performing turning movements at tight corners (Staplin, Harkey, Lococo, & Tarawneh, 1997).

Overall, crash numbers should not be used in isolation but should instead be analyzed in relative terms using (for instance) Vehicle Miles Travelled (VMT), number of licensed drivers, and considering their physical and cognitive fragility, and the risk they pose to other road users. The following section becomes important for understanding the fatalities and injury numbers and associating these numbers with the correct exposure rate to understand the crash risk, which the older population represents and also to understand the subset of crashes that occur at intersections.

### **2.2.1.3 Exposure Measure: The Real Numbers**

In the past decade, the overall number of older driver fatalities has decreased, leading many observers to conclude that the older driver group is a safer group and that through self-regulation they have substantially reduced their crash risk. Although it is important in any risk assessment task to represent the exposure relative to the task involved. Here we report the fatalities relative to an exposure measure like miles travelled by the total population and by licensed drivers. Evans (2000) analyzed fatality rates per licensed driver, per mile driven, along with the age and sex of the driver and reported that an 80 year old male driver has a 121% higher fatality rate per licensed driver and a 662 percent higher fatality rate per mile driven when compared with a 40 year old male.

Another study for crashes involving two vehicles revealed that drivers 75 years or more had greater proportion of deaths than the proportion of crashes (Dellinger, Kresnow, White, & Sehgal, 2004). A finding which was backed by Li, Braver, & Chen (2003) who used a nationwide crash and injury data between 1993-1997 from the Fatality Analysis Reporting System(FARS), General Estimates System (GES), and the Nationwide Personal Transportation System(NPTS). Other studies have found drivers who were younger than 20 and those 75 or older had a higher driver fatality rate per Vehicle Mile Travelled (VMT) and also a higher accident rate per VMT for 75+, comparable to inexperienced drivers (Bryer, 2000). This points to the older driver frailty in crash incidents in comparison to other driver groups.

Dellinger et.al. (2004), also estimated that drivers aged between 16 and 19 and those above 60 years of age drove fewer miles, considering their share to the overall licensed driver population. The study also reported how drivers aged 75 to 84 represented 4.7 % of the licensed drivers but drove only 2.0% of the total miles. This was in stark contrast to the drivers between ages 20-34 and 35-59, who each had 31.4% and 43% licensed drivers of the population but drove 35.5% and 49% of the total miles. Hence, the middle age group drove a higher proportion of miles compared to their contribution to the licensed driver population when compared to the older driver group, especially the driver group between 75-84 which had driven less than half the number of licensed drivers.

Thus, crash data research supports the claim of older drivers being overly involved in crashes, especially when distance travelled is used as the exposure measure. In addition literature exists which states that a direct correlation between an elevated crash risk and mileage might not be present (confirming that fewer miles travelled could be associated with higher crash risk). Langford, Methorst, & Hakamies-Blomqvist (2006) found that the relationship between annual mileage and crash risk is not a linear function, of higher crash risk with increasing mileage but one in which there exists a cut-off of miles travelled. The study concluded that older drivers travelling less than 3000 km/year gave an indication of elevated crash risk. Even though higher exposure rates to fatal crashes for older drivers is established, it is important to understand that driver mileage regulation alone is not sufficient to deal with this problem. This section iterates how this whole system needs to be viewed and tackled with a multi layer approach and that the exposure rates highlights how the older driver population is still at higher risk then sometimes assumed by observers.

#### **2.2.1.4 Risk to Self and Other Road Users**

In this section, we include the aspect of how older drivers impose a higher risk to other people who are sharing the transportation space with them. A way to find out the risk older drivers impose to others is by looking at the number of target driver (i.e. driver causing crash) deaths and separating those from passenger fatalities, occupants of other vehicle fatalities, non-motorists fatalities.

Braver & Trempe (2004) utilizing crash data, travel estimates and insurance data to reveal the impact of older drivers to other passengers and road users. They reported how driver of age 75 and older had higher fatality rate and the rate of crashes resulting in an injury to occupants of other vehicles was somewhat higher when compared to the drivers between the ages 30 and 59. An analysis for crash data between 1999-2003 for those aged 16 and 17, 25 percent were killed outside of the target driver's vehicle, for age group of 30-39 year olds, 33% lie outside the target vehicle, and for the the 75+ age group the percent outside is 17 % which drops to a low of 10% for the 85+ age group (Tefft, 2008). The finding in the Braver & Trempe (2004) study supports the finding from, Dellinger et.al (2004), Li et.al (2003) that older drivers pose more risk to their passengers occupants of other vehicles, and non-motorists.

Table 1, shows the relative risk calculation for the older age group while encountering intersection scenarios. The data reveals that relative risk increases with increase in age for almost all intersection scenarios. Further, older drivers were 2.26 times more at risk for multiple vehicle involvements at intersections compared with 1.29 times more at risk in all other situations (Preusser, Williams, Ferguson, Ulmer, & Weinstein,1998). The study also calculated how drivers aged 85 and above were 10.62 times more at risk for multiple vehicle crashes and that the relative crash risk was particularly high for older drivers at uncontrolled and stop sign controlled intersections.

**Table 1:** Relative Risk (RR) in Ran Traffic Control Cases (FARS 1994-1995). All relative risks are calculated respective to drivers aged 40 -49. All Confidence interval using 95% confidence did not include 1.00 RR except those in bracket.

*Source: Preusser, D., Williams, A., Ferguson, S., Ulmer, R., & Weinstein, H. (1998). Fatal crash risk for older drivers at intersections. Accident Analysis and Prevention , 30 (2), 151-159. Used under FAIRUSE guidelines(2011)*

	Driver age				
	65–69	70–74	75–79	80–84	85–up
All intersection	2.16	5.01	15.50	17.74	33.71
At traffic light	(0.91)	2.92	7.58	14.58	11.93
At stop sign	(2.41)	5.48	11.96	23.27	61.97
No traffic control	9.00	10.50	126.00	24.00	53.40
Going straight	(0.73)	3.50	12.14	13.21	26.72
Turning left	(0.89)	(1.45)	(1.91)	(2.45)	4.38

Dellinger et.al (2004) found out in a comparison of emergency department transfer that the older driver group above 75 along with the younger teen drivers pose the highest transfer rate (per 100 million miles travelled) as shown in Table 2. This was a stark contrast as the older driver transfer rate contribution to the overall transfer rate was the lowest and was five times lower than the younger teen driver group. Although using the exposure rate of per 100 million miles travelled their transfer rate was significantly higher.

**Table 2:** Emergency department transfer of others in two-vehicle crashes by drivers age, Wisconsin, 1992-1994,

*Source: Dellinger, A., Kresnow, M., White, D., & Sehgal, M. (2004). Risk to self versus risk to others: How do older drivers compare to others on the road? American Journal of preventive medicine , 26 (3), 217-221.*

*Used under FAIRUSE guidelines(2011)*

	Driver age						Total
	16-19	20-34	35-59	60-74	75-84	≥85	
Transfers (%) <sup>b</sup>	5,737.5 (15.5)	14,312 (38.6)	12,313.5 (33.2)	3,209 (8.6)	1,282.5 (3.5)	215 (0.6)	37,069.5 (100.0)
Transfers by driver age <sup>c</sup>	1434.4	954.1	492.5	213.9	128.3	14.3	
Transfers/100 million miles driven <sup>d</sup>	45.64	10.33	6.44	8.09	16.34	25.29	
Excess transfers relative to drivers aged 35 to 59	4927.4	5,390.9	referent	654.2	777.1	160.2	

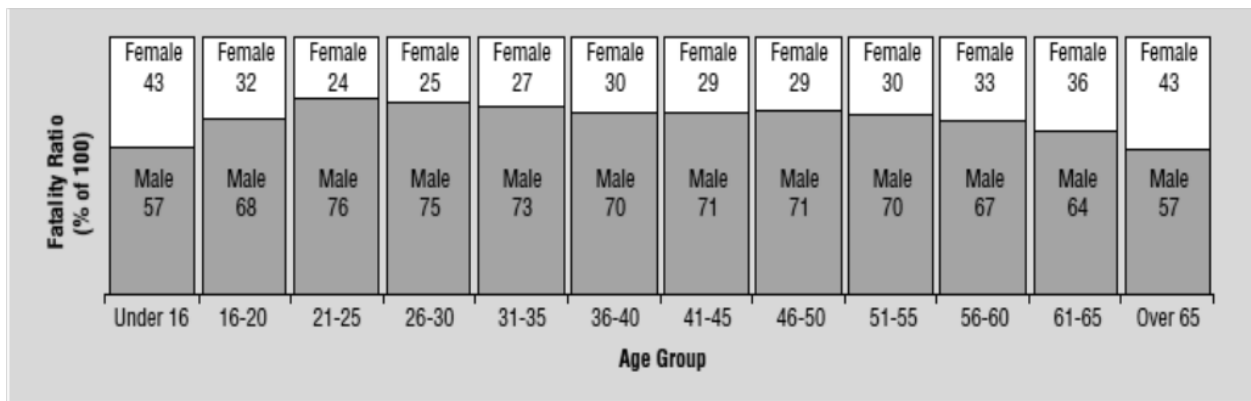
Overall the research by Dellinger et.al (2004) found out how the older drivers were a larger burden to themselves than to others. Dulisse (1997) found support for this and reported that older driver involvement increased the risk of fatality and hospitalization for every mile travelled for crashes involving two-vehicles.

### 2.2.1.5 Gender Differences – Older Drivers

The overall sex ratio, described as the number of males per 100 females, in 2000 was 96 for the total population, but is only 70 for people 65 and over (Gist & Hetzel, 2004). The overall trend for the sex ratio steadily drops with age from 82 for the 65-74 age groups to 41 for the 85 and over age group.

Li et.al (2003) analyzed data from national sources to determine the driver fatality rates per unit travelled, and they were both higher for the youngest (16-19) and the oldest (65+) age groups. The fatality rates were at the lowest during ages 30-59, started rising by ages 65-69, and then sharply after age 74 for both male and female drivers.





Data Source: FARS 1996-2005 (Final), 2006 (ARF)

**Figure 3:** Distribution of Total Crash Fatalities by Sex and Age group from 1996-2005,

*Source: Chang, D. (2008). Comparison of Crash Fatalities by Sex and Age Group. Washington, D. C.: NHTSA's National Center for Statistics and Analysis. Used under FAIRUSE guidelines(2011)*

The study also reported that death rates for men were significantly elevated when they were younger than 30 or above the ages of 80 when compared to women. In addition, fatality rates were 13 times higher for 80 or older, when compared with driver ages 30-59 for both men and woman. The distribution of total crash fatalities by sex and age group is an inverted U-shape curve (Figure 3), where overall contribution by males to total fatalities is higher than for females across all ages. In addition, the number of male fatalities is highest in the middle age group region but is reduced at either ends of the distribution i.e., below the age group of 20 and above ages 65.

## 2.2.2 Teen Drivers

### 2.2.2.1 Teen Fatalities and Injuries

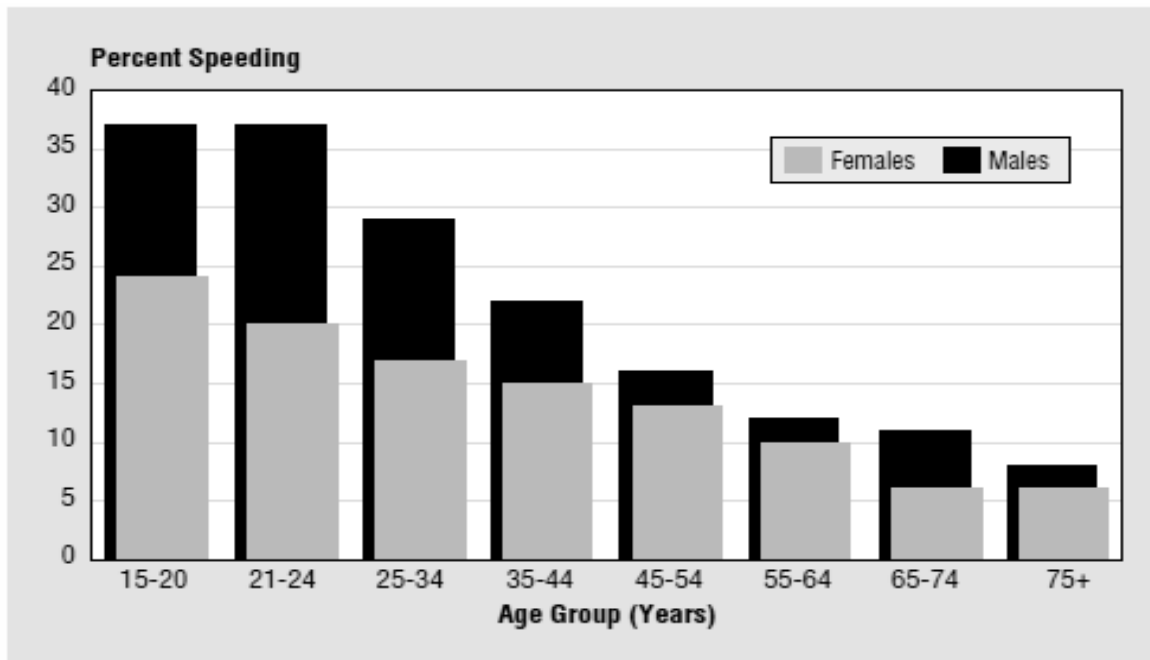
The teen population (15 -19years) in the United States is about 7 percent of the total population and the percentage of licensed drivers for the same age group is about 4.9 percent (Census Bureau, 2009) (National Safety Council, 2007). Whereas their contribution to total vehicle crash fatalities is almost 4 times of the licensed driver contribution and almost 3 times of the total population contribution by this age group at 19 percent (NHTSA, 2009) (National Safety Council, 2007).

The exposure numbers for teens are even worse, for the drivers between the ages of 16-20 years, in 2007 there were 52.8 fatal crashes per 100,000 licensed drivers involved in fatal crashes (NHTSA, 2009). Interestingly, the overall driver involvement was only 27.1 fatal crashes per 100,000 licensed drivers. In addition, those aged between 16-19 years had a crash involvement of almost 32 crashes per 100 million-vehicle miles travelled, higher than the crash number if all ages between 20-79 years old were compared. (Shope & Bingham, 2008)

A even more concerning number is the contribution of vehicle crash fatalities to overall fatalities for the teen age group. From 1998, even though the total number of fatalities for the drivers between the age-group 15- 20 has dropped from 3431 to 3174 in 2007, the contribution of fatalities in crashes to the overall fatality rate has increased from 39% to 41% (NHTSA, 2009). As previously noted by Dellinger et.al (2004) the drivers aged between 16 and 19 drove fewer miles given their proportion of licensed drivers.

#### **2.2.2.2 Driving distraction and other factors**

When compared to other age groups the young age group which includes teens are a more distracted age group and have a tendency to underestimate dangerous situations or not able to recognize hazardous situations. As new infotainment technology entered 21<sup>st</sup> century lifestyle, teen age group are the most adoptive of these newer technologies. A survey of technology use found that 87% of U.S teens aged 12-17 use the internet, whereas by contrast only 66% of adults use the internet (Lenhart, Madden, & Hitlin, 2005). The study also found the high usage of cell phones by teens, of those aged between 15 and 17, 75% of drivers have cellular phones when compared to only 47% of non-drivers in that age group. Secondary task involvement causes this relatively inexperienced group of drivers to have potentially elevated crash risk. The following sections would discuss the potential effect of teenage inexperience in much more detail.



**Figure 4:** Percentage of drivers speeding in fatal crashes by age and sex

*Source: NHTSA. (2008). Traffic Safety Facts, U.S. Department of Transportation. Washington D.C. National Highway Traffic Safety Administration. Used under FAIRUSE guidelines(2011)*

Amongst other factors, teens are more likely than older drivers to speed and allow shorter headways, almost 32% of all fatal crashes occur due to speeding for drivers between the ages of 15 and 20, which is the highest amongst all age-groups (NHTSA, 2009). Males are overrepresented amongst teens for the fatal crashes involving speeding, as shown in Figure 4.

Alcohol involvement is also a major concern for teenage drivers, 31% of drivers between 15 to 20 years old died and had blood alcohol concentrations (BAC) of 0.01 grams/deciliter (g/dL) or greater, and 26% of young drivers had BACs of 0.08 g/dL or greater (NHTSA, 2009). What compounds the problem of elevated BAC level is young teen driver's not wearing seat belt. It was estimated that three out of every four teen drivers did not wear seat belt after drinking and driving (CDC, 2010).

### **2.2.2.3 Inexperience and Teen driver training**

The previous section listed some of the factors that contribute to teenage crashes and the factors contributing to teenager's high propensity for crashes. The cause for many of these problems stems from teen driver inexperience. Driver death rates per 10 million trips increased with the number of passengers for drivers aged 16 or 17years old, with that subsequently increasing with

age and experience (Chen, L. et al., 2000). The research tabulated that the trip-based driver death rate for 16 and 17 year olds was 5.61 and 4.52 for three or more passengers, which was a three-fold increase when there were no passengers present. This number in comparison for driver age-group of 30-59 dropped to less than 1 death per trip irrelevant of the number of passengers.

The Graduated Driver Licensure (GDL) program helps the new teen driver better cope with the problems they face in driving-related tasks and train them to make better decisions. The GDL typically consisting of three stages: first the learner's permit stage in which teen drivers may only drive with a fully licensed adult in the vehicle, second stage a provisional or intermediate license stage, in which novice teen drivers may drive unsupervised, but with restrictions and third and finally full licensing (NHTSA, 2009) (IIHS, 2010).

Results of the GDL have been positive with other research indicating that laws rated good are associated with 30 percent lower fatality rates per population for 15-17 year olds (McCartt, Teoh, Fields, Braitman, & Hellinga, 2010). The study revealed how graduated licensing laws that include strong nighttime and passenger restrictions, and laws that delay the learner's permit age and licensing age are associated with lower teenage fatal crash rates. Further, states that adopt such laws are expected to achieve substantial reductions in crash deaths.

Finally, this research will explore conditions that could (in the future) have implications for recommendations regarding negotiation of intersections and how it could be a part of a teen driver licensing/training program or a driver evaluation tool.

#### **2.2.2.4 Parental influence on teen driving**

Teens look upon their parents as role model, Martin et.al. (2000) found out in a study that role models have a statistically significant influence on adolescents between the age of 13 and 18, also the study revealed how fathers and mothers were the top two consisting of other external role models (Martin & Bush, 2000).

Parents that are high in strictness, supervision, but also high in acceptance and/or involvement, which includes being affectionate and accepting, providing comfort and support, and being

involved in their children's academic and social development, have their children exercise autonomy and self-reliance within structured standards and limits (Beck, Hartos, & Simons-Morton, 2002). Beck et.al (2002) also found how parenting practices of setting instructions or limits on behavior could restrict risky driving behavior among teens.

Although current research that links parenting practices with teen driving risk is limited to cross sectional survey, Mayhew et.al (2003) showed how the crash rates of teen drivers in the first 24 months of licensure reduced three-folds under the supervision of an adult per 10,000 drivers. It is thus important to know how parental driving influences their children. A study using data from the North Carolina driver history file to match the crash and violation records of young drivers between the ages of 18 and 21 with those of the parents was done to examine this relation (Ferguson, Williams, Chapline, Reinfurt, & Leonardis, 2001). The study found that children whose parents had three or more crashes on their record were 22 % more likely to have had at least one crash compared to those with children whose parents had none and 38% for parents with violations. Ferguson et.al (2001) concluded how children's driving record in their first few years of licensure is dependent to the driving record of their parents.

This research puts the parent-teen driving relationship into light as the teen driving study from which the data is extracted comprised of driving data for teens and their parents. The intended driver age-groups investigated in this research comprises of the older driver, the middle-age driver and the younger teen driver. The middle-age driver in this research will be parents of teen drivers who were the subject of primary importance for the teen driver study. The literature findings suggest that there exists a co-relation between these newly licensed teen drivers and their parents in terms of their driving behavior. Thereby, all familial relationships are avoided by choosing either the teen driver or their parents as drivers, not both. This is further discussed in the Methods section.

#### **2.2.2.5 Gender Differences – Teen drivers**

Vehicle crash fatalities are higher for males than females across all age groups, but males between the ages of 16 and 20 had the highest fatality rates, whereas females under the age of 16 had the lowest fatality rate (NHTSA, 2009). The fatality rates are higher for both males and females for the 15-19 age-group, and how this divide between males and females for the young age group has reduced over the past 2 decades (Shope & Bingham, 2008).

A significant problem while studying gender differences amongst teen drivers is the peer aspect and passenger gender that also influences risk-taking ability. Apart from having elevated crash rates for males, male and female teenage drivers allow shorter headways in the presence of a male teenage passenger, while the presence of a female teenage passenger resulted in longer headways for male teenage drivers (Simons-Morton, Lerner, & Singer, 2005). Simons-Morton et.al (2005) also found that the rate of high risk driving i.e. travelling at a speed of 15 mph over the speed limit and/or headway of less than 1 sec, for the teen male driver/male passenger condition was two times more than general traffic condition.

The above results were in accordance with another observational study by McKenna et.al. (1998) where they found that relative to young drivers with no passengers, situations when a male passenger was present led to greater mean speed for both male and female drivers. The gap distance was also less for both male and female drivers in the presence of a male driver, and greater gap distance in the presence of a young female driver for both males and females (McKenna, Waylen, & Burkes, 1998).

Overall teen drivers are at crash risk as much as older drivers, and it is important to understand the various driving characteristics exhibited by drivers in general which make the task of negotiating an intersection all the more difficult.

## **2.3 Problem Breakdown and Key Areas**

### **2.3.1 Cognitive and Physical limitation for Older drivers**

Driving is a complicated psychomotor task that requires simultaneous processing of information and co-ordination of multiple simultaneous control activities. An analysis using multiple national data systems also explained how fragility and crash-over involvement contributed to the excess death rates among older drivers- and how of these, it was fragility, which was of over-riding importance (Li, Braver, & Chen, 2003).

There is literature, which suggests that the increase in age is associated with a decrease in the speed with which many information-processing operations are executed, and how such reduction in speed leads to impairments in cognitive functioning (Salthouse, 1996). The physical limitations amongst older driver are a major concern and how their psychomotor co-ordination is significantly compromised with age. A study of older and younger group of people on their range of motion movements like flexion, lateral bending and axial twisting of the lumbar spine using electromyographic recordings found that the older group were slower moving, and reduced range of motion in full flexion and lateral bend (McGill, Yingling, & Peach, 1999).

The driving environment has a lot of dynamically changing information and drivers need to quickly assess the situation and make compensatory decisions to navigate from potential hazards. The slowing of cognitive and motor process which would impair such critical driving decision-making, and research has shown that reductions in the speed of information processing as a fundamental contributor age-related memory loss (Luszcz & Bryan, 1999).

There is also a slowing amongst older adults with respect to the use of executive control. Executive control refers to a subset of processes required for selection, scheduling, coordination, and monitoring of processes that are responsible for perception, memory and action (Meyer & Kieras, 1997). A study for 53 physically active older individuals and younger individuals observing neuroelectric indices for action monitoring in a task-switching paradigm found that the older adult exhibit slowing in reaction time and task involving executive control (Themanson,

Hillman, & Curtin, 2006). Other studies have supported how age has an effect on slowing on cognitive, perceptual and motor processing (Jastrzembski & Charness, 2007).

Rosomer & Fisher (2009) found that through a combination of simulator and field-drives that for the three driver age groups (young, middle, old) there is a correlation between cognitive and physical decline. The study using secondary look as a surrogate for higher level of situational awareness found that cognitive status was a significant predictor of side-to-side glances and not physical condition (Rosomer & Fisher, 2009).

These potential problems which slows down the motor and cognitive processes for the older driver becomes critical when they deal with intersection scenarios to which they are crash prone. The efforts made in this research will further highlight the problems faced by this age-group, facilitating in countermeasures which will help in reducing these older driver fatalities.

### **2.3.2 Driving Performance**

As discussed in the previous section, cognitive and physical decline makes older driver have elevated crash risk. The perception-reaction time (PRT) to make decisions is a critical aspect of driving performance, and subsequent brake and accelerator responses are significantly responsible performance measures amongst the elderly (Staplin & Fisk, 1991).

A study using Event Data Recorders (EDR) capturing 5 seconds of pre-crash data showed that older drivers are late in applying the brakes prior to rear end collisions (Gabler & Hinch, 2009). They found that teen drivers on an average apply brakes 2.2 seconds prior to crash, compared to older drivers who apply brakes 1 second prior to crash. The average brake time application and the average pre-crash deceleration in G's, where again older drivers had lower g values depicting that not only were they late but also soft in their brake application.

Another study found that older drivers ran the yellow light more often when compared to younger drivers (Edwards, Creaser, Caird, Lamsdale, & Chisholm, 2003). The study tabulated the perception reaction time (PRT) for 4 critical events: Pedestrian – sudden appearance of a pedestrian during a right turn, Yellow light- a dilemma zone last second yellow light, a Dynamic



Flicker—an unexpected appearance of a pedestrian using a grey mask to induce change blindness, and Vehicle Incursion- a vehicle violating a red light while the participant has a green light. Table 3, gives the PRT values for the 4 events for both age groups and it can be seen that all PRT values were lower for the younger age-group when compared to the older age-group for all the events that the study tested.

**Table 3:** PRT means and standard deviation (in seconds) for each event type and age group,

*Source: Edwards, C., Creaser, J., Caird, J., Lamsdale, A., & Chisholm, S. (2003). Older and younger driver performance at complex intersections: Implications for using perception-response time and driving simulation. Proceedings of the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, (pp. 33-38). Washington D.C. Used under FAIRUSE guidelines(2011)*

Event Type	Age Group	
	Perception Reaction Time PRT (sec) (SD)	
	19 to 23	65 to 83
Pedestrian	0.97	1.44
Yellow Light	0.76	1.26
Dynamic Flicker	0.62	1.4
Vehicle Incursion	1.14	1.5

Overall, the older drivers take a longer time to perceive dangerous situations in a driving environment and thereby need longer time to take the necessary actions. Bao & Boyle (2008) found how younger drivers are better in avoiding imminent collisions and on the contrary older drivers who brake late to a stop sign. As intersection design specifications for older drivers using PRT as a measure often use very simple situations and they need to take into consideration the demands of a visually complex system which the following sections would address.

### **2.3.3 Visual Attention and Scanning**

The two critical age groups i.e. the young teen driver group and the older driver group, both dealing with different type of visual driving related problems. The most critical component of driving is the capturing of driving related information and processing it to make safer driving decisions, Robinson et.al (1972) discussed how 90% of driving information is captured through the eye (Robinson, Erickson, Thurston, & Clark, 1972). Thereby it is imperative that drivers of all age group are visually attentive and keep their eyes on the road, more specifically the teen drivers.

As discussed in previous sections teens are distracted while driving due to non-driving related tasks that lead to impaired judgment. The result of engaging in secondary tasks while driving for these relatively inexperienced younger drivers is disastrous. Olsen et.al (2009), conducted a closed test track study that found how teens were more willing to engage in secondary tasks and were less likely to suspend a task while entering an intersection as opposed to adults . The teens exhibited higher confidence in their ability to drive while carrying out a secondary task and had fewer glances to mirrors than adults while engaged in the secondary task.

Taking eyes off road is a definite crash risk and a study by the Virginia Tech Transportation Institute (VTTI) found that texting while driving increases crash risk by 23 times compared to just driving (VTTI, 2009). The 100-Car naturalistic study also conducted by the Virginia Tech Transportation Institute (VTTI) also supported the finding of how teens are four times more likely to be involved in a crash while performing complex secondary tasks like text messaging (Dingus, et al., 2006).

The importance of visual scanning is further raised at intersection negotiation, due to complex geomtery, speed differences, and higher rates of non stopping traffic (Chan, 2006) (Laberge, Creaser, Rakauskas, & Ward, 2006). Differences in driver visual attention at a T-Intersection were examined in one study, with more head movement while making a left turn compared to making a right turn (Summala, Pasanen, Rasanen, & Sievanen, 1996). Reasons include less glance in the periphery than central visual field, longer mean fixation durations (Maltz & Shinar, 1999) and more search errors (Ho, Scialfa, Caird, & Graw, 2001). Drivers in the older age group

have the highest crash risk by exposure for other crash types. Loss of visual acuity and contrast sensitivity (Burg, 1967) (Ball K. O., 1993) (Decina, 1993) are also major concerns for dealing with highway-rail grade crossings.

In other studies, it was found that while performing baseline driving and doing in vehicle tasks novice teens ( those under 17.5 years old and within 4 weeks of licensure) had higher Eyes-Off-Road (EOR) time than experienced adults (Lee, Olsen, & Simons-Morton, 2006). This research also elaborated that how EOR time by teens were mostly spent looking at task display, whereas the adult group used it to check mirrors or windows. In a follow up to their findings, the authors also conducted to see whether 6 months of driving experience improved the situation. The rearview and left mirror glances for the teens improved for teens but the teens still had significantly less glances to mirrors compared to adults while engaging in secondary task.

Bao & Boyle, (2008) in their study calculated entropy rate as a measure of scan randomness across the visual field for three age groups while making a left turn, driving straight across and making right turns on two stop controlled intersections. Shannon (1948) first stated how the amount of information can be found by calculating the number of yes or no questions needed on average to ascertain the state of that system. It was also found how the entropy metric for a non-equiprobable state-space is specified by the state-space probability weighted average of all possible yes/no questions. Shannon computed his entropy equation as

$$\text{Entropy} = \sum p_i \log_2(1/p_i)$$

Where,  $p_i$  = State-Space probability (Weight)

Gilland (2008), used this modified Entropy formula and found how eye movement behavior captured by the entropy metric are useful for understanding the correlation between normal adult aging and task-induced cognitive demands within the context of real-world driving. Findings from Boa & Boyle (2008) found that entropy rate was the lowest for the older driver group for all maneuvers and the middle age group had the highest entropy rate. To quantify the differences in visual scanning between the younger and older drivers, Maltz & Shinar (1999) found how older subjects allocated a larger percentage of their visual scan time to a small subset of areas in the

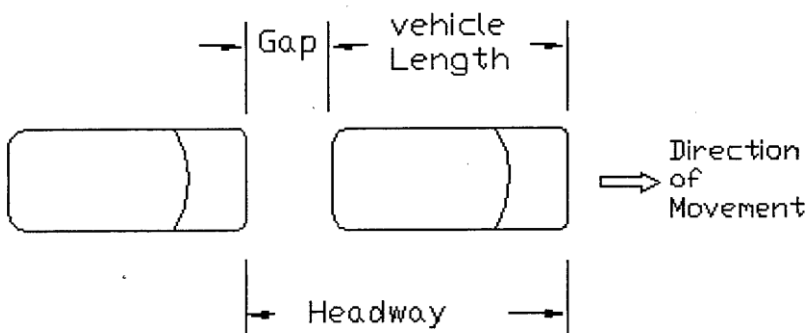
image, while younger subjects scanned the images more evenly. The study used a stability ratio estimate to show even though the scans looked similar they lacked in stability focusing on the areas-of-interest (AOIs) (Maltz & Shinar, 1999). Overall, the authors suggested how aging was affecting the effectiveness of visual information processing which leads to the important question of how the older drivers and younger drivers accept gaps in traffic while making turns in an unprotected intersection scenario.

This research will utilize visual entropy, mean-duration to glance locations as dependent variables to answer research questions related to visual pattern and scanning while negotiating an intersection.

### 2.3.4 Gap Acceptance

In the above section, we discussed how older drivers have attention and information processing decrements. Such declines of perceptual and cognitive abilities makes critical decision making in situations like making unprotected turns across on-coming traffic a challenge for the older population.

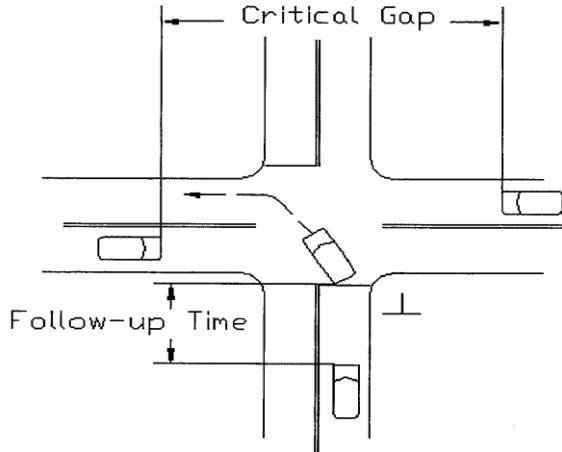
The Highway Capacity Manual (HCM) defines gap as the time interval between passage of one vehicle and the arrival of the next vehicle (Highway Capacity Manual, 2000). Gap should not be confused with headway, as headway is measured from the front bumper of the front vehicle to the front bumper of the next vehicle (see figure 5)



**Figure 5:** Time-Space Interval

*Source: Highway Capacity Manual. (2000). Washington, D. C., United States of America: Transportation Research Board., available in Public Domain. Used under FAIRUSE guidelines(2011)*

Further, there is also a concept of critical gap which is defined by the HCM as the “minimum length time interval that allows intersection entry to one minor street vehicle”. The figure 6 used by Gattis & Low (1998), illustrates the concept of critical gap.



**Figure 6:** HCM critical Gap and Follow-up Time,

*Source: Gattis, J., & Low, S. (1998). Gap acceptance at non-standard stop-controlled intersections. University of Arkansas, Mack-Blackwell Transportation Center, Fayetteville. 1998 available in Public Domain. Used under FAIRUSE guidelines(2011)*

Therefore, gap-acceptance is the process in which a driver of a vehicle accepts the critical gap presented to him/her as sufficient to for a turn to be made, and starts to initiate a turn maneuver and subsequently complete it. There is a lot of debate about the acceptable gap size, but the Highway Capacity Manual (HCM, 2000) estimated the following critical gaps for stop controlled intersections as shown in table 4.

**Table 4:** Base Critical Gaps for Stop-Controlled Intersections,

*Source: Highway Capacity Manual. (2000). Washington, D. C., United States of America: Transportation Research Board., available in Public Domain. Used under FAIRUSE guidelines(2011)*

Vehicle Movement	Base Critical Gap, $t_{c,base}$ (s)	
	Two-Lane Major Street	Four-Lane Major Street
Left turn from major	4.1	4.1
Right turn from minor	6.2	6.9
Through traffic on minor	6.5	6.5
Left turn from minor	7.1	7.5

Even though, the table illustrates the critical gap time; it may not be applicable for all age groups. Dissanayake et.al (2002) conducted a field observational study where over 1500 incidents of day and nighttime gaps were recorded for left-turns into through traffic conditions at three Two-Way Stop Controlled intersections. The study found how the older driver age group gave the longest critical gap value for both left turn and through maneuvers irrespective of day or nighttime driving, these gap time are tabulated in table 5 below.

**Table 5:** Critical gap values during daytime and nighttime driving for all age groups.

*Source: Dissanayake, S., Lu, J., & Yi, P. (2002). Driver age differences in day and night gap acceptance capabilities. International Association of Traffic and Safety Sciences. Used under FAIRUSE guidelines(2011)*

Driver Group	Maneuver	Daytime		Nighttime	
		Number of Observations	Critical Gap (sec.)	Number of Observations	Critical Gap (sec.)
Older	Left-Turn	154	7.164	68	7.585
	Through	188	7.084	85	7.361
Middle	Left-Turn	206	6.775	219	7.088
	Through	212	6.585	189	6.871
Young	Left-Turn	90	6.024	89	6.367
	Through	118	5.985	94	6.054

Looking at the table it is very likely to conclude that younger drivers had the smallest critical gaps and thereby are the most competent driver-group. Such a conclusion is wrong as younger drivers could adopt elevated kinematic behavior to complete a turn by accepting smaller gaps than those that are ideally required to complete the turn.

Other findings suggested that drivers above the age of 70 are less likely to accept shorter gaps when compared to other drivers (Zhou, Lownes, Ivan, Ravishanker, & Gårder, 2009). In addition, how elderly drivers compensate for their diminished perception reaction ability by being more conservative in their driving attitude, but how that compensatory behavior is not

significant for the drivers between the age of 55 and 70 who have their gap acceptance behavior similar to younger drivers.

In another study, the ability to predict motion of vehicles for different ages was examined. Motion extrapolation differences in younger and older drivers for car following scenes was studied using frame drawings of a car-following scenario which had the participant having to choose the correct position of the car based on the previous frames depicting the lead up to that frame (DeLucia & Mather, 2006). The study found that older drivers were biased towards choosing a less advanced reappearance position, whereas younger drivers were biased towards a more advanced reappearance position. DeLucia et.al (2006) concluded that older drivers extrapolated the motion slower than did younger drivers.

From the findings above it is clear that older driver group exhibit biases in their gap estimation, making them susceptible to certain types of decision errors. As a result in this research the driver gap-acceptance and rejection behavior was examined in varying traffic conditions to gain a better understanding of existing driver age-related differences.

## **2.4 Naturalistic Driving Research**

Most research for studying driving behavior has been done through highly controlled simulator experiments or controlled experiments on closed-course tracks or roads. The advantage of such experiments is that researchers can rule out potential confounding variables by executing controls and observe behavior directly. However, controlled experiments that take place in artificial study settings have their own challenges in terms of generalization and providing concrete external validity. Although there has been a shift from the simulator to the real car for on-road studies, there is often still a lack of traffic or only a partial representation of the driving environment. Further, whether a driver's true behavior is observed in an experimental setting when under observation by researchers for a driving session is questionable.

Naturalistic driving observation is an unobtrusive method to observe various driver behaviors. Naturalistic driving observation includes objective and unobtrusive observation of drivers in

their normal driving context while driving. Participants get their own vehicles equipped with devices that, for a considerable length of time, continuously monitor various aspects of driving behavior, including vehicle movements, behavior of the driver, and characteristics of the environment. The data logging device can record various driving behaviors such as speed, braking, lane keeping/variability, acceleration, deceleration, and it often includes the data from one or more video cameras as well.

Brainin (1980) used an in-vehicle observation technique and reported how participants felt more at ease with no prying experimenter observing them. The study required the participant drivers to follow a pre-determined route in a given time slot. The naturalistic approach to data collection for the study by Brainin involved a large data collection period where drivers used the instrumented vehicle for their personal use and did not follow a pre-determined route.

Dingus et al. (2006) conducted a naturalistic driving study involving 109 vehicles that included 109 primary drivers and 132 secondary drivers in the northern Virginia and DC metro areas. Driver ages ranged from 18 to 73 year old, with 60 percent of drivers being male. All participants' cars were fitted with multiple cameras, sensors, and a processing unit that collected video and parametric data regarding participants' normal, daily driving. The overall data collection lasted for over a period of 12-13 months per vehicle and captured over 2,000,000 vehicle miles of driving, 42,300 hours of driving data. This research helped answer questions regarding driver inattention, distraction caused due to performing secondary tasks and analysis into all crashes and near-crashes that occurred during the data collection period.

Thus, naturalistic driving research methods offer the opportunity to learn about how real drivers behave under natural circumstances, and yield new insights about factors that contribute to crashes. For this reason, naturalistic driving data was chosen as a source of data for use in this thesis work. No known prior studies on left turns at intersections have been done with data from naturalistic driving.



### **3. Rationale for Thesis Study**

To summarize, this review of the literature shows that prior scientific work has used controlled experimental studies (along with epidemiological studies of crash incidence) to examine age-related differences between driver groups at intersections. More specifically not much literature exists regarding unprotected turns.

This research has identified differences between drivers at intersections – e.g., in visual scanning and other selected measures of behavior. However, several voids can be identified in the literature. The biggest difference is the utilization of a naturalistic driving data, as no research has used naturalistic driving data previously to examine age-related differences during intersection turns.

In addition, whether the presence of other vehicles at an intersection affects visual scanning or other aspects of driver behavior at the intersection, has not yet been examined -- nor whether presence of traffic interacts with age effects (especially perceptual and cognitive processes that change with age). This along with the unprotected (no right-of-way) nature of the intersection turn, makes this research valuable.

Finally, gap acceptance judgments by age have not been studied in vehicle natural driving but have been mostly outside the vehicle observation studies. This form of observational study does not incorporate the driver conditions and behaviors associated with making such gap related judgments. Therefore, this thesis research is intended to take a step toward addressing these gaps in research. Learning more about these key areas would push the state of understanding forward about how drivers negotiate intersections.

As a reminder, the three questions that this thesis will focus upon are the following:

- 1. How do drivers regulate their visual glances while making unprotected turns?**
- 2. How do drivers manipulate their gap acceptance levels across age groups?**
- 3. Are there age-related differences in driving kinematics while making unprotected turns?**

The methods to be used in addressing these questions are described in the next section.

## 4. Method

### 4.1 Project Design and Overview

The research utilizes existing naturalistic driving data from two previously completed studies (originally performed to answer different research questions) namely, the Older Driver Study and the Naturalistic Teen Driving Study. Relevant data containing negotiation of intersections for three age groups of drivers: older, middle-age and younger teen drivers will be obtained from the existing data for the purpose and requirement of the study. The middle age drivers are parents of the teen drivers from the Naturalistic Teen Driving Study, all driver and additional details are discussed in the following sections. First, however, it is necessary to briefly provide some background about the two driving studies that will serve as data sources for this research.

### 4.2 Naturalistic Teenage Driving Study

The Naturalistic Teenage Driving Study (NTDS) followed a group of newly licensed teenagers continuously for 18 months after licensure. The initial recruitment had 315 teenager candidates, of whom certain candidates dropped out or were not included due to conflicting licensure criteria, time unavailability, ineligible vehicle type, logistical issues like being far away from study site or being diagnosed with ADHD. The final sample included 42 newly licensed teen drivers 16 years of age during their first 18 months of independent driving. The study also included the parents of the teen as secondary drivers, table 6 shows the mean age of the teen participants and parent participants by their age. The parents of teens serve as the middle-age driver group for the purpose of this research, but all familial ties between teens and their respective parents are avoided by utilizing either one of them for each experimental design block

**Table 6:** Teen participant age information by age and gender

<b>PARTICIPANT</b>	<b>AGE</b>	
	<b>Male (s.d)</b>	<b>Female(s.d)</b>
<b>Teen</b>	16.4 (0.3)	16.4 (0.4)
<b>Parents</b>	49.4(5.3)	45.7(5.1)

Overall 33 vehicles were instrumented which comprised of 17 vehicle makes. The study concluded with teens and parents driving approximately 500,000 miles in nearly 102,000 trip files (ignition on to ignition off). The teenagers on an average drove 367 miles per month for the duration of the study period.

### 4.3 Older Driver Study

The objective of the older driver study was to compare the various functional abilities of a group of older drivers with that of a cohort of older individuals who had recently given up driving. The total number of participant for the study was 49, but the driver group had 26 participants, with 20 of those participating in the year-long study which required the participant vehicle to have been instrumented for that period. Tables 7 tabulate the age-range and mean age of participants by their gender for the older driver study.

**Table 7:** Older Driver participant age information by driving group and gender

<b>GENDER</b>	<b>DRIVERS</b>	
	<b>Age Range (n)</b>	<b>Mean Age (s.d.)</b>
<b>Male</b>	70-84 (14)	77 (4.6)
<b>Female</b>	71-85 (12)	79 (4.3)

The older participants functional abilities were assessed during two sessions on two different days with the first one being conducted at the Virginia Tech Transportation Institute (VTTI), which primarily required them to review and sign informed consent form followed by some questionnaire and assessments. The second sessions had the participants taking part in tests regarding their general mobility and health, conducted in the Locomotion Research Laboratory and the Vision Controls Laboratory both at the Grado Department of Industrial & Systems Engineering at Virginia Tech. In total, the study collected over 30,000 trip (ignition on to ignition off) files, which represent over 4600 hours of driving data.

This research uses the data from the concluded Naturalistic Teen Driving Study and Older Driver Study. A joint IRB proposal for the use of data from both the studies was submitted for the

purpose of this research. (See Appendix A has the submitted IRB protocols while Appendix B contains the IRB-Approval letters)

#### **4.4 Data Acquisition**

The primary reason for the use of these two driving databases is that they contribute a wide range of different aged drivers with varying levels of driving experience. However, another very important reason was the similarity of the data acquisition system between the two studies. Although the data collection for the two driving study were not simultaneous, this accordance of collected data made it a good choice. All vehicles across the two driver studies were equipped with a Data Acquisition System (DAS), which included an array of cameras, bumper-mounted front and rear radar unit, and other data collection instruments to record parametric environmental data to a central unit located in the trunk of the vehicle. The parametric data collected included variables such as vehicle speed, distance to forward vehicles, turn signal status, and lane position. The 4 cameras provided a view of the forward road way, drivers face, an above the shoulder view for the driver and a view of the rear of the vehicle. The detail description of the Data Acquisition System along with its various components can be found in Appendix C.

#### **4.5 Data Mining and Reduction**

The whole Data-Mining and reduction aspect is shown using a process flow-chart in Appendix-C. The following section describes each individual component of this process.

##### **4.5.1 Data Mining**

###### **4.5.1.1 Initial Data Aggregation and Sorting**

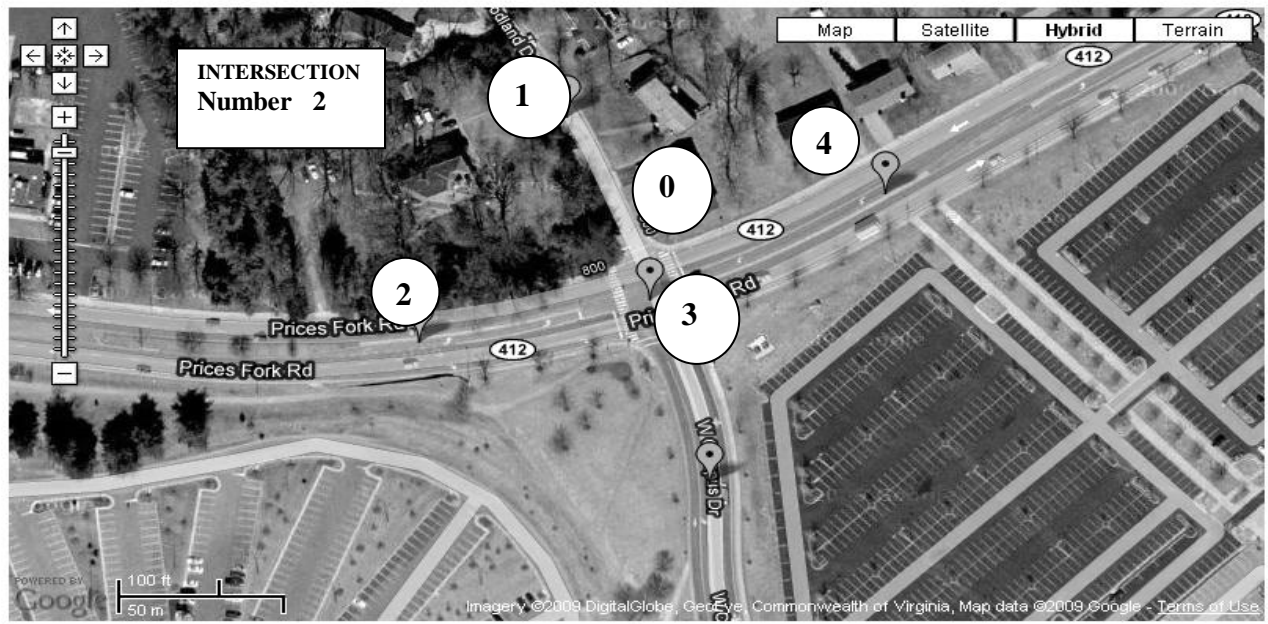
This research utilizes naturalistic data from two different naturalistic data sets, so in order to create an Experimental Design which could be proposed, the first step was to aggregate these massive naturalistic datasets and then to find and extract the relevant reduced data set required for this research. Since it is desired to observe driver behavior while negotiating intersections, the first step was to identify a common geographic location-zone which is shared by most of the participants with regards to where their residences and work areas are located. A list of eighty-

one intersections was identified along with their latitude and longitudinal GPS positions, the list comprised of both signalized and non-signalized intersections. Researchers at the Virginia Tech Transportation Institute created this list with relation to geographic location, traffic probability and crash propensity.

Once all the intersections were shortlisted, the next step was to find all driving trips made across those intersections from the available naturalistic driving data from the two studies. The next section describes how the algorithm/code was developed but the aim of this section (on Data Aggregation and Sorting) is to discuss how the intersections were number-labeled, so that they could be used in the next stage of code development and use. Geo-spatial co-ordinates of all eighty-one intersections were found.

Further, for each intersection, individual road branches or legs are geo-tagged i.e., each intersection is identified using a set of multiple points which are used to determine not only whether a driver drove through the intersection but also from which direction a driver approached the intersection and proceeded from the intersection.

#### Latitude and Longitude of a Point



**Figure 7:** Latitude and longitudinal GPS co-ordinates displayed on a map which was used for the purpose of identifying instances of any driver driving through the intersection

Figure 7 explains how a 4 way signalized intersection was geo-tagged. Here the numbers enclosed in the bubble represent various intersection leg-points, where 0 depicts the center of intersection and 1 the northern facing intersection and thereby going counter-clockwise to each of the legs.

This type of tagging is helpful in differentiating when two drivers who both go through the same intersection (Intersection # 2) use a different route through it. This means that one could approach the intersection from the north, i.e. 1 and going through the intersection makes a right turn towards west i.e. 2, thereby having the Route ID as 102, whereas the other driver could approach from the south i.e. 3 and make a left turn towards west i.e. 2 thereby having the Route ID as 302. In the following section a description is given of how the data-mining algorithm utilizes these Route ID numbers for the purpose of this research.

#### **4.5.1.2 Data Mining Algorithm Logic**

A data table was created where all the intersection and their legpoints containing their geo-spatial/GPS co-ordinates was listed, for each driving trip file in the whole dataset from both the studies. The trip file contained the GPS co-ordinates that provide information about the route taken by the driver for that trip. Hence, the algorithm logic compared individual trip file to the list of eighty-one intersections to find out whether the driver went through any of the listed intersections in that trip. The logic for finding this was to calculate the distance of each GPS co-ordinate from the driving trip to all the intersections --e.g. a driving trip containing 300 seconds of data contains about 900 continuous GPS co-ordinates (because GPS recorded at 3hz), now the distance between each of those 900 points and 81 intersection points are calculated. Whenever this distance is under 50 ft buffer, it is stored in a local repository. This application of the algorithm reduces the huge amount of driver data from each database to only contain driver data and instances of GPS positional data when their distance to any of the intersection legpoints was less than 50ft.

Next, all the distances were matched to a timestamp value i.e., at what time in the trip is the distance recorded. To gain further information as to what kind of turn maneuver the driver makes by arranging it by the timestamp and observing the order in which the legpoints were crossed.

Once the trip information is received, video checks were done to confirm whether all selected/reduced files have the intersection scenarios that the algorithm suggested

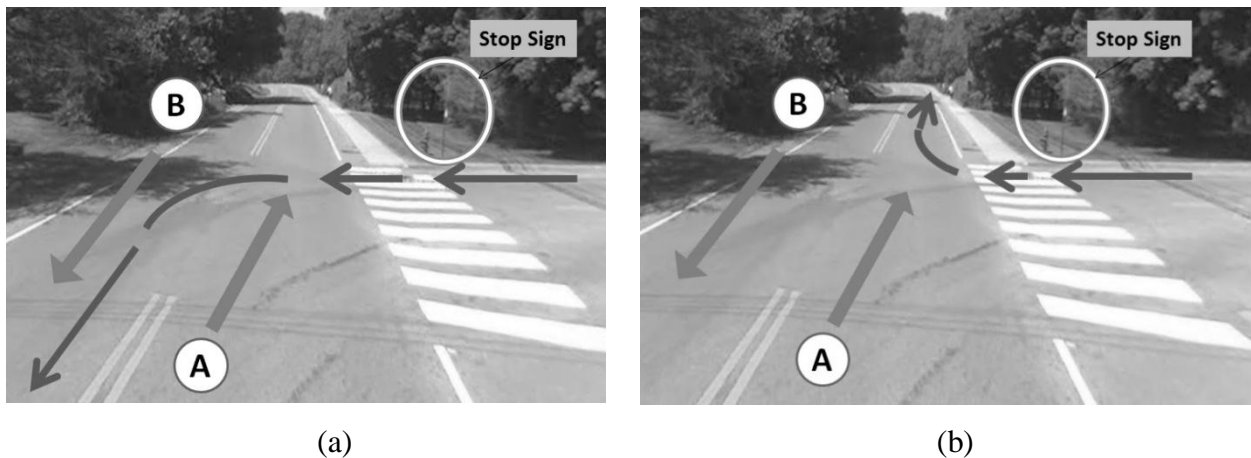
**Table 8:** Output Table from the data mining algorithm

Database	Trip Id	Timestamp	Vehicle Number	Intersection number	Intersection Leg-point	Distance (Ft)
Older Driver	12	840	1	2	1	6.02572
Older Driver	12	870	1	2	0	15.40987
Older Driver	12	920	1	2	3	9.937178
Older Driver	12	1150	1	1	1	12.70175
Older Driver	12	1200	1	1	0	12.54777
Older Driver	12	1229	1	1	3	13.65183
NTDS	2	3360	1	13	4	10.85953
NTDS	2	3411	1	13	0	25.60811
NTDS	2	3431	1	13	2	11.87241
Older Driver	12	4166	1	10	1	8.064499
Older Driver	12	4476	1	10	0	4.23344
Older Driver	12	4566	1	10	3	9.31955
NTDS	11	9921	1	9	3	7.944183
NTDS	11	10311	1	9	0	9.732666
NTDS	11	10390	1	9	1	6.475656

The table 8, above illustrates an example output table of the algorithm. Here it can be seen for Trip Id #12 from the older driver study at the 840<sup>th</sup> sync (84<sup>th</sup> second into the trip). The Driver approaches the intersection # 2 from the leg-point #1, where the distance of the participant vehicle from the established intersection leg-point 1 (see Figure 13) is 6.025 feet. Thereby we can say the driver made a right turn at the intersection # 2. However, some further analysis was needed to determine whether any teens and parents are related between the cells of the first two columns – and, if they are, to determine how much data remains if only non-related participants are retained.

Once the data-mining algorithm was applied to the whole database, intersections with largest number of turn events across all the age-groups were then identified. The Unsignalized intersection with the most replication was a turn in Blacksburg, VA. This Intersection was a T-shaped intersection with a one-way stop sign, with the traffic that stopped at the stop sign made an unprotected turn into flowing traffic condition. This intersection posted a very unique problem of drivers coming to a stop-sign and making a turn onto flowing traffic condition. Unlike other intersection scenarios where drivers right-of-way to complete a turn is governed either by a signal, or a stop-sign where drivers from all streams of the intersection have to come to a stop and their right-of-way is based on their priority of arrival, depart the intersection.

Figure 8, shows some pictures of the intersection and the left and right turns that drivers need to make into flowing traffic streams depicted by the letter A and B.



**Figure 8:** Photograph of the three way Unsignalized intersection (a) Left Turn (b) Right Turn

Figure 8(a) depicts a generalized driving line (depicted by the thin arrows) that drivers need to follow to complete a left turn, with flowing traffic condition from both traffic streams A and B. Similarly, figure 8(b) shows the generalized driving line that drivers need to complete while making a right turn. It is important to understand that traffic stream A and B have the right of way ahead of the vehicle which stops at the stop sign. Also for making right turns, drivers will mostly be concerned with the traffic stream denoted by letter A, whereas both A and B need to be accounted for while making a left turn.



The initial number of total participants and individual trips made through the intersection are tabulated in table 9 below. This initial data is prior to the elimination of trips which contained broken files, and before eliminating driver trips to avoid for parent teen familial relationship. Once this subset of files the next step was to reduce the data for visual glances, gap acceptance and traffic density.

**Table 9:** Data Available for the Non-Signalized T-Intersection.(prior to elimination of familial relationships, sorting into traffic-levels, and removal of corrupt data files).

Driver →	Teen Driver		Parent Driver		Older Driver	
Turn Type	Unique Participants	Total Number of Trip Files	Unique Participants	Total Number of Trip Files	Unique Participants	Total Number of Trip Files
Right Turn	17	530	12	141	8	43
Left Turn	15	159	7	33	10	31

The final number of participants dependent on individual experimental block constructed for to answer and test a particular hypothesis and more so a research question.

## 4.5.2 Data Reduction

### 4.5.2.1 Visual Glance Reduction

The driving trips obtained from the data mining process are further reduced for the relevant intersection event by the aid of multiple trained data analysts (data reductionists). The reductionist use proprietary glance reduction software, developed at VTTI to record eye-scanning patterns. Reductionists review the video and mark glances corresponding with the video.

The glance locations used for this study were as follows:

- Forward
- Instrument Cluster
- Rearview Mirror
- Left Mirror
- Right Mirror
- Left Windshield
- Right Windshield
- Over –the –Shoulder (Left or Right)
- Unknown
- Center Stack
- Cell phone/ Other personal devices
- Interior object
- Passenger
- Eyes Closed
- Left Window
- Right Window
- Eye Closure

From this data (glance locations recorded at each time sync of the video), it was possible to extract all of the planned dependent variables related to glances.



**Figure 9:** (a) Composite video depicting four views from the different cameras (Left),

(b) Dialog box for Visual-glance selection, used to code visual glance for each frame of data (Below)

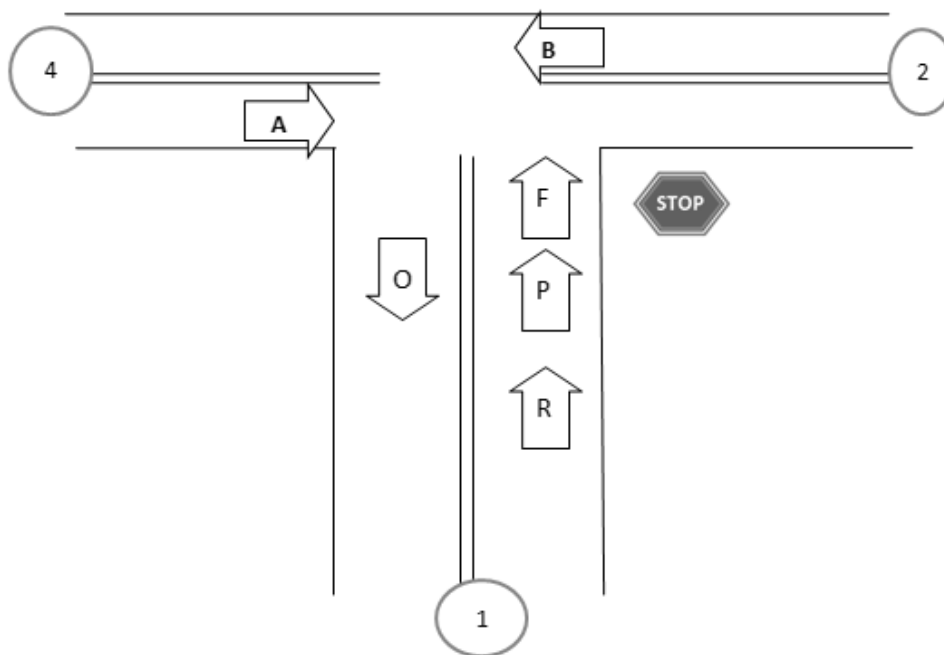
*Note:* The blurred video frame on the top left corner is the camera capturing the driver face



The reductionist sees the video frame by frame and a dialog box with the various glance location options appears on the side where they click the applicable location option. Figure 9(a) shows the snapshot of the continuous multiple channel video streams available to the experimenter and data reductionists. Also Figure 9(b) depicts the dialog box which is used by the reductionist to select visual glances for every video frame.

#### 4.5.2.2 Traffic Density Reduction

This study analyzed the level of traffic at each of the traffic intersection events, in order to determine how it affects driver behavior. Therefore, a convention for coding traffic density from the video of each intersection was formulated. Figure 15 was developed to show a visual scheme of traffic flow at different channels of the intersection – and to facilitate development of a coding scheme for quantifying traffic density.



**Figure 10:** A Non-Signalized One-Way Stop Sign Intersection Event

*Note: The arrows depict the vehicular traffic (see table for details)*

Table 10 below lists the data codes that were used for coding traffic density, and their respective definitions for the visual scheme (Figure 15). All code assignments were made utilizing the In-

Vehicle video as shown in Figure 14(a). Once coding was completed for the video images of each trip, the amount of traffic present in different locations at each intersection was quantified.

**Table 10:** New Traffic Density Levels incorporated for the study

CODE	CODE DEFINITION
P	Subject Vehicle
1,2,4	Direction Markers (Heading)
R	# of cars behind the subject vehicle at the time of departure from the intersection
F	# of Vehicles in front of the subject vehicle when it comes to a stop for the first time while approaching the intersection
A	# of vehicles coming from 4 and continues to head towards 2
B	# of vehicles coming from 2 and continues to head towards 4
BO	# of vehicles coming from B making a turn towards O
AO	# of vehicles coming from A-4 making a turn towards 1)
O	# of vehicles in the opposite lane that passed the subject vehicle while its waiting at the entire duration of the stop sign
<p><i>Note: The code O will be used in instances where it is not possible to assign a vehicle under either AO or BO, i.e., what turn a certain vehicle made</i></p>	

Under each Code the number of vehicles that were present in the stream were counted and recorded. All counts of other vehicles were performed while the primary/participant vehicle was at the stop-sign waiting to make the turn. Only for level ‘F’ the number of vehicles ahead of the participant vehicle waiting at the stop sign were counted, when the participant vehicle first came to a stop. Coding was then completed for the entire data available for that intersection using the levels shown in table above. It was found for an individual analysis of traffic density levels there

were not enough instances per level. Therefore, traffic code- levels were collapsed across two levels to get more number of trips. The levels that were used for this research were presence of traffic in intersecting lanes and the absence of traffic in intersecting lanes.

**Table 11:** New Traffic Density Levels incorporated for the study

<b>New Traffic Levels</b>	<b>Left Turn</b>	<b>Right Turn</b>
<b>Traffic- Present</b>	Vehicle present through both traffic <b>stream A and B</b>	Vehicle present through <b>stream A</b>
<b>No Traffic Present</b>	No vehicles through <b>stream A and B</b>	No vehicles through <b>stream A</b>

Table 11 shows the new traffic levels that were finally used for the purpose of this research. For traffic present all instances of left turn that had traffic in the A and/or B stream were coded traffic present. For traffic present level for right turns, only those trips were assigned that level which had traffic in the A stream. Finally no-traffic present were instances where there was no traffic in either A or B stream while making the left turn, whereas only A stream for making right turns.

## 4.6 Experimental Design

The study as described in previous sections utilizes existing naturalistic data and matches similar intersection events for different drivers across different studies. The only control executed for this study was the location of the intersection and turn type. The study incorporates three different intersection turns, Left and Right turns from a non-signalized 3-way intersection controlled by a one-way stop sign into through traffic, and a Left turn made at a signalized intersection during yield signage. This section will list the Independent and Dependent Variables for the study to answer the posted research questions and underlying hypothesis.

### Independent Variables

#### Independent Variable

Age (3 levels): *Younger (16-20), Middle-age (35-55), Older (70+)*

The younger and older driver groups are a critical age group established by the literature review in previous sections. The middle-age drivers, who are the parents of the teen drivers, serve as a base line comparative amongst the driver group. Again all familial ties will be avoided by either selecting the teen or their respective parents but not both for individual experimental design blocks.

Level of Traffic (2 Levels): *No Traffic & Traffic Present*

The effect of presence or absence of traffic faced by the driver in a natural driving environment is included to provide a deeper understanding of glance pattern variability while encountering the same intersection event in varying traffic conditions.

Glance Location (5 Levels): *Forward Roadway, Left window, Left windshield, Right Windshield, Right Window*

The glance location levels will help in understanding driver differences for different glance location in varying traffic condition. More so the mean-duration of glances to each location level was used as a dependent variable to analyze driver differences for this specific independent variable. This variable will be manipulated within-subject, thereby each individual participant will have a

## **Dependent Variables**

Entropy: Literature has indicated that there are significant glance differences for different age-groups. Further, it has identified how the importance of glances is elevated at intersection negotiation due to the complex geometry and merging traffic conditions that occur there. These require multidirectional visual scanning and processing. This research will utilize the visual entropy (a measure of the lack of organization in the spatial distribution of glances) as discussed in the earlier section as a measure to observe and differentiate driver differences stemming from visual glances. Other descriptive statistics were computed regarding the glance duration, visual link analysis amongst other.

Gap Time Accepted and Rejected: The gap acceptance time chosen by drivers for making a left turn varies significantly with driver experience and age. Previous literature and existing observational studies have pointed out that gap times differ across age group and this study will try to substantiate and extend that work with the use of this naturalistic data.

The gap acceptance time chosen by the driver to make a turn in a busy free flowing stream of traffic to make unprotected turns for both the signalized and non-signalized intersections will be calculated. Apart from utilizing accepted gap times, which show drivers acceptability of gaps, it is of equal interest to see reasonable gaps which drivers may reject. The gaps in traffic that are presented to the drivers in this research present themselves naturally and randomly. Using both accepted gap times, and not-accepted gap times will give us a better idea of driver preference for their gap acceptance.

Mean-Duration of Glances per Location: The mean duration to each location was calculated for each driver turn event. This variable will help to explore drivers visual fixation to location while negotiating intersection turns. Drivers of different age-group might exhibit locational pattern while turn negotiation which will be interesting to the purposes of this research.

Kinematic Measures: The physical and cognitive decline of older individuals may manifest in delayed reaction times to traffic when initiating and making left turns. On the contrary, for

teenagers aggressive driving habits may manifest during turns. These age-related differences underscore the importance of examining kinematic measures and putting them in the context of these intersection task scenarios. Measures like peak lateral and longitudinal accelerations, peak and average speed are already available in the datasets and will be used to see if any strong differences exist between age groups (or are affected by other independent variables)

There are two types of experimental design block as shown in table 12, with one design being a two-factor design and the other being a single-factor design. This design applies to a single intersection turn and its analysis. When analyzing there is a partial overlap between participant samples due to the inherent nature of naturalistic data, not all participants drive through all intersections, so a full factorial of participants X conditions cannot be achieved.

**Table 12:** The Experimental Design Matrix template (a) Two-factor Design (b) A Single-Factor Design

Age-Group	Traffic Level	Participant
Young	Traffic present	$S_1, \dots, S_n$
	No Traffic present	$S_{n+1}, \dots, S_m$
Middle Age	Traffic present	$S_{m+1}, \dots, S_p$
	No Traffic present	$S_{p+1}, \dots, S_q$
Older	Traffic present	$S_{q+1}, \dots, S_r$
	No Traffic present	$S_{r+1}, \dots, S_t$

Age-Group	Participant
Young	$S_1, \dots, S_n$
	$S_{n+1}, \dots, S_m$
Middle Age	$S_{m+1}, \dots, S_p$
	$S_{p+1}, \dots, S_q$
Older	$S_{q+1}, \dots, S_r$
	$S_{r+1}, \dots, S_t$



There will be a mix of some of the same and some different participants who drive through each intersection. The experimental design blocks are utilized with this mix of the same and different participants for different dependent variables to answer various research questions. Overall, the attempt is to have a complete between subject design for each experimental design block. It is also critical to observe that the number of participants vary between each separate design blocks, hence the subject number is denoted with a different letter subscript in table 12. Also the number of subjects per cell may or may not be equal, leading to unequal sample sizes. This problem of dealing with unequal sample sizes is dealt with in the next section.

#### **4.7 Analysis Method**

In selecting methods for analyzing the data for this study, two issues were particularly important. These were: (1) Issues Related to Unequal Sample Sizes and (2) Whether to Use Univariate or Multivariate Analyses. These issues are discussed below, as the analysis methods are described. When data are extracted from naturalistic studies, it is often the case that there are unequal numbers of observations for different types of conditions. This is because natural conditions do not allow for presentation of a treatment to a sample of participants. Instead, a sample of participants are observed and, if they naturally all are exposed to the experience, or generate the behaviors of interest, then those can be observed and used in analyses to assess effects. This usually produces unequal numbers of observations across the cells of an analysis (as it did in this study).

The first problem in dealing with unequal sample size is determining that the variable of interest did not themselves cause any loss of data from cells, i.e. whether a particular driver group had a smaller or larger sample size because of an inherent driver behavior that may confound the results. In this research, there were more observations for teen drivers making left turns at the selected left turn intersection than middle-aged drivers, and fewest observations for older drivers. This difference of sample size was investigated and the two reasons were attributed for this cause. First, the Naturalistic Teen Driving Study had 42 teen drivers as primary drivers. The older driver group had only 26 participants in comparison and recorded only 30,000 trips

whereas teen driver study had over 100,000 trips. The middle age drivers were the parents of teens who were recruited as secondary drivers from the teen driver study. Overall, teen drivers drove the most, so there was a difference between the exposure levels of drivers.

The second reason for higher observations for teen drivers was the result of the intersection's proximity to a high school (leading to higher exposure of teens to the intersection). Thereby this over expo– and hence more robust sample sizes for teens – rather than due to a loss of data for the other age groups that could have been caused by some factor of interest for the study (e.g., age-related avoidance behavior, etc.).

To avoid the confounding results from unequal  $n$ , the use of weighted and unweighted means becomes critical. Weighted mean is computed by multiplying each mean by its sample size and dividing it by the total sample ( $N$ ), whereas unweighted means are simply the mean of the two treatment means. Using weighted means can be misleading in the case of unequal sample size as the difference between the treatment means can be inflated due to the weighting for sample sizes. Weighted means ignore the effects of other variables and result in confounding; unweighted means control for the effect of other variables and therefore eliminate the confounding. Statistical analysis programs use different terms for means that are computed controlling for other effects. All analysis in this research was performed using SAS JMP, where unweighted means are called least square means.

In the case where confounded sums of squares are apportioned to sources of variation, the sums of squares are called Type I sums of squares. When confounded sums of squares are not apportioned to any source of variation, the sums of squares are called Type III sums of squares. The Type III sums of squares are tests of difference in unweighted means. The possible use of Multivariate Analysis of Variance (MANOVA) was also considered, considering its inherent advantage in the case of using two or more dependent variables. Although, there are several assumptions to MANOVA that need to be met before they can be used for analysis. For applying the Multivariate approach, the dependent variable should be normally distributed within groups and there exists a linear relationship among all pairs of dependent variable. Other assumptions include homogeneity of variances that is where the dependent variables need to exhibit equal levels of variance across the range of predictor variables.

One range of dependent variables that are going to be used are kinematic variables, and Multicollinearity determines that Dependent variables with high correlation should not be included in MANOVA analysis which is the case for these kinematic variables. Also if an independent variable has more than 2 groups, the post hoc approaches planned for this research following Univariate ANOVA (simple effects, post hoc tests) can be used to further evaluate significant effects which are not possible in MANOVA. Overall, MANOVA requires more assumptions than ANOVA, it requires larger sample sizes in comparison to ANOVA.

**Conclusion from these considerations:** Univariate ANOVAs that focus on the effects of IVs for each DV separately is the most suitable approach and was selected for use. (MANOVA can be reserved for when it is really needed). In the event of a significant concern about the number of ANOVAs to be performed, an experiment-wise adjustment to the alpha level can be applied to protect against too many significant results being obtained simply by virtue of the numbers of analyses performed.

The issue of unequal-Ns and the sparseness of data in some cells will constrain the power of statistical tests to detect effects under study. Thus, the results of this thesis will likely reveal trends in some instances, but not always definitively. Thus, some findings are likely to be exploratory and suggestive only. However, exploratory approaches have an important role to play in science, along with more definitive hypothesis-testing research that can be applied once exploratory work has opened up new avenues of investigation. For example, descriptive statistics for glance distribution and kinematic ranges can be very helpful -- quite apart from hypothesis testing outcomes. In addition, important files/cases can be identified as opportunities for learning and use as possible case studies later for better understanding and aiding this line of research.

Therefore, this thesis provides value – though it is an exploratory one that ventures into new areas of technical content, using newly available naturalistic driving data. As more such data become available, the preliminary findings here can be re-examined with more robustness using the methods developed in this thesis.

## 5. Results

The data were analyzed using an Analysis of Variance routine (applied using JMP software), employing a between subject design. The research analysis was accomplished in two parts, with most analysis replicated for the two turn types, left and right turns. As mentioned previously in the proposal, this was done because the subject samples between the two turns are not completely exclusive – nor are they matched – they were partially overlapping (as this is natural data, some drivers made both left and right turns, while some made only one). Henceforth, this study can be viewed as a two-part study with two different turn types in the same intersection. There was no analysis that was done to compare the two turn types, they were seen as two separate maneuvers (left and right turn), which were analyzed separately but happened to be at the same intersection. The following section explains in detail the findings of the individual research questions and their underlying hypotheses.

### 5.1 **Results: How do drivers regulate their visual glances while making unprotected turns?**

To answer the research question of how drivers regulate their visual glances while making unprotected turns, two underlying hypothesis were constructed to study the difference between the driver groups. The first hypothesis tests the difference between driver groups while making unprotected turns in the presence of flowing intersecting traffic.

#### 5.1.1 **Hypothesis 1: The presence of traffic at the intersection increases the amount of visual scanning that driver's exhibit prior to initiation of their turns for all age groups.**

To test Hypothesis 1, a measure reflecting the spatial extent of visual scanning was needed. As described earlier (in the Methods section), visual entropy is such a metric. Visual entropy values are higher as a driver scans a driving scene more broadly (fixating on more areas in the scene), and is lower as a driver concentrates scanning in fewer, more selectively focused areas. Thus,

visual entropy is a useful measure of the spatial extent of visual scanning that can be used to test Hypothesis 1, which is formulated into the more specific null and alternative hypotheses below

Ho: There will be no difference in the visual entropy values for drivers in the presence or absence of traffic.

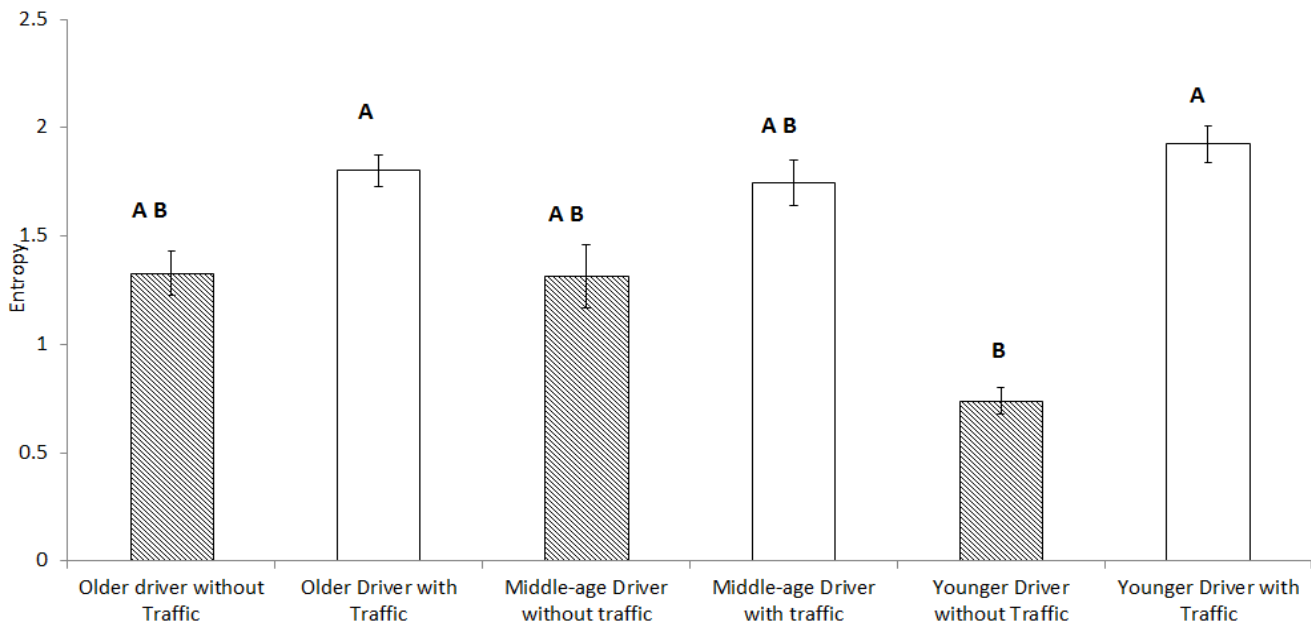
Ha: There is a difference in the visual entropy values for drivers in the presence or absence of traffic.

The experimental design incorporated is a  $3 \times 2$  block between-subject design, with 3 levels of driver group and 2 levels of traffic condition. The driver group levels comprise of Older Driver, Middle-Age Driver and Younger Driver, and the traffic level was summarized in two levels namely, Traffic present and No Traffic present. Table 13, is the ANOVA table for the above Experimental Design. The analysis reveals a significant main effect of traffic level on visual entropy, with p-value (0.0011\*). All driver-age-groups showed an increase in their visual entropy values when in the presence of traffic, indicating that the presence of traffic prompted a broadening of visual scanning. In addition, the interaction of Driver-Group x Traffic-Level approached significance ( $p = 0.08$ ).

**Table 13:** ANOVA table for visual entropy utilizing a Driver-Group  $\times$  Traffic-levels design for making Left Turns

<b>Dependent Variable</b>	<b>Source</b>	<b>DF</b>	<b>Type III Sum of Squares</b>	<b>Mean Square</b>	<b>F Ratio</b>	<b>Prob &gt; F</b>
Entropy	Driver Group	2	0.20	0.10	1.14	0.35
	Traffic Level	1	1.59	1.59	18.40	0.0011*
	Driver-Group X Traffic-Level	2	0.53	0.26	3.05	0.08
	Error	12	1.04	0.09		

Tukey's Post-hoc comparison test, also known as Tukey's HSD test and Tukey-Kramer test revealed a significant difference in the interaction terms for the driver group and traffic levels. Figure 11, below illustrates the different entropy means for the combination of driver group and traffic condition, It can be seen that the largest difference (and a significant one) occurs for the younger drivers, who exhibit the largest increase in visual entropy in the presence of traffic when compared to their entropy values without traffic, denoted by different letters. The effect of traffic on increasing visual entropy was not quite this large for the other age groups.



**Figure 11:** Entropy Means for Driver Age Group and Traffic Condition while making Left Turns

Similar to the Left turn, the analysis of visual entropy was replicated for the Right-Turn, but no significant differences from traffic were observed for the driver-group or the traffic-level. Table 14 shows the ANOVA table for the entropy levels while making right turns. The thing to note is that the p-value for the traffic level differences for making right turns does approach significance ( $p = 0.13$ ), and so is worth noting in light of the small and unequal n in the cells of the analysis, even though it is not as profound as in the case of making left turns.. It can be speculated that a larger sample size (and hence more statistical power) for this analysis of entropy levels in the presence of traffic while making right turns may have yielded a significant effect.

**Table 14:** ANOVA table for visual entropy utilizing a Driver-Group ×Traffic-levels design for making Right Turns

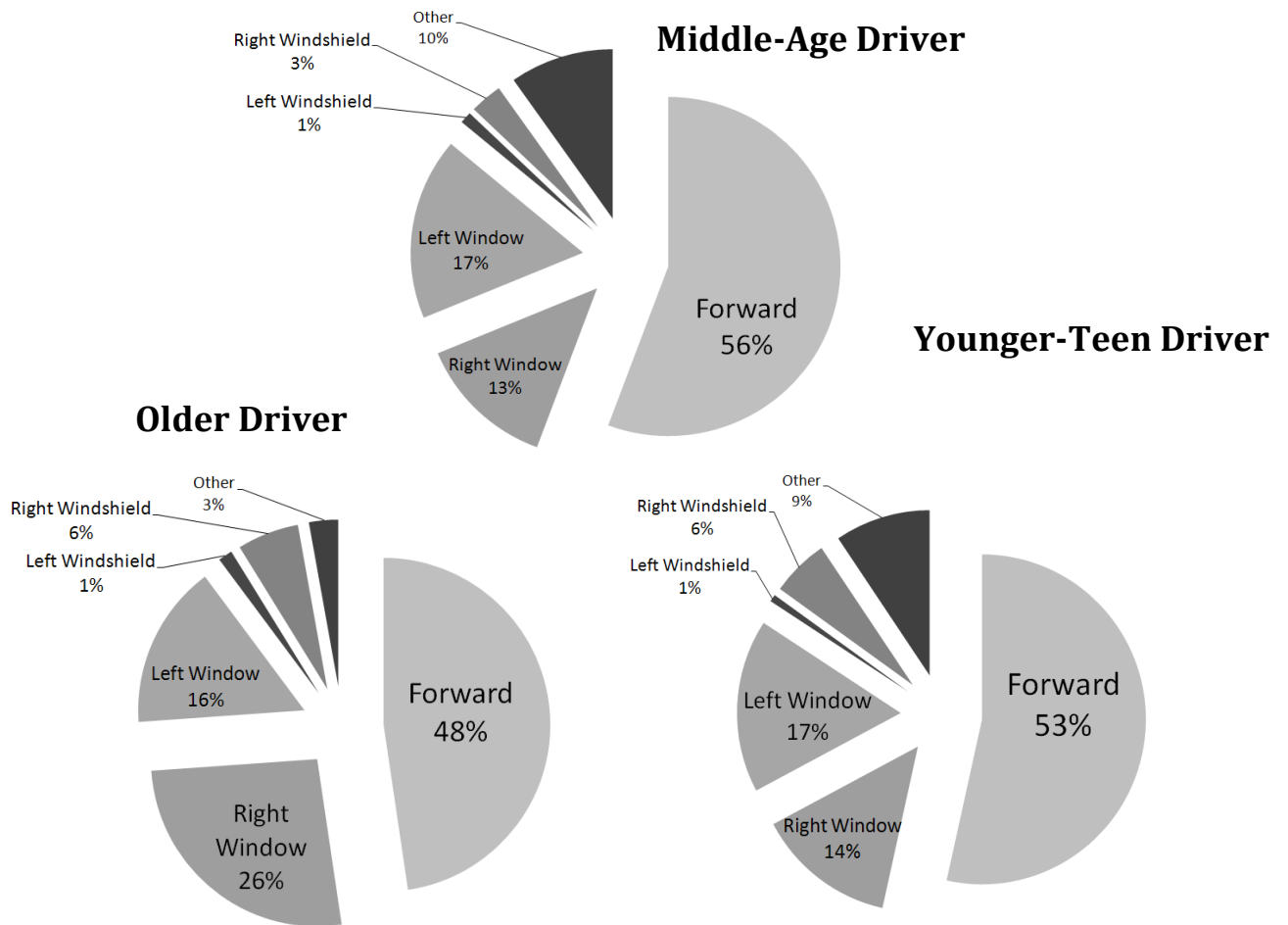
<b>Dependent Variable</b>	<b>Source</b>	<b>DF</b>	<b>Type III Sum of Squares</b>	<b>Mean Square</b>	<b>F Ratio</b>	<b>Prob &gt; F</b>
Entropy	Driver Group	2	0.13	0.07	0.37	0.70
	Traffic Level	1	0.46	0.46	2.56	0.13
	Driver-Group X Traffic-Level	2	0.11	0.05	0.31	0.74
	Error	16	2.88	0.18		

Overall, the Null Hypothesis (that the presence of traffic has no effect on visual scanning at intersections) is rejected for left turns (i.e., there is a difference in the entropy values for drivers in the presence of traffic) – but not for right turns (although the effect approached significance). However, there was likely not enough statistical power to reject the Null Hypothesis in the case for making right turns. The trends thus suggested that both for left and right turns, the presence of traffic increased the spatial extent of visual scanning at the intersection for all driver age groups. In addition, findings were definitive in showing that this effect was largest for younger drivers making left turns.

The findings from this block is revealing because for the earlier hypothesis without traffic levels there was a significant difference between the driver groups for the right turn. However, with the inclusion of traffic as an independent variable the differences in visual entropy between the driver groups were not present anymore. Apart from doing hypothesis testing, the visual glance reduction data was also used to create some descriptive statistical data with which to understand visual scanning in more depth.

Figure 12 shows the glance distribution across all three age groups while making a left turn. For left turns most driver groups have similar distribution by location, with the forward-looking glances almost comprising half of all glances, followed by glances to windows. The noticeable difference is for older drivers, where the second most glances were towards the right window followed by left window, which was the other way around for both the middle-age drivers and the younger drivers. More specifically the older driver had ten percent greater glances to the right

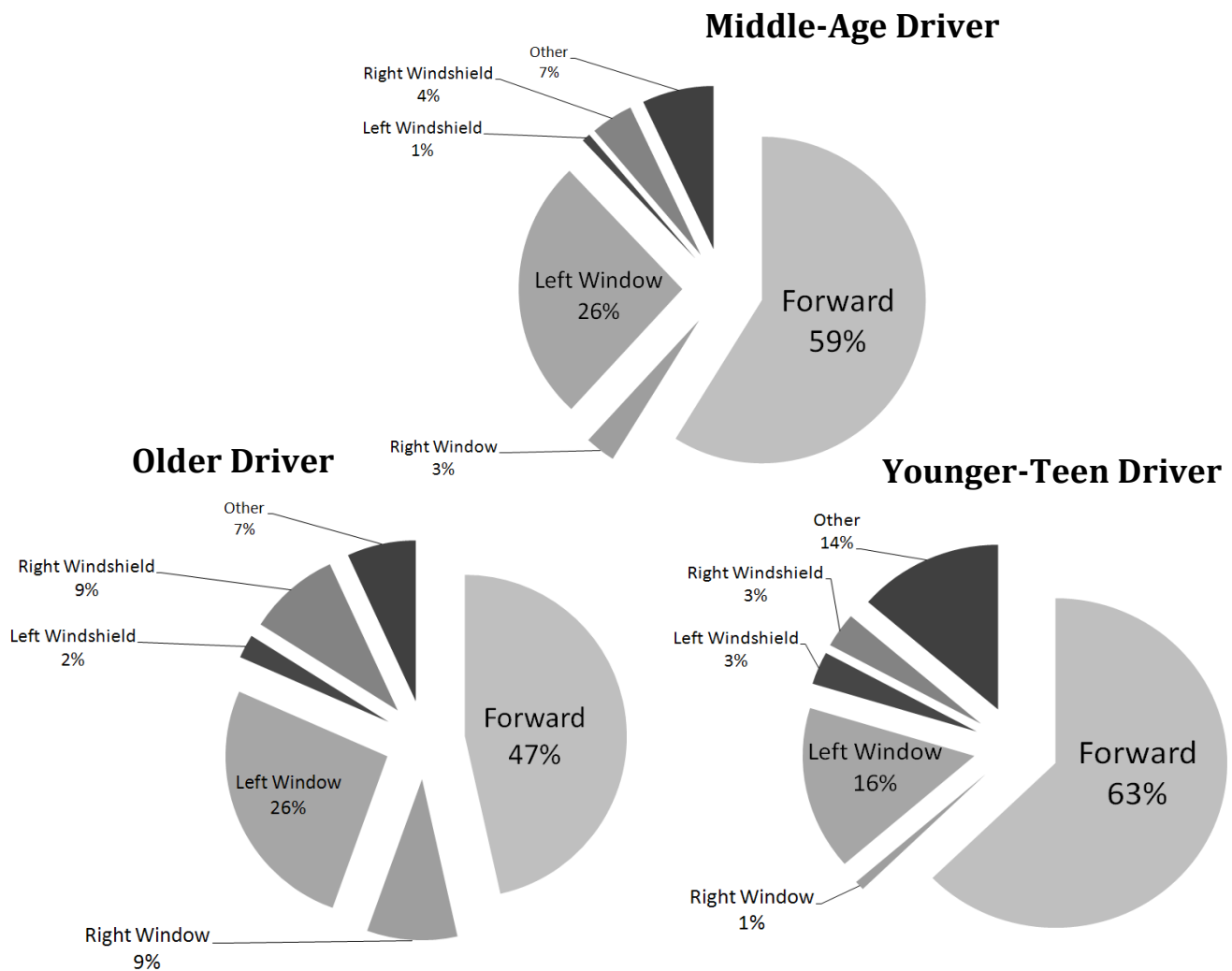
window than left, which is about sixty percent more than the glances allocated to the left window.



**Figure 12:** Glance Distribution by location for different Driver groups while making a Left Turn

Similar to glance distribution for left turns there is a pattern for the glance distribution for the right turns as well, with the forward glance location having about fifty percent of the glances (Figure 13). The patterns are more consistent across the age groups for right turns, with left window glances occupying the second most glance percentage.





**Figure 13:** Glance distribution by location for different driver groups for making a Right Turn

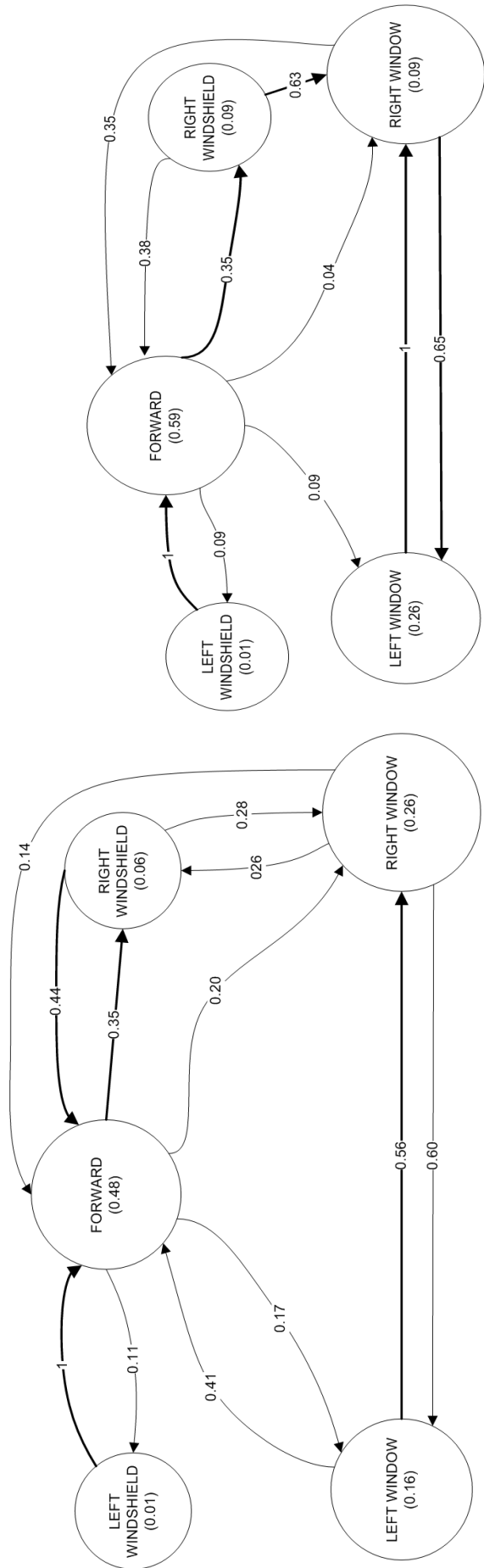
The left turn glance distribution shows similarities to right turn glances in their forward glances share, for left turns there were equal glance distribution between left and right window. In the case for right turn glances to right window are negligibly reduced when in comparison to the left turn glances. This can be explained by the fact that while making a left turn into flowing or through traffic the drivers need to check the traffic stream from the left, thereby checking their left window and then checking the traffic stream from the right, the lane to which the vehicle is going to merge. On the other hand, the percentage of right window glances drop when making a right turn as the drivers are only concerned with the traffic approaching them from the left, so most glances are to the left window.

Link Analysis of different driver groups for both the left turn and right turn were done. Link Analyses depicts the sequence and probability with which drivers glance to different locations over a period of time (such as driving through an intersection. In this case, they were done in order to discover whether the driver age groups scanned the intersections with the same pattern. Link probabilities were calculated as relative frequencies similar to how it was calculated in Tijerina et.al (1997). The individual probability for a glance location was a ratio of the number of glance occurrences for a particular location to the total number of glance occurrences.

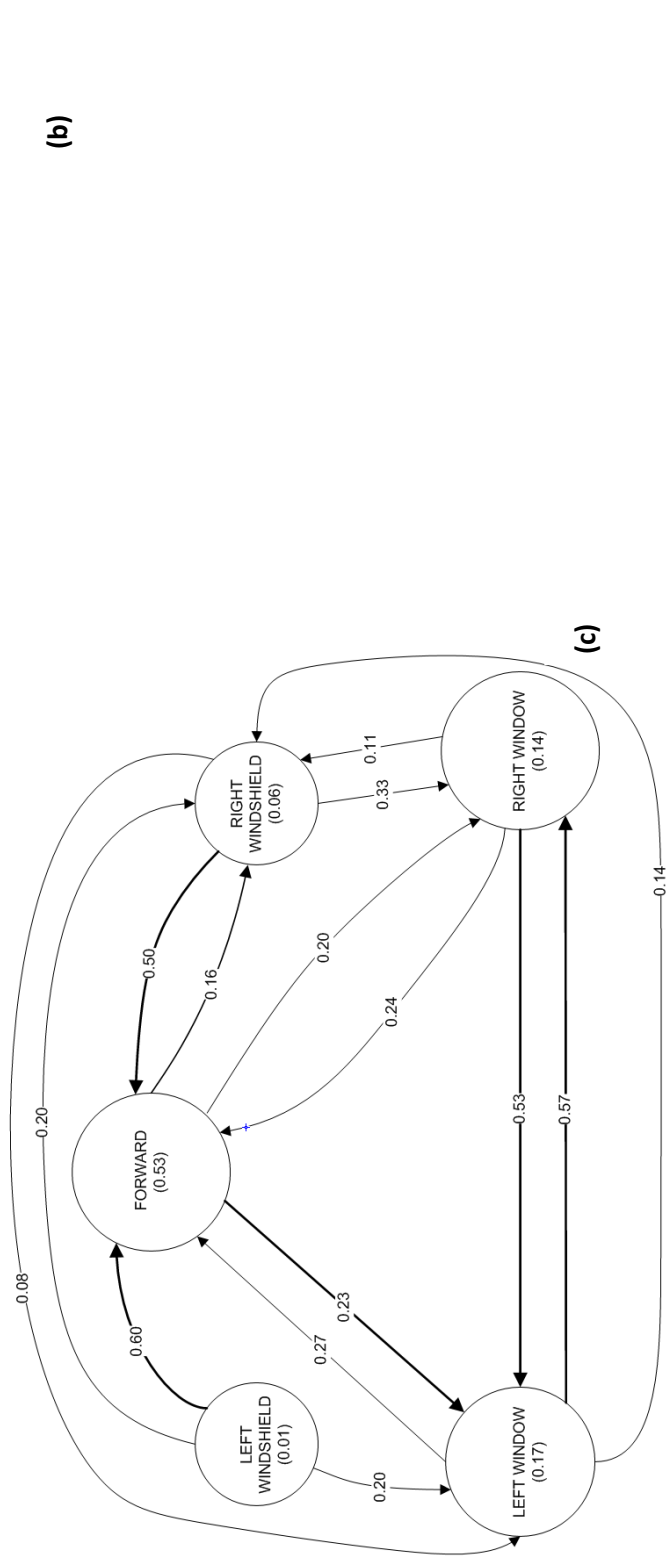
Figure 14 and 15, show the link-diagram for different glance locations, where the probability between two different glance locations shown on the link between the two locations and the proportion of glance per location mentioned inside the circle. When the visual glance reduction was carried out, twenty locations were coded, but all locations which were initially coded are not included in the link diagram. For purposes of a link analysis such as this one, it is useful to prune the links so that the most frequently traversed can be clearly seen and are not obscured by low-probability nodes and links that arise from the outlying tails of a group's glance-frequency distribution. Therefore, the inclusion rule applied in this analysis was two-fold: All locations were included in the link analysis if the link between them and any other glance locations were present such that their frequency was greater than 5 percent of the total number of link transitions between all locations for each age-group, and/or if a link went to/from one of the five 'major' nodal glance locations, namely: Forward roadway, Left windshield, Left window, Right windshield and Right window. These five were locations to which a majority of the drivers had glances, and these locations thus were revealed in the data as important glance locations for the task of making unprotected intersection turns.

From figure 14 is the link diagram for all driver groups while making a left turn. It can be seen that while making left turns drivers, one of the most important location transition was a scanning pattern from side to side i.e. from left window to right window. This would make sense considering that drivers need to continuously monitor both streams of traffic while making a left turn. A key difference for left turns was for both older and middle-age drivers the highest probability of next glance location from the forward roadway direction was to the right

windshield, whereas for the younger driver that location was the left window. There was also some disparity for transition from Right Windshield to other locations for both the older drivers and younger drivers, who had the highest probability to move back to the forward location whereas the middle-age drivers transitioned to the right window. Similarly figure 15 like the figure 14 shows the link diagram for all age groups while making a right turn.



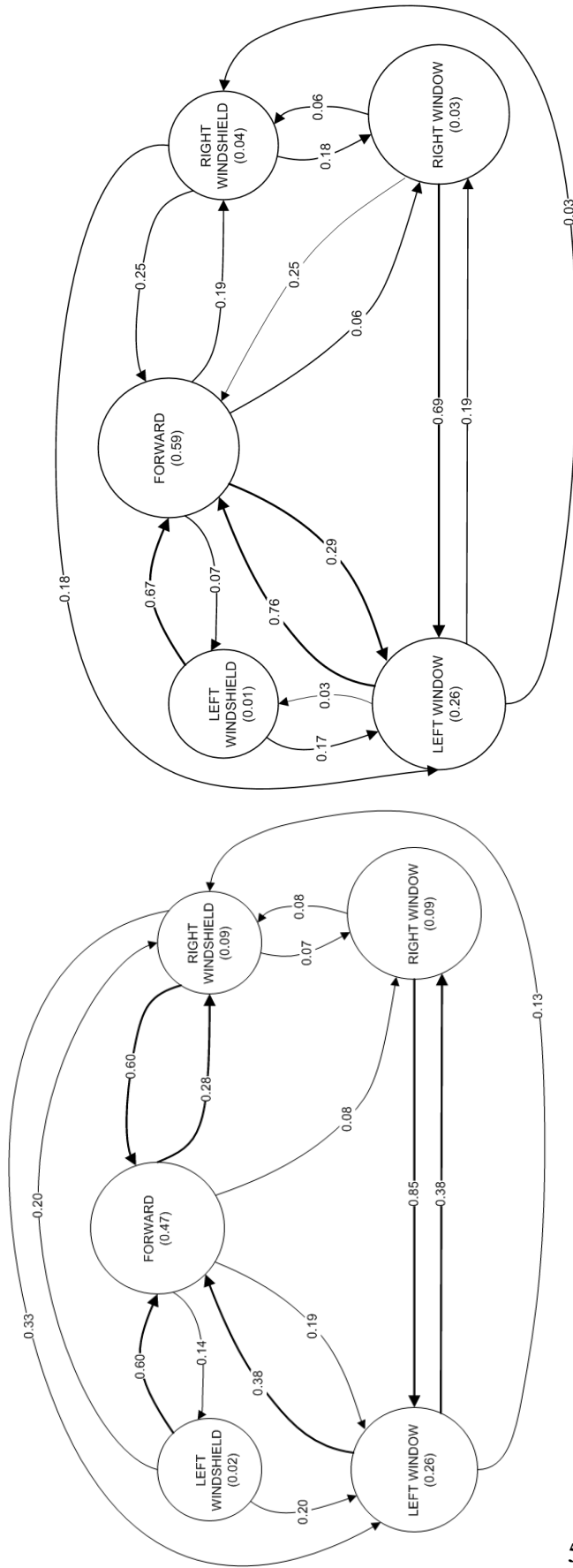
(a)



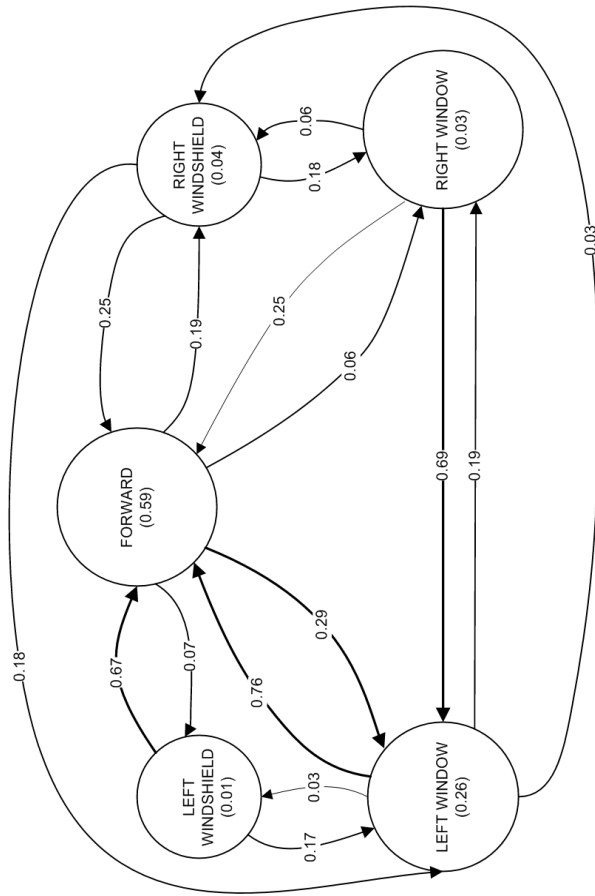
(b)

(c)

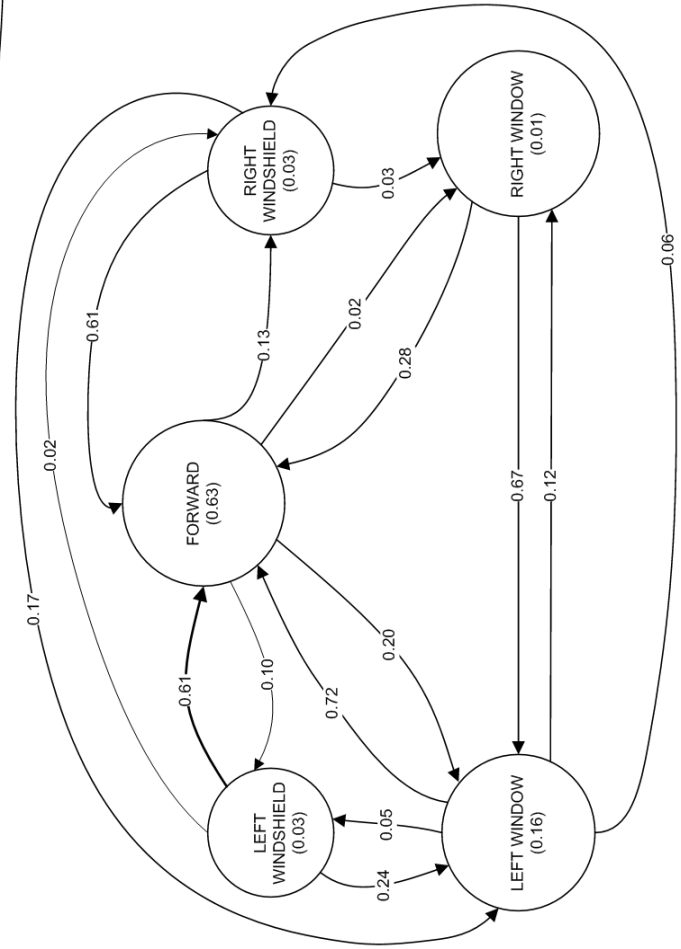
**Figure 14:** Probability Link Diagram for glance transitions between different glance locations while making LEFT TURN for (a) Older Driver, (b) Middle-Age Driver and (c) Younger – Teen Driver



(a)



(b)



(c)

**Figure 15:** Probability Link Diagram for glance transitions between different glance locations while making RIGHT TURN for (a) Older Driver, (b) Middle-Age Driver and (c) Younger –Teen Driver

Similarly figure 15, like figure 14, shows the link diagram for all age groups while making a right turn. One of the key differences is for both the middle-age driver and the teen driver the highest probability transition from the forward direction is to the Left window, which would make sense considering that there the traffic stream from that side is critical for the driver in making the turn. Whereas, older drivers had a higher probability to transition to the right windshield from the forward direction. Also for right turns the most likelihood of transition from the right window is the left window for all drivers. Overall, Link diagrams show a very different driver performance characteristic usually not captured by traditional descriptive statistics like glance duration.

### **5.1.2 Hypothesis 2: *Older drivers will have longer fixated glance durations in comparison to the teen driver***

To test this hypothesis the average duration of glances to each location is calculated. This measure is reflective of the fixation of the driver glances to each glance location. The null and alternate hypotheses are listed below

Ho: There will be no difference in the Mean Duration to various glance locations for different driver groups.

Ha: There will be a difference in the Mean Duration to various glance locations for different driver groups.

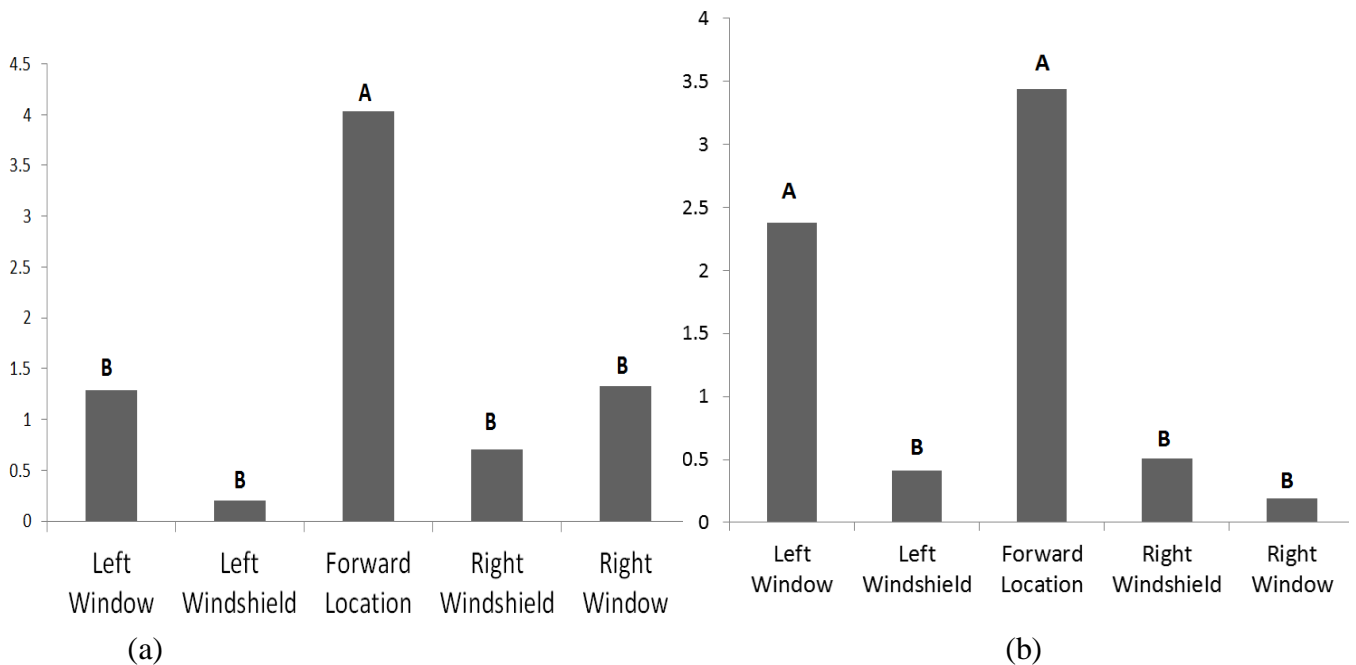
To investigate for the above hypothesis, a mixed -factor design block was created to analyze mean duration of glances to each location. Compared to the previous experimental design block Glance location is introduced as an independent variable with five levels. The levels identified, were those which had the most proportion of glances for all three driver-age-groups, but were also considered to be critical glance location with regards to making an unprotected turn. The five locations were Forward roadway, Left windshield, Left window, Right Windshield and Right Window. It is important to note that IV driver-group and Traffic –level are between subject IV, whereas for the glance location IV it is manipulated as a within subject variable.

In previous sections we have discussed how this research will predominantly use Univariate ANOVA for analysis purpose. However only for this particular research hypothesis, which has an unbalanced mixed design block, the Restricted Maximum Likelihood Method (REML) approach to ANOVA will be used. The ANOVA model is complicated in the case for a mixed-factor design as the participant is marked to have random effects and a generalized linear model is hard to obtain. Further, as this is an unbalanced design with unequal sample sizes, the estimated mean square to be calculated for a mixed design is difficult. REML does not need the decomposition of the sums of squares but instead uses a likelihood function calculated from the probability distribution of contrasts; the contrasts are obtained through transformation of original data. Table 15 below shows the fixed effect tests for the two turn types, all interaction term for Location level were not considered as that would reduce the degrees of freedom for the Main effects degrees of freedom, considering that there are 5 levels of locations.

**Table 15:** Type-3 test of Fixed effects table for the two turn types

<b>Dependent Variable</b>	<b>Source</b>	<b>DF</b>	<b>F- Ratio</b>	<b>Prob &gt; F</b>
<b>LEFT TURNS</b>				
Mean Duration of Glances	Driver Group	2	0.96	0.3884
	Traffic-Level	1	0.001	0.9972
	Location-Level	4	38.77	<0.0001*
	Driver-Group X Traffic-Level	2	0.26	0.7726
<b>RIGHT TURNS</b>				
Mean Duration of Glances	Driver Group	2	0.36	0.6982
	Traffic-Level	1	0.92	0.3407
	Location-Level	4	33.67	<0.0001*
	Driver-Group X Traffic-Level	2	0.17	0.8479

From table 15 it can be seen that significant differences exist between the location levels for both the turns. Post-hoc Tukey's HSD test for the glance location levels for their mean duration of glances while making a left turn reveal that there is a significant difference between the forward location compared to other location levels. Figure 16(a) shows the different means for the mean duration of glances for the different glance location for left turns and it can be seen that the forward location compared to any other locations. In contrast, for right turns there is a significant difference between the left-window and forward-location. Note that for the figure levels not connected by the same letter are significantly different i.e. the younger and the middle-age driver.



**Figure 16:** Means of mean-duration of glance per location for (a) Left Turn (b) Right Turn

The difference in the glance pattern for the two turn types is justified, while making a left turn drivers have to scan both sides of the traffic thereby there is an equal proportion of glances to the left and the right window. Whereas while making a right turn there is a higher proportion of glances to left side compared to the right, as the traffic stream from the left is more critical to the drivers making turns.



## **5.2 Results: How do drivers manipulate their gap acceptance levels across age groups?**

### **5.2.1 Hypothesis 3: The younger driver group will accept lesser gaps in traffic to make unprotected turns when compared to other age groups.**

The dependent variable used was the accepted gap times, i.e. the gap-time that were accepted by the drivers. All gaps presented to the drivers in their naturalistic driving scenario, which they decided to either accept or reject.

Ho: There will be no difference in the accepted gap times for different driver-groups

Ha: There is a difference in the accepted gap times for different driver groups

The experimental design incorporated here was similar to the one incorporated before i.e. a  $3 \times 2$  block between-subject design, with 3 levels of driver group and 2 levels of traffic condition. The driver group levels comprised of Older, Middle Age and Younger Driver, and the traffic levels were contained two levels namely, Traffic present and No Traffic present.

Table 16 reveals that there is no significant difference between either the driver-groups, traffic – levels or their interaction term for accepted gap times. To this, we can conclude that there is not enough evidence to reject the null hypothesis with confidence.

However, even though there were no statistical difference overall, for the right turn the effect of driver age group approached significance ( $p=0.057$ ) for accepted gap times. On further exploration, trends suggest that older drivers wait for longer gaps in traffic before making their right turn. Post-hoc Tukey HSD test did not show any significant difference. However, the student t post-hoc test, which is not as conservative as the Tukey test, revealed a significant difference between driver groups.

**Table 16:** ANOVA table for Accepted Gap-time utilizing a Driver-Group ×Traffic-levels design

Dependent Variable	Source	DF	Type III Sum of Squares	Mean Square	F-Ratio	Prob > F
<b>LEFT TURN WITH TRAFFIC LEVELS</b>						
Accepted Gap Time	Driver Group	2	1.88	0.94	0.27	0.77
	Traffic Level	1	6.09	6.09	1.71	0.23
	Driver-Group X Traffic-Level	2	5.91	2.96	0.83	0.47
	Error	8	28.42	3.55		
<b>RIGHT TURN WITH TRAFFIC LEVELS</b>						
Accepted Gap Time	Driver Group	2	19.67	9.83	3.65	0.057 <sup>#</sup>
	Traffic Level	1	0.02	0.02	0.01	0.93
	Driver-Group X Traffic-Level	2	2.78	1.39	0.52	0.61
	Error	12	32.36	2.70		

Figure 17 shows this: that the student-t post hoc test revealed a significant difference between the Older Driver Group and the Younger Driver Group for their Accepted Gap times. The key below the figure shows the letter denotation of the two different post hoc-tests (Student-t and Tukey's HSD) with different letters identifying where the significant difference lies.

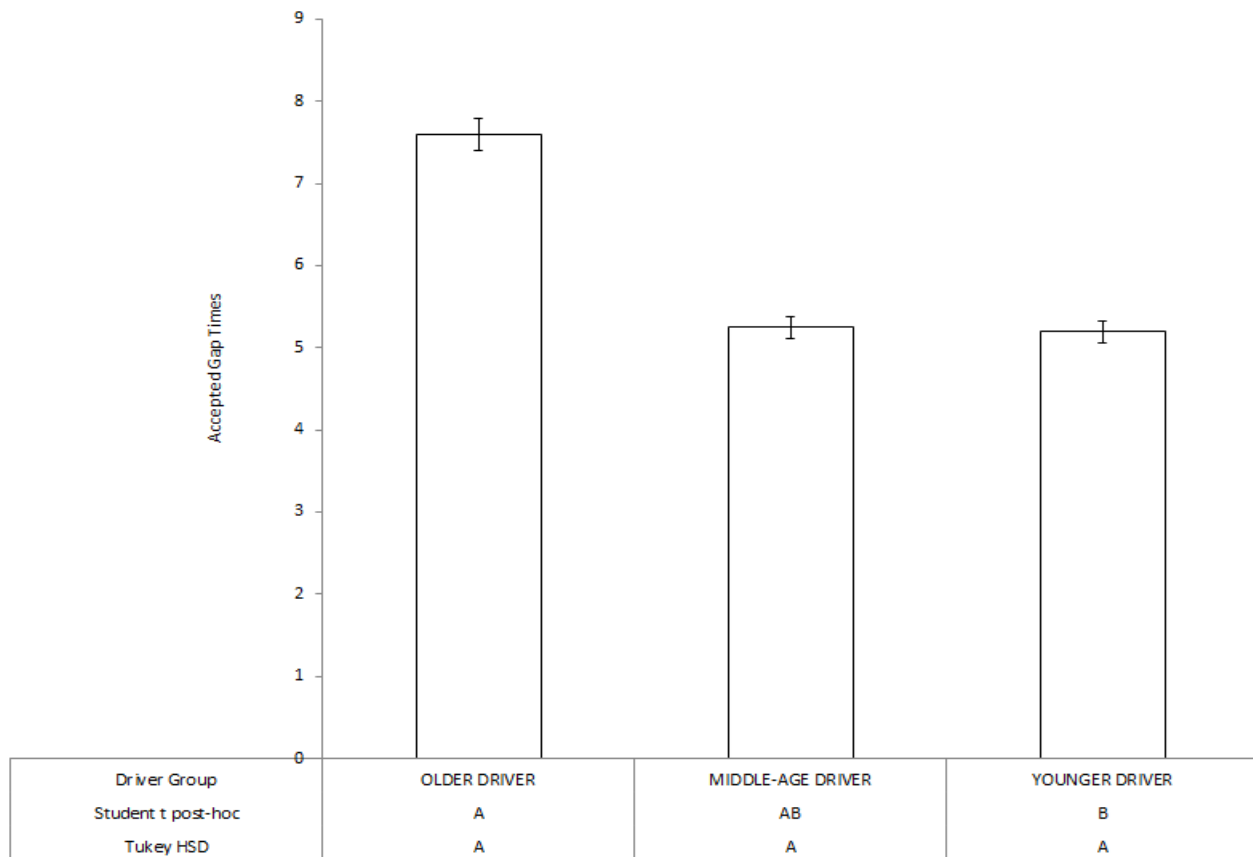


Figure 17: Accepted Gap time for different driver groups while making a right turn

### 5.2.2 Hypothesis 4: Older driver group need significantly larger gaps to make unprotected turns and will reject smaller gaps available compared to other drivers

The following null and alternate hypotheses are constructed to answer the primary hypothesis above:

Ho<sub>1</sub>: There will be no difference in the *Not-Accepted* gap times for different driver-groups

Ha<sub>1</sub>: There is a difference in the *Not-Accepted* gap times for different driver groups

Ho<sub>2</sub>: There will be no difference in the *Accepted* gap times for different driver-groups

Ha<sub>2</sub>: There is a difference in the *Accepted* gap times for different driver groups

To support the hypothesis of whether older drivers need larger gaps and that they will reject smaller gap opportunities, an analysis of variance was carried out on the accepted gap time and the not-accepted gap time. Apart from the accepted gap times that were analyzed, gaps that presented themselves to the drivers but were not accepted were also recorded and analyzed. These not accepted gaps, like the accepted gaps, put light on driver preferences in gap selection

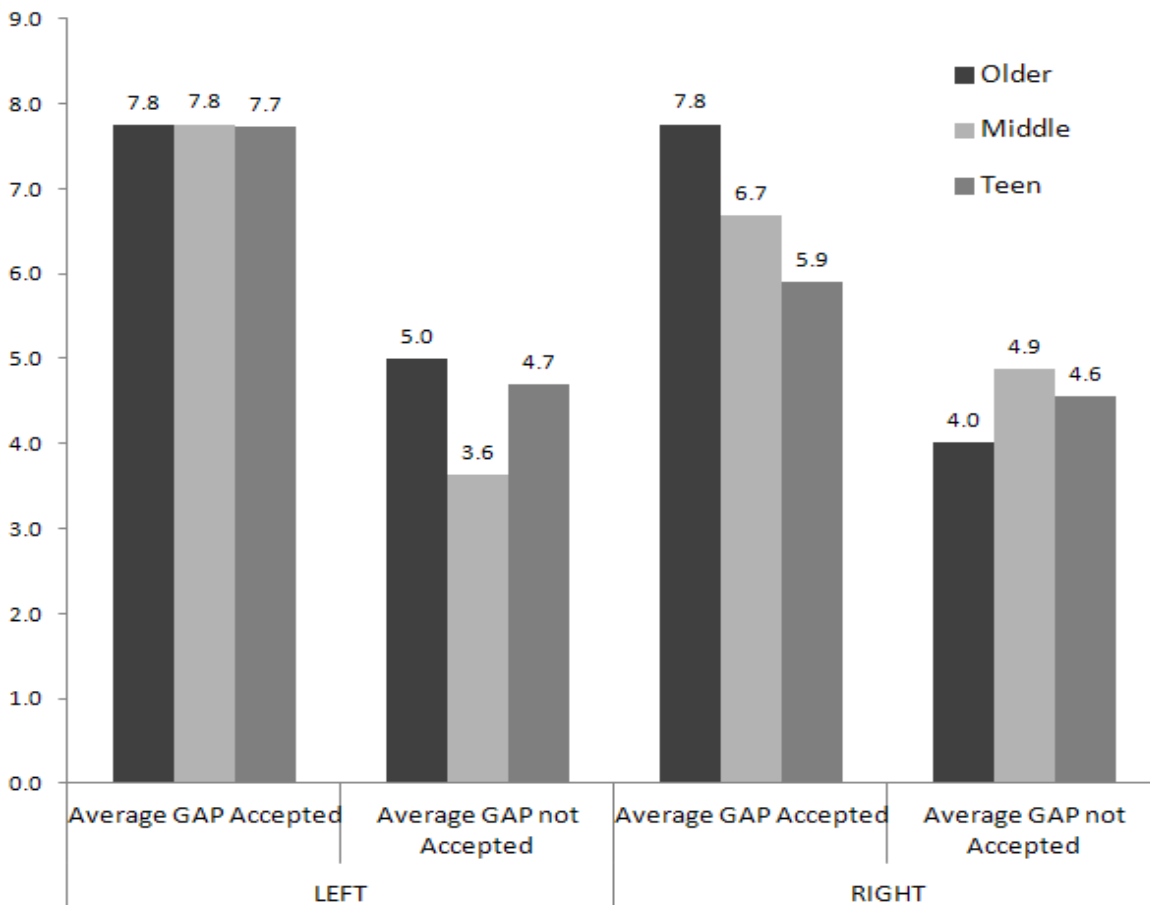
A one-factor ANOVA was performed to see driver group differences for different turn types for both accepted and not accepted gaps. Table 17, contains the ANOVA table for both accepted-gap times and Not-Accepted Gap times for both left and right turns.

**Table 17:** ANOVA table for Accepted gap-times and Not-Accepted Gap times by driver group

Dependent Variable	Source	DF	Type III Sum of Squares	Mean Square	F Ratio	Prob > F
<b>LEFT TURN</b>						
Accepted Gap Time	Driver Group	2	0.40	0.20	0.06	0.94
	Error	11	33.69	3.06		
Not Accepted Gap Time	Driver Group	2	3.17	1.59	0.66	0.53
	Error	12	28.65	2.39		
<b>RIGHT TURN</b>						
Accepted Gap Time	Driver Group	2	11.75	5.87	1.64	0.22
	Error	17	60.89	3.58		
Not Accepted Gap Time	Driver Group	2	4.17	2.08	0.89	0.43
	Error	17	39.58	2.33		

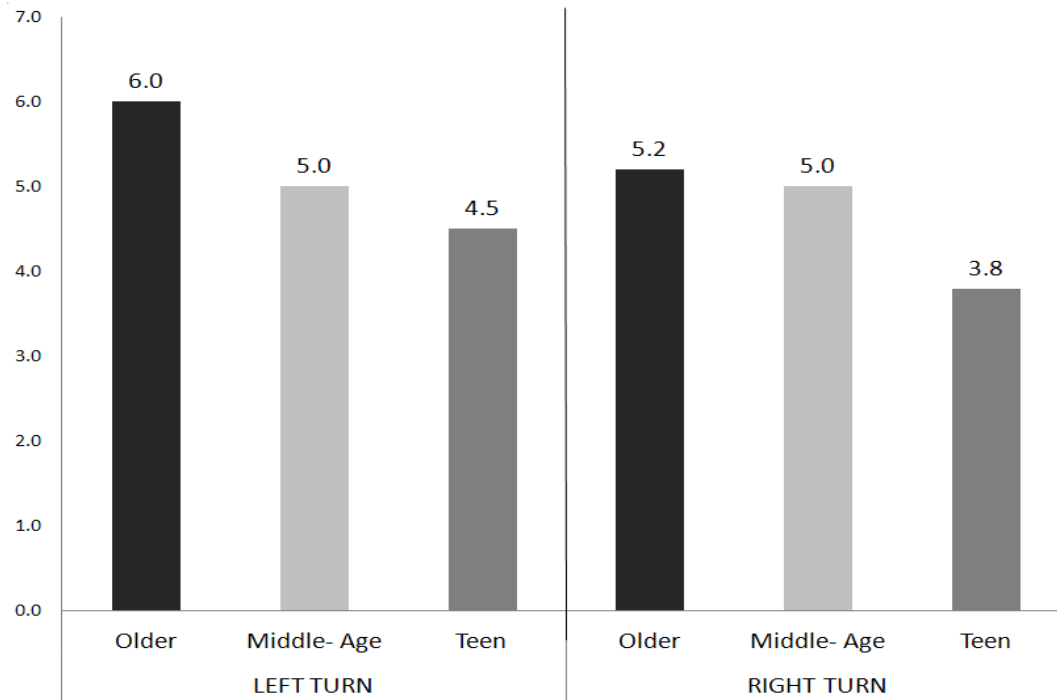
Table 17 reveals that there was no significant main effect of driver age groups for either the accepted gap times or the not-accepted gap times. Thus, there was not sufficient evidence to reject the null hypothesis that there are differences in the driver age group for accepting gaps of specific duration for either the left turn or the right turn. Similarly, there was not enough evidence to reject the null hypothesis that drivers of different age-group have differences in the gaps that they reject or do not accept while making either a left turn or a right turn.

Overall, the complexity of Gap-acceptance and rejection behavior in naturalistic driving stems from the fact that the gaps that present themselves to the driver are not controlled for. Figure 18 shows the average time of accepted gaps and not accepted gaps for each driver-group as they existed in their driving data.



**Figure 18:** Average gaps-accepted and gaps not-accepted time (in seconds) for all drivers by age-group and turn type

It can be seen from the figure that there is no specific direction of trend in gaps that exist. Average accepted gap for left turns for all the driver groups are close, even though there is a declining trend for the same average accepted gap for right turn going from older driver to middle-age driver to teen drivers. In comparison figure 19, shows the smallest accepted gaps for each of the driver groups.



**Figure 19:** Smallest Accepted Gaps (in seconds) for all Age-Groups while making a left and right turns

It can be seen from figure 24 that older drivers usually accept gaps of larger size followed by middle-age drivers and teen drivers irrespective of the turn type. It is purely by chance that gaps that presented to the younger teen drivers were larger gaps that they accepted. The importance of studying any gap acceptance behavior is to find critical-gap acceptance times i.e. the gap time below which the drivers will reject all gaps presented to them. In other words the smallest gap that each driver will accept is critical to the gap acceptance/rejection behavior. We will discuss more on this in the discussion section about other ways in which this data can be analyzed.

### 5.3 **Results:** Are there age-related differences in driving kinematics while making turns at the intersections?

#### 5.3.1 Hypothesis 5: The Younger Driver group will exhibit higher kinematic values (lateral & longitudinal accelerations, mean speed etc.) in their initiation, execution, and completion of their turns compared to the other driver groups

To test this hypothesis, several kinematic variables were used as dependent variables. More specifically, one kinematic measure was chosen to reflect driving performance during **each** of the three phases of the turn, in addition to one measure which was chosen to characterize the turn as a whole. These were:

1. **Peak Longitudinal Acceleration.** This is reached during the **initiation phase** of the turn, as the vehicle accelerates from a stop (turn initiation zone).
2. **Peak Lateral Acceleration.** This is achieved during the **middle-part** or **execution phase** of the turn, (also known as the “conflict zone”).
3. **Peak Speed.** This is typically achieved as the vehicle has completed the turn and exits the turn, returning to steady-state, straight-path driving (the zone of completion).
4. Finally, **Average Speed.** This is used to characterize the speed throughout the *entire* turn – during all three phases of turn initiation, execution and completion.

The following are the specific hypothesis for each of the kinematic dependent variable repeated for left and right turn:

**H<sub>01</sub>:** There will be no difference in the Peak speed values for different driver-groups

**H<sub>a1</sub>:** There is a difference in the Peak speed values for different driver groups

**H<sub>02</sub>:** There will be no difference in the Peak Longitudinal Acceleration values for different driver-groups

**H<sub>a2</sub>:** There is a difference in the Peak Longitudinal Acceleration for different driver groups

**H<sub>03</sub>:** There will be no difference in the Peak Lateral Acceleration for different driver-groups

**H<sub>a3</sub>:** There is a difference in the Peak Lateral Acceleration for different driver groups

**H<sub>04</sub>:** There will be no difference in the Average Speed for different driver-groups

**H<sub>a4</sub>:** There is a difference in the Average Speed for different driver groups

Table 18 is the ANOVA table for the driver group and different dependent variables for both left and right turns. From the table we note that for left turns, there is a significant difference between the driver groups for peak speed and average speed. Post-hoc Tukey HSD test to find specific level differences were done to find and revealed a significant difference between the Older and the Younger Driver for both the peak speed and the average speed as shown in figure 20.

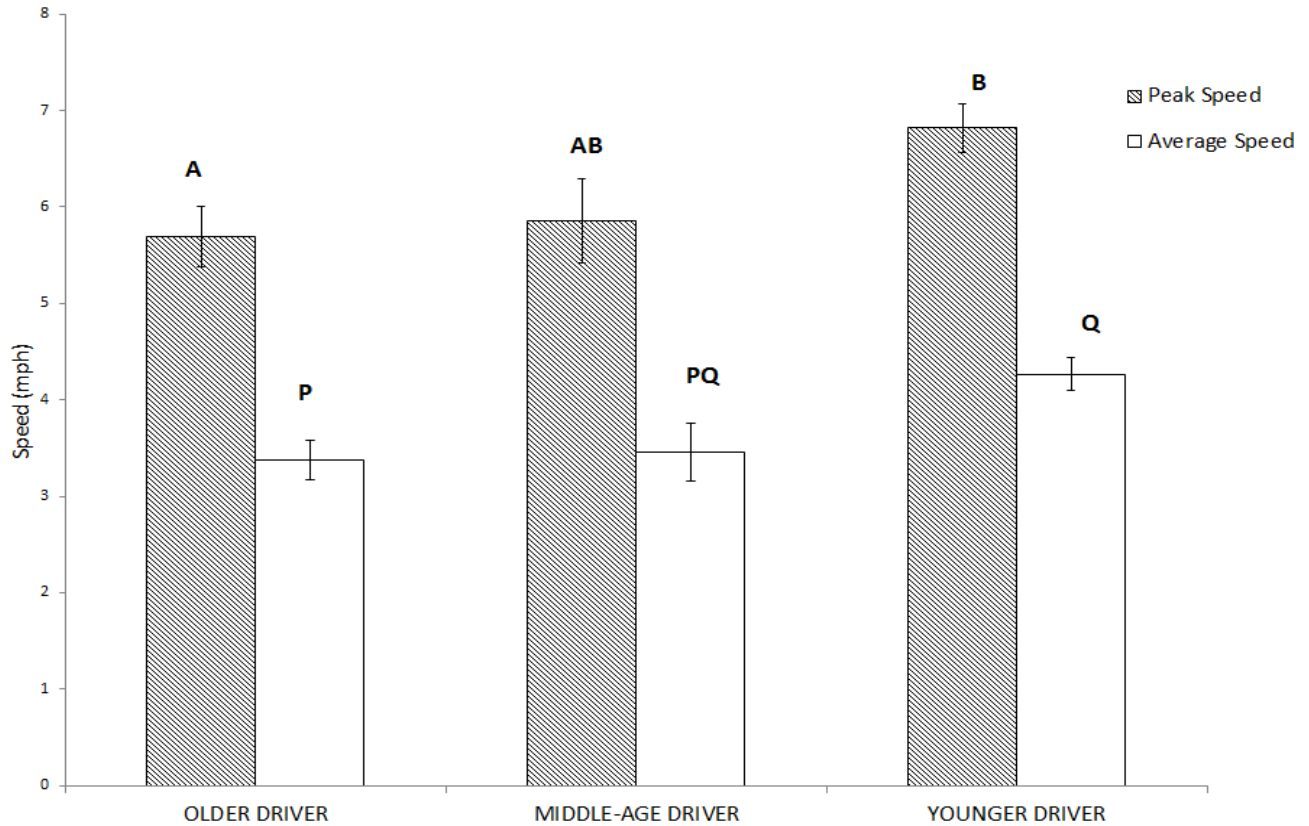


**Table 18:** ANOVA table for various kinematic dependent variables by driver group and different turn type

Dependent Variable	Source	DF	Type III Sum of Squares	Mean Square	F Ratio	Prob > F
<b>LEFT TURN</b>						
Peak Speed	Driver Group	2	5.26	2.63	4.59	.0278*
	Error	15	8.59	0.57		
Peak Longitudinal Acceleration	Driver Group	2	0.01	0.00	0.73	0.50
	Error	15	0.08	0.01		
Peak Lateral Acceleration	Driver Group	2	0.00	0.00	0.08	0.92
	Error	15	0.06	0.00		
Average Speed	Driver Group	2	3.34	1.67	6.34	0.0101*
	Error	15	3.95	0.26		
<b>RIGHT TURN</b>						
Peak Speed	Driver Group	2	0.96	0.48	0.79	0.46
	Error	22	13.28	0.60		
Peak Longitudinal Acceleration	Driver Group	2	0.02	0.01	1.87	0.18
	Error	22	0.09	0.00		
Peak Lateral Acceleration	Driver Group	2	0.03	0.02	2.47	0.108
	Error	22	0.15	0.01		
Average Speed	Driver Group	2	0.14	0.07	0.26	0.78
	Error	22	6.13	0.28		

However, for right turns, there was no significant difference between the driver groups for any of the dependent variables. However, on the dependent variable of peak lateral acceleration, the main effect for driver age group approached significance ( $p= 0.108$ ). Upon further investigation, although the Tukey HSD test revealed no significant level difference, the student t post-hoc test yielded a significant difference between the Younger and the Older Driver age groups with the

younger driver having significantly higher peak lateral acceleration compared to younger teen drivers.



**Figure 20:** Peak Speed & Average speed Means for Left Turns

For left turns, the null hypothesis is rejected for the peak speed (with teens show higher speeds in the zone of completion) and the average speed (with teens showing higher speeds throughout the whole turn). There was not enough evidence to reject the null hypothesis for the remaining kinematic variables on left turns -- either the peak longitudinal acceleration or peak lateral acceleration. For right turns, the null hypothesis could not be definitively rejected, but trends suggested that for lateral acceleration (the zone of conflict), the age groups may differ (if more statistical power were available to test the hypothesis). This trend indicated that teens execute the turn (in the conflict zone) more aggressively, with higher lateral acceleration than did older drivers. However, there were hints of trends on the remaining kinematic variables.

**5.3.2 Hypothesis 6: Older driver group will exhibit more cautious and lower kinematic values in their initiation, execution, and completion of their turns, and this tendency toward slow responding will be amplified in the presence of other traffic.**

The hypotheses blocks are similar to the ones previously used apart from the fact that there is a traffic component included in each of the hypothesis, so they state as follows:

1. **H<sub>01</sub>**: There will be no difference in the Peak speed values for different driver-groups in presence of traffic

**H<sub>a1</sub>**: There is a difference in the Peak speed values for different driver groups in presence of traffic

2. **H<sub>02</sub>**: There will be no difference in the Peak Longitudinal Acceleration values for different driver-groups in presence of traffic

**H<sub>a2</sub>**: There is a difference in the Peak Longitudinal Acceleration values for different driver groups in presence of traffic

3. **H<sub>03</sub>**: There will be no difference in the Peak Lateral Acceleration values for different driver-groups in presence of traffic

**H<sub>a3</sub>**: There is a difference in the Peak Lateral Acceleration values for different driver groups in presence of traffic

4. **H<sub>04</sub>**: There will be no difference in the Average Speed values for different driver-groups in presence of traffic

**H<sub>a4</sub>**: There is a difference in the Average Speed for different driver groups in presence of traffic

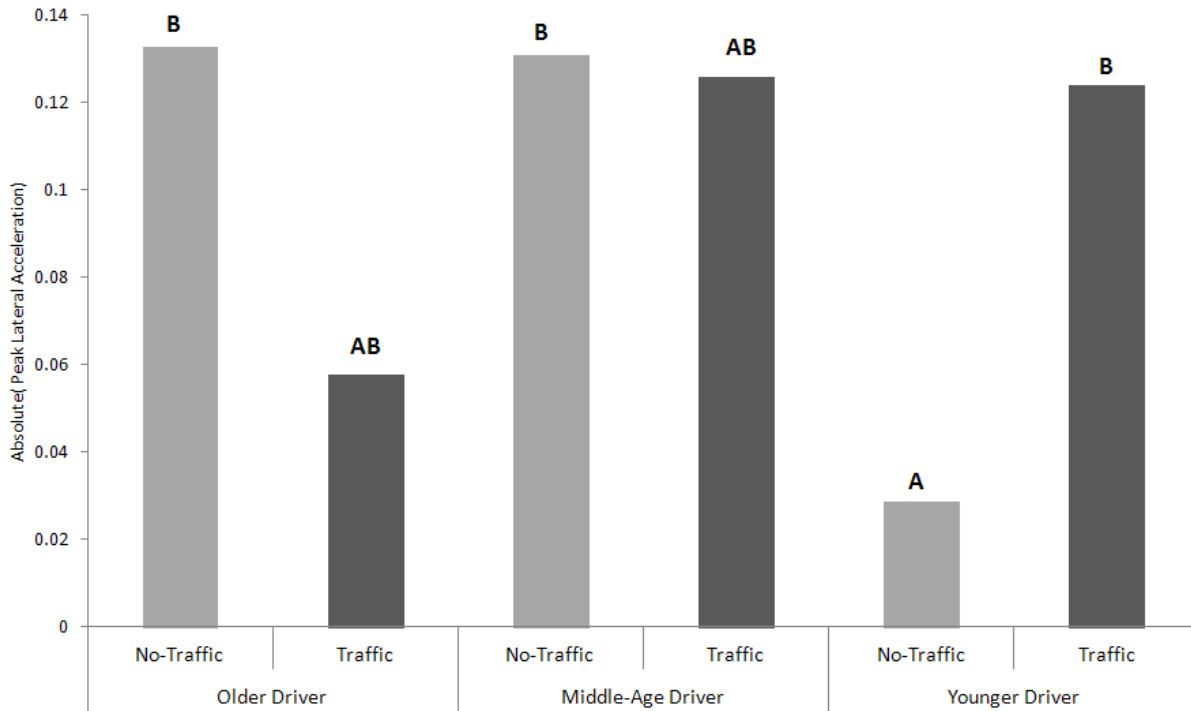
A  $3 \times 2$  block between-subject design, with three levels of driver group and two levels of traffic condition was used. Table 19 shows the ANOVA table for the different dependent variables analyzed for driver groups and traffic for left turns. The analyses revealed the following significant findings for kinematic variables:

- For Peak Speed (zone of completion), there was a significant main effect of Traffic Level , where peak speed was higher when no traffic was present in the intersecting lanes when compared to the presence of traffic.
- For Peak Lateral Acceleration, there was a significant interaction of Traffic Level X Driver Group, which is illustrated in figure 21. The figure also shows the student-t post hoc test where levels not connected by the same letter have significant difference.

**Table 19:** ANOVA table for Driver Group by Traffic level when making Left turns

Dependent Variable	Source	DF	Type III Sum of Squares	Mean Square	F Ratio	Prob > F
Peak Speed	Driver Group	2	4.27	2.14	3.41	0.07
	Traffic Level	1	3.99	3.99	6.37	0.0267*
	Driver-Group X Traffic-Level	2	0.02	0.01	0.02	0.98
	Error	12	7.52	0.63		
Peak Longitudinal Acceleration	Driver Group	2	0.011	0.005	0.953	0.413
	Traffic Level	1	0.000	0.000	0.058	0.814
	Driver-Group X Traffic-Level	2	0.007	0.004	0.646	0.542
	Error	12	0.067	0.006		
Peak Lateral Acceleration	Driver Group	2	0.006	0.003	1.18	0.34
	Traffic Level	1	0.000	0.000	0.04	0.85
	Driver-Group X Traffic-Level	2	0.024	0.012	5.10	0.0250*
	Error	12	0.028	0.002		
Average Speed	Driver Group	2	1.05	0.52	1.00	0.40
	Traffic Level	1	0.33	0.33	0.63	0.44
	Driver-Group X Traffic-Level	2	0.13	0.06	0.12	0.89
	Error	12	6.32	0.53		

Analysis of the Lateral acceleration measures showed a significant interaction between the traffic levels and driver age group while making a left turn. This significance in Peak Lateral acceleration is due to the presence of traffic, as in the presence of traffic drivers tend to complete the turn at a faster rate, thereby generating more peak lateral acceleration.



**Figure 21:** Absolute values of Peak Lateral Acceleration MEANS for different combination of factor-levels while making a left turn

From figure 21 it can be seen that the younger driver had a significantly higher peak lateral acceleration mean value in the presence of traffic in comparison to the absence of traffic. Further, the peak lateral acceleration mean value in the absence of traffic for younger drivers was significantly lower than the drivers of the other age-groups for the same no-traffic condition. On the contrary the older driver had the, albeit not significant but, the lowest peak lateral acceleration mean value in the presence of traffic compared to the other driver age-groups.

Table 20 is the ANOVA table for the different dependent kinematic variable tested for driver groups and traffic levels and unlike for left turns, no significant differences were found for the right turn.

Finally, to sum up the Hypothesis there was only evidence to reject the null hypothesis for the peak speed and peak lateral acceleration while making a left turn coupled with the factor of traffic presence/absence. No such differences were found for the right turn for any of the kinematic dependent variables.

**Table 20:** ANOVA table for Driver Group by Traffic level when making Left turns

Dependent Variable	Source	DF	Type III Sum of Squares	Mean Square	F Ratio	Prob > F
<b>RIGHT TURN</b>						
Peak Speed	Driver Group	2	2.88	1.44	0.89	0.43
	Traffic Level	1	1.28	1.28	0.79	0.39
	Driver-Group X Traffic-Level	2	0.99	0.50	0.31	0.74
	Error	16	25.90	1.62		
Peak Longitudinal Acceleration	Driver Group	2	0.01	0.00	1.06	0.37
	Traffic Level	1	0.00	0.00	0.80	0.38
	Driver-Group X Traffic-Level	2	0.01	0.00	0.62	0.55
	Error	16	0.06	0.00		
Peak Lateral Acceleration	Driver Group	2	0.02	0.01	1.60	0.23
	Traffic Level	1	0.01	0.01	1.27	0.28
	Driver-Group X Traffic-Level	2	0.03	0.01	1.98	0.17
	Error	16	0.10	0.01		
Average Speed	Driver Group	2	0.47	0.24	0.56	0.58
	Traffic Level	1	0.16	0.16	0.37	0.55
	Driver-Group X Traffic-Level	2	0.49	0.25	0.58	0.57
	Error	16	6.73	0.42		

## 6. Discussion

This research work mainly tried to test for differences in various driver groups separated by age, in their negotiation through an unprotected turn. More specifically this research aimed to answer all the posted research questions by observing drivers in their natural driving environment, rather than having them drive in a controlled experimental setup.

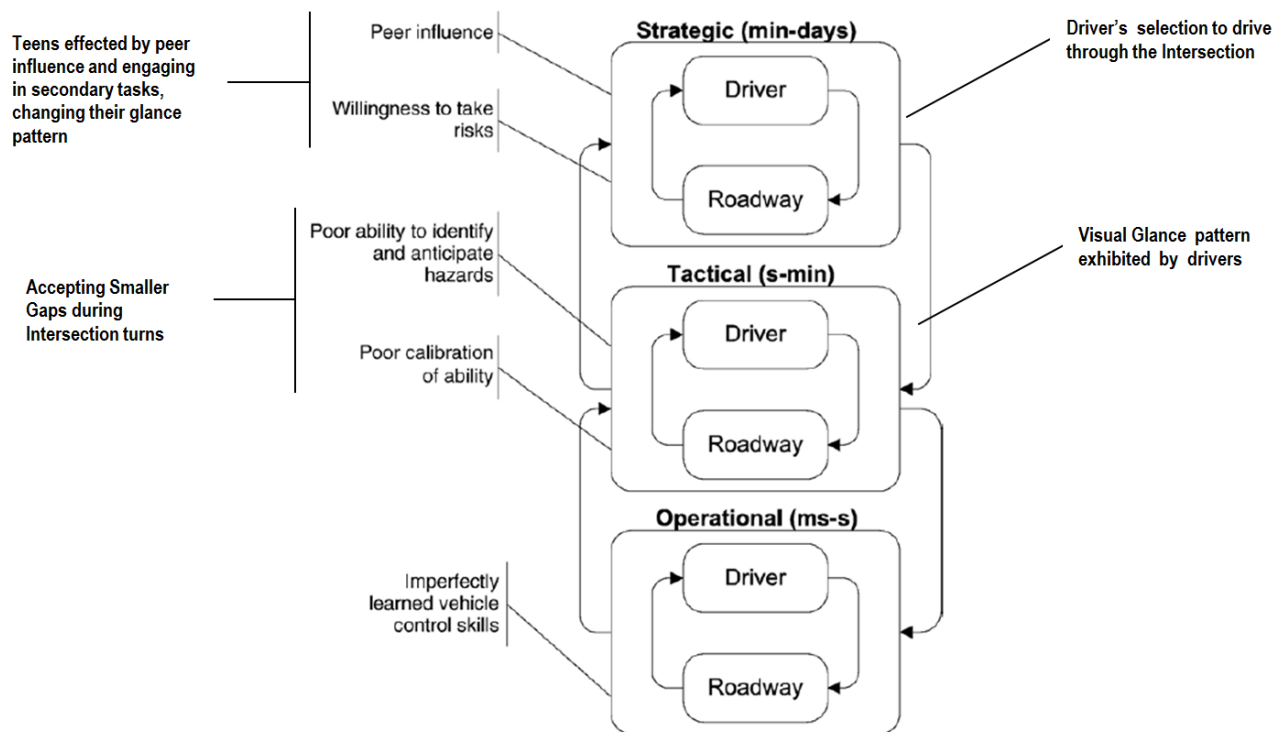
### 6.1 How do drivers regulate their visual glances while making unprotected turns?

Visual entropy values were calculated and used as the dependent measure for all the experimental design blocks. This entropy measure gives out an elevated value when the drivers have a spread distribution of glances across multiple glance locations. Entropy analysis revealed that there is a significant difference between entropy values of drivers in the presence or absence of traffic for left turns and approaching significance value for right turns. Further, younger teen drivers had lower entropy compared to other drivers in no-traffic conditions, but also had the highest entropy compared to other drivers in traffic condition. So overall teen drivers had the highest discrepancy in their visual entropy values

Now ideally if the glance distribution is spread out to locations which are critical for a driver to make the turn into flowing/through traffic it can be considered as glances of importance. Link analysis for all drivers had similar locations, but overall the younger driver glances are distributed to Off-Road glance locations. Some of these non-relevant locations for the younger teen drivers were not included in the link analysis as they comprised of not-task (executing the turn) related glances to locations which include passengers, Interior Objects, Cell-phone amongst other things. These glances are important in the aspect of how this driver group have the propensity of engaging in secondary tasks or are a more distracted driver group. Lee et.al (2006) in their research found how teen drivers had significantly higher Eyes-Off-Road time than adults, while performing in-vehicle tasks. More specifically the Lee and her colleagues found how novice teen drivers spent most of their overall eyes off road time looking at task display whereas adults used the same eyes off road time to check mirrors or windows.

Beyond the visual scanning behavior, other researchers have noted that sometimes it is not just the ability to detect hazards and imminent dangers by this younger driver group, but the tendency to underestimate them that cause crashes (Lee J. D., 2007). Previous intersection related driving research has often been conducted neglecting the traffic component in driving. A lot of research studies have been done in a controlled environment removing the need to study traffic levels or are simulator research that only mimics a real world-driving situation. Similar to the single factor level (driver-group) study of entropy, a new factor was introduced to the design in the form of a traffic level. The traffic level contained two levels, No traffic present in the intersecting stream and Traffic present in the intersecting stream.

Lee, J.D. (2007) created a multi-level control diagram for driving to represent driving as a three level control task in which breakdowns at one level propagate to other levels. Figure 22 is an adaptation to depict the control diagram in light of the work around unprotected intersections in this research.



**Figure 22:** Modified multi-level control diagram for driving through an unprotected intersection turn.

*Source:* Adapted from Lee, J. D. (2007). *Technology and teen drivers. Journal of Safety Research* , 203-213.

*Used under FAIRUSE guidelines(2011)*

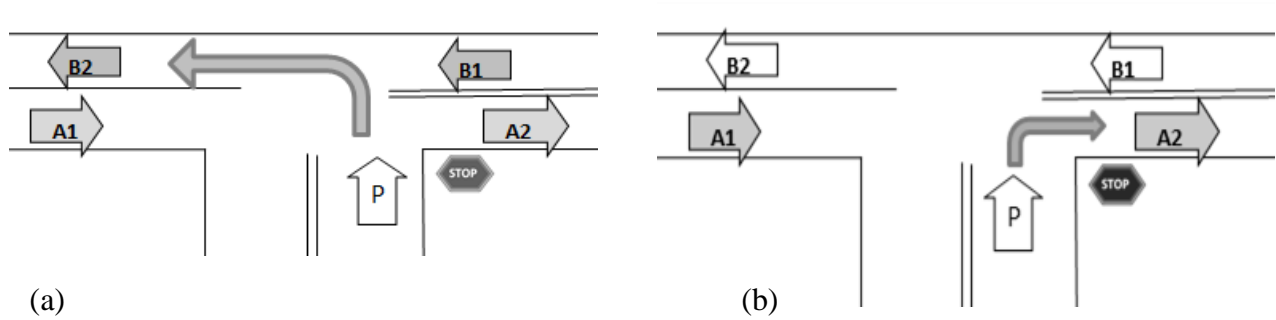


The bottom level deals with operational controls like the ability to maintain a speed, lane position etc., and the second level is the tactical level, which reflects on driver's ability to select an appropriate speed, identify and anticipate hazard etc. Finally, the top level is the strategic level, which is the choice of destination, route, acceptance of norms and risks, allowing passengers in car. Lee, J.D. (2007) presented the case that how the failure of control at each level and their propagation into other levels contribute to crashes. About the visual aspect of dealing with unprotected turns, the problem lies at the tactical level for the younger drivers, who overestimate their ability to identify and anticipate hazards. Lee, J.D. (2007) made a connection for the tactical level for the teen driver to the strategic level where the teen driver includes other teens as passengers and through peer influence elevates his/her ability to take risks. It can also be seen that on an operational level the lack of experience and knowledge of visual glancing can lead to poor decision making in the tactical level.

This can be observed as younger-teens had more glances to locations otherwise not present for older or middle-age drivers. Further, literature has pointed out how younger drivers are more likely to engage in secondary tasks in comparison to any other age-group. This leads to a lot of glances which do not constitute significant glances to driving and negotiating driving related hazards.

Older Drivers also exhibit a breakdown in their tactical control level. Their acceptance of smaller gaps or rejection of reasonable gaps to wait for extremely larger gaps is an example of that. The risk older drivers put themselves to choose to drive through an intersection with through traffic conditions can be seen as a strategic level choice that they are willing to make.

Now the analysis for the visual entropy revealed significance for left turns but there was no significance between the traffic levels for right turns. This discrepancy in the results for the turn types can be potentially attributed to the varying traffic density levels and the other could be smaller sample size.



**Figure 23:** (a) Traffic Illustration while making a left turn, (b) Traffic Illustration while making a right turn.

Note: *Highlighted traffic stream are of concern.*

Hypothesis 2 tested for the fixation to specific glance location for different driver groups in varying traffic levels. Although no differences for driver group were highlighted, there was a fixation pattern that was found for the two turn types. Figure 23 depicts how while making a left turn the drivers are concerned with traffic streams from both the left and the right directions, which causes a higher change in entropy as drivers scan the road in two opposite directions.

In comparison while making right turns drivers are only concerned with the traffic approaching them from the left. This assumption can be validated by seeing the glance distribution between different location for either turn types from figure 12 and 13 as presented in the earlier section, along with figure 16 which shows the mean duration to glance location for the two turn types. For left turns followed by the forward glances there is an equal spread between the left and right window glances, whereas on the contrary the right window glances are diminished while making a right turn. Even though the explanation just provided could be a factor but another possible reason for no significance while making the left turn is the lack of a larger data sample. This will be discussed more in the future work section later.

## **6.2 How do drivers manipulate their gap Acceptance levels across age groups?**

To answer this question, time of gaps that presented to the drivers for each of the turns were noted. There was no significant reported difference for the accepted gap times in the presence of traffic, although a smaller p-value was noted for the driver group in accepted gap time while making a right turn in the presence of traffic levels. Further exploration of this factor difference through post-hoc testing revealed that there was a significant difference between the older driver and the younger driver. We should understand that accepting a specific gap to make a turn requires a decision-making component based on cognitive and physical ability.

We can tie this back to classic model of human information processing by Wickens and Holland (1999). The model utilizes on a multi-level processing stages each connected to each other. To make decisions there is a reliance on sensory inputs, either externally or internally generated along with the working memory, which interact with long-term memory to make sense of the presented situation, which in this case is the presented gap. The working memories interaction with long term memory is critical for making a decision based on prior experience and knowledge, to either accept or reject the presented gap. This gap related decision making thereby relies on the bridge between the working memory and the long term memory and further choosing the right response and its execution i.e., completion of the turn. This can now be extended that for older drivers cognitive slow-down due to aging can automatically delay this process of gap acceptance. More so, the response execution is also a critical part for older drivers, as physical limitation due to aging makes it difficult for them.

Earlier in the paper it was discussed how younger drivers lack experience and how that inexperience is a cause for many fatalities. Accepting the right gap in flowing traffic conditions is critical to whether or not a driver ends up being in a crash. Although, the younger drivers have quicker response time than drivers of other age group, it is their lack of experience which makes them a crash risk while attempting to make unprotected turns. With reference to the Information Processing flowchart, the link between working memory to long term memory on which any driver relies to make decision based on past experiences is lacking for younger drivers.

The analysis conducted through this research failed to point out any significant difference between driver groups for a single factor anova as well. Although, it is critical not to forget that the gaps that presented themselves to the driver were not controlled, like many other gap investigative studies. Again how this situation of gap can be handled for naturalistic driving will be discussed in the future section later.

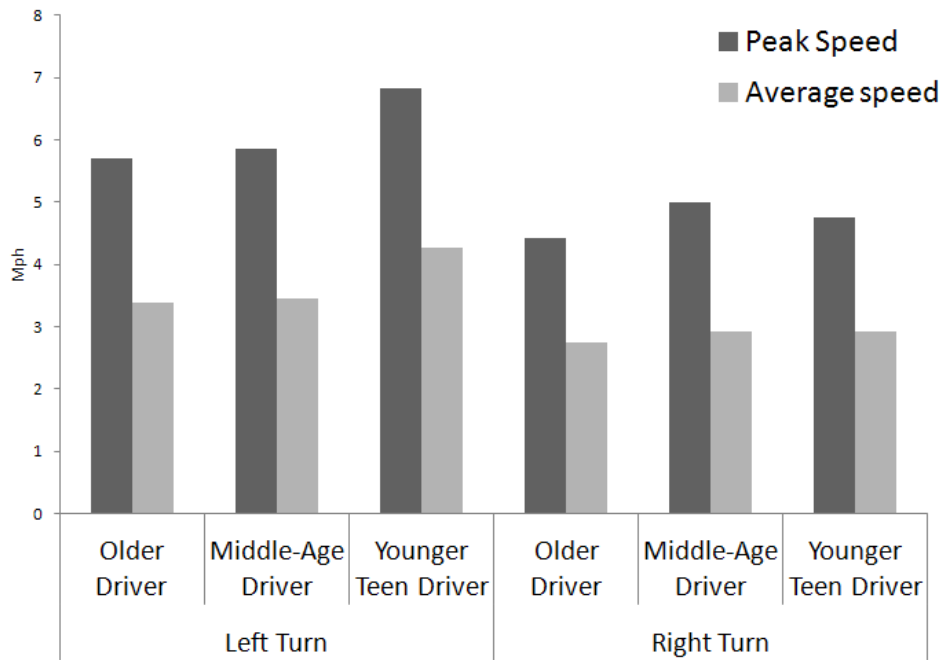
### **6.3 Are there age-related differences in driving kinematics while making unprotected turns?**

To understand driving kinematics, four kinematic dependent variables were used namely average speed, peak speed, peak longitudinal acceleration, peak lateral acceleration. It is important to note that each kinematic variable used serves a different purpose for understanding the drivers kinematic behavior at the initiation, execution, of the peak longitudinal acceleration is usually achieved in the initiation of the turn from a stop, peak lateral acceleration is achieved during the middle-section of the turn. Similarly, peak speed is achieved by the end of the turn event, where the vehicle has now slowly accelerated while completing the turn. Average speed is the only measure which is reflective of the overall turn maneuver.

For a single-factor (Driver-group) ANOVA there was a significant difference for peak speed and average speed while making a left turn. The post-hoc test found that the level differences were significant between the older driver group and the younger driver groups, with the younger group having higher mean values than older drivers. Similar analysis between driver groups was then carried out in the presence of traffic levels, where the driver group differences were significant again in the presence of varying traffic levels for peak speed. There was a significant difference between the drivers for their peak speed means in the presence and absence of traffic. It was also interesting to see where the differences between the driver groups were predominantly between the older and the younger drivers, inclusion of traffic levels brought about significant difference between the younger and the middle-age driver, and the younger drivers and the older driver groups for the no-traffic levels. It is important to understand and was previously discussed that the presence of traffic is merely a high-level factor for this analysis, and it does not account for the specific density/number of the traffic. However, in the absence of traffic, which serves as a

baseline of traffic situation, younger drivers exhibited higher peak speed values than either driver groups.

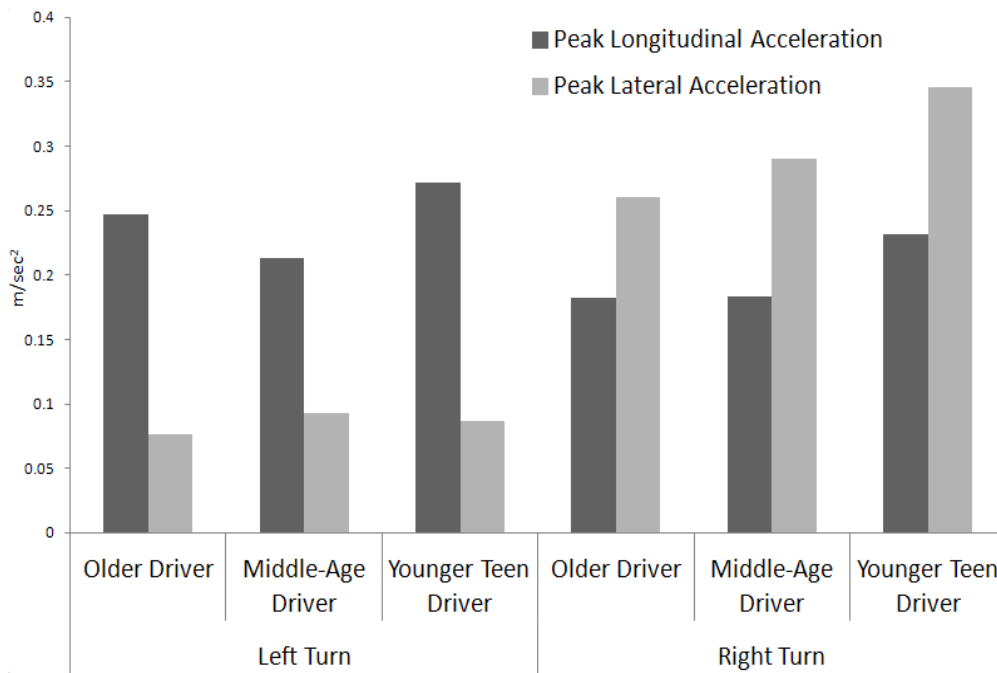
Another important finding was that driver differences were significant for different levels of traffic conditions for peak lateral acceleration while making left turns. Again making a reference to the figure 23, it should be seen that drivers while making a left turn have to deal with traffic from both direction. This potentially has driver adopting an elevated turning behavior to avoid being in a crash. An argument for such a behavior can be, to complete this left turn drivers need to accept smaller gaps and thereby compensate this small gap acceptance by adopting a higher kinematic turning characteristic. However, gap analysis (Table 16) revealed no significance in accepted gap times for drivers in varying traffic conditions, so we can say that this behavior is not a compensatory behavior but something that drivers adopt, when they have traffic in intersecting lanes.



**Figure 24:** MEAN values for Peak Speed and Average Speed for all the driver groups

Figure 24 plots the mean values for peak speed and average speed for all the drivers, and it can be seen that there is a trend in terms of elevated kinematics going from older driver to middle-age driver, with younger teen drivers having higher mean values for both left and right turns.

Similarly figure 25 plots the mean values for peak longitudinal and lateral acceleration. It should be noted that for lateral acceleration the absolute values are used for the convenience of plotting, as negative lateral acceleration is achieved while making left turns. It can be seen that again mostly younger teen drivers have higher mean values in comparison to the other two age groups while making both left and right turns.



**Figure 25:** MEAN values for Peak Longitudinal Acceleration and Peak Lateral Acceleration for all the driver groups

Overall, younger drivers have elevated Mean values for all kinematic measures and hence show their proclivity to adopt an aggressive driving behavior.

## 6.4 Conclusion

Therefore, this thesis provides interesting trends for different driver groups while negotiating turns of unprotected nature. The research found how wide gaps in driving performance exist predominantly between the Older and the Younger driver group. More so the exploration of traffic levels, gap acceptance, gap non-acceptance were exploratory efforts, one that ventures into new areas of technical content, using newly available naturalistic driving data. Overall this thesis work provides interesting trends for different driver groups while negotiating turns of an unprotected nature. The research suggested that the largest differences in driving performance exist predominantly between the Older and the Younger driver group. Although two naturalistic datasets were combined, there were still a limited number of observations for many cells of the analyses – limiting statistical power to detect significant effects. Even though some findings are exploratory and suggestive in this research, exploratory approaches have an important role to play in science, along with more definitive hypothesis-testing research that can be applied once exploratory work has opened up new avenues of investigation. As more naturalistic-data becomes available, the preliminary findings here can be re-examined with more robustness using the methods developed in this thesis.

## 7. Future

### 7.1 Improvements in Research Methodologies

Although this research looked into various aspects of driver performance while negotiating an unprotected intersection turn, there is still an opportunity for some changes which would further improve the validity of future research work in this area. The lack of sample size primarily in the larger dataset from which it was data mined for per treatment level led to unequal sample size being used in this research. A larger sample size of participant data means that while looking into the visual sequencing part we can include a lot more glance locations. The data for this research came from two naturalistic studies that had a total participant recruitment of less than hundred. After using the data mining technique to identify the trips and events of importance for the purpose of research, the unique participant pool reduced significantly. In the future, a large-scale naturalistic study will address this problem of a larger participant pool. The second Strategic Highway Research Program (SHRP2) is a joint effort administered by the Transportation Research Board (TRB) along with federal highway administration and the America Association of State Highway and Transportation Officials to collect more data related to crashes, near crashes, exposure and determine relative crash risk for different factors. The SHRP-2 Naturalistic Driving Study is going to recruit 3100 participants over a two-year period across various states across the United States (Campbell K. , 2011). This sort of a driving study, which is almost 40 times the size of the current data available, has the potential of removing the problems faced in this research through unequal sample sizes.

This study did not explore the daytime vs. nighttime driving events, but only considered daytime driving. A huge void in previous work around intersections has been the difference lighting causes for different driver age-groups for making intersection turns. Further no gender effects were explored due to an uneven spread amongst driver of both genders. This can be particularly important in the aspect of kinematic differences between drivers of different genders as literature has suggested male drivers to have elevated kinematic values than females. Again, the availability of data through a larger naturalistic study like the SHRP-2 can make the study for lighting, and gender effects possible.



A direct link to having less data for the study meant the link diagrams only included a relatively small amount of links from each of the locations to other lower-probability locations. A variant of the link diagram previously presented (Figure 14 and Figure 15) will look like the one shown below in figure 26. This sort of Link analysis provides much more granular information on driver's visual behavior, and expands to depict locations which were not illustrated in the earlier link diagrams presented for this research. Inclusion of locations like interior objects, passengers, music player have a potential to answer questions related to driver distraction especially with the younger driving group who have been identified as the most distracted group of drivers with the highest propensity to engage in secondary tasks.

However, in order to include these locations in a link analysis, it would be necessary to have more data (more observations) in order to assure that they reflected robust *patterns* of glance that were characteristic of a group, rather than anomalous or atypical glances that occurred by happenstance (and were not reflective of a group pattern).

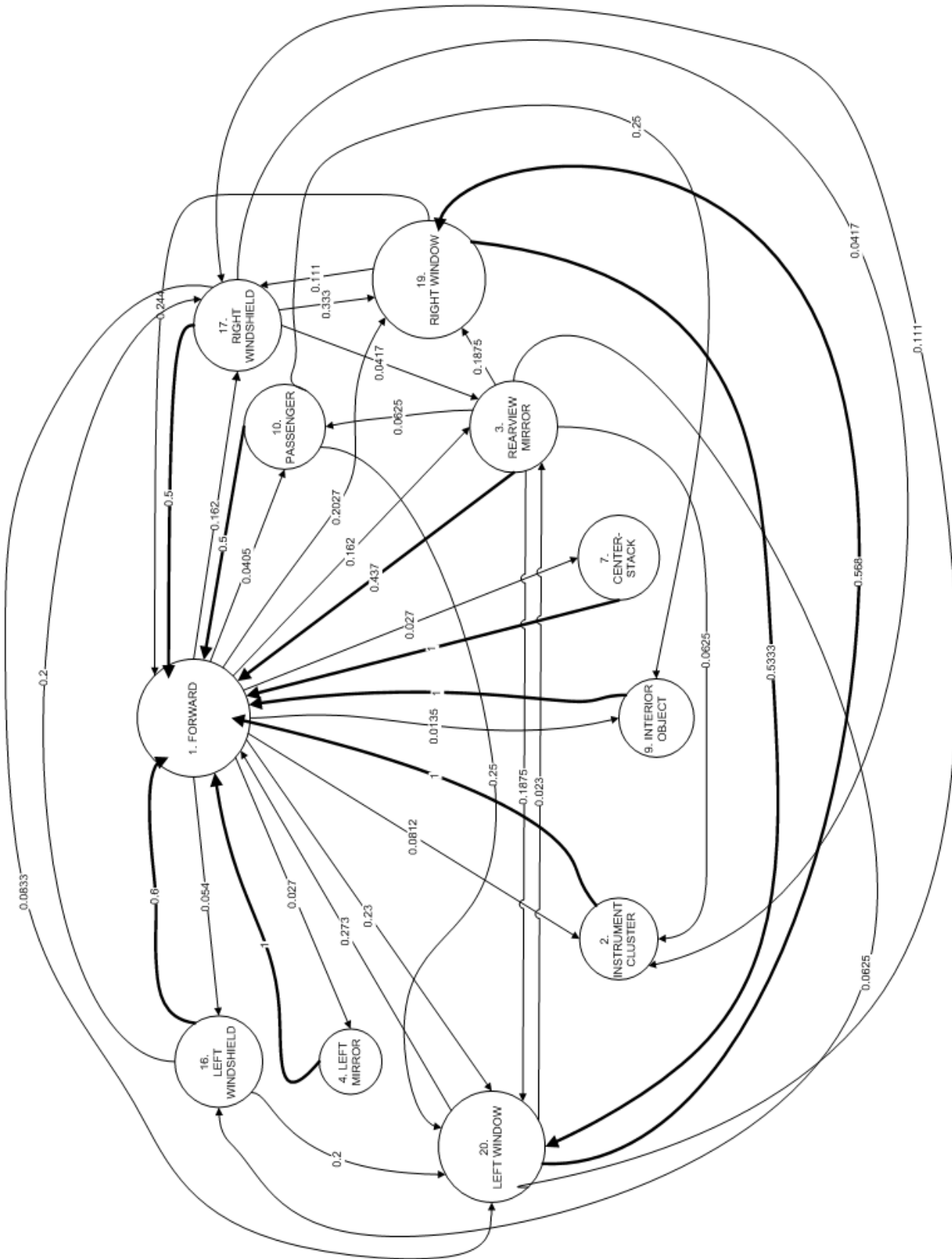


Figure 26: A lternative link diagram with several glance locations

For this research the traffic examples were collapsed under two broader categories namely, traffic present or traffic not-present. Through the availability of a larger dataset the traffic reduction can actually lead to a traffic density model, with specific number of vehicles the participant/primary vehicle interacts with while making the intersection turns. In the method section, the methodology of how the traffic reduction at the intersection carried out was noted. From Table 10 it can be seen that traffic was coded at six different levels, including the traffic in front of the vehicle when it first arrives at the intersection. A major obstacle of studying gap-acceptance behavior utilizing naturalistic data is the lack of control to the presentation of the gaps. This type of research alone requires the largest sample of data and gap acceptance instances of different range and driver groups to provide concrete answers. Another methodology for working with the gap-data is by transforming the data through normalizing.

In Naturalistic data as gaps of all sizes are available, there is a need to identify a critical range of gaps outside of which it can be hypothesized that a vast majority of drivers will accept those gap times. For example for the intersection used in this research the mean of accepted gap time was around 5.5 seconds, with the smallest gap acceptance time at 3.5 seconds. Thereby, while defining gap-not-accepted times only those times will be considered which are above a certain threshold (like > 3 sec). Similarly, for accepted gap times all duration of gaps that are greater than for example 10 seconds can be considered as gap-times that all drivers will accept. Another way of normalizing is by using a standard gap-acceptance time, table 21 shows standard gap acceptance time for each turn type and different vehicles proposed in a human factors guideline for road systems (Campbell, 2008).

**Table 21:** Acceptable Gap Distance based on vehicle type, turn type and roadway construction,

*Source:* Campbell, J. L. (2008). *NCHRP 17-31 & 17-41: Human Factors Guidelines (HFG) for Road Systems Current Status and Next Steps*. AASHTO. Used under FAIRUSE guidelines(2011)

Design Vehicle	Time Gap (ts)(seconds) at design speed of major road	
	Left Turn	Right Turn
Passenger car	7.5	6.5
Single-Unit truck	9.5	8.5
Combination truck	11.5	10.5

*Note: To account for time needed to traverse additional lanes add 0.5 seconds for passenger cars and 0.7 seconds for trucks*

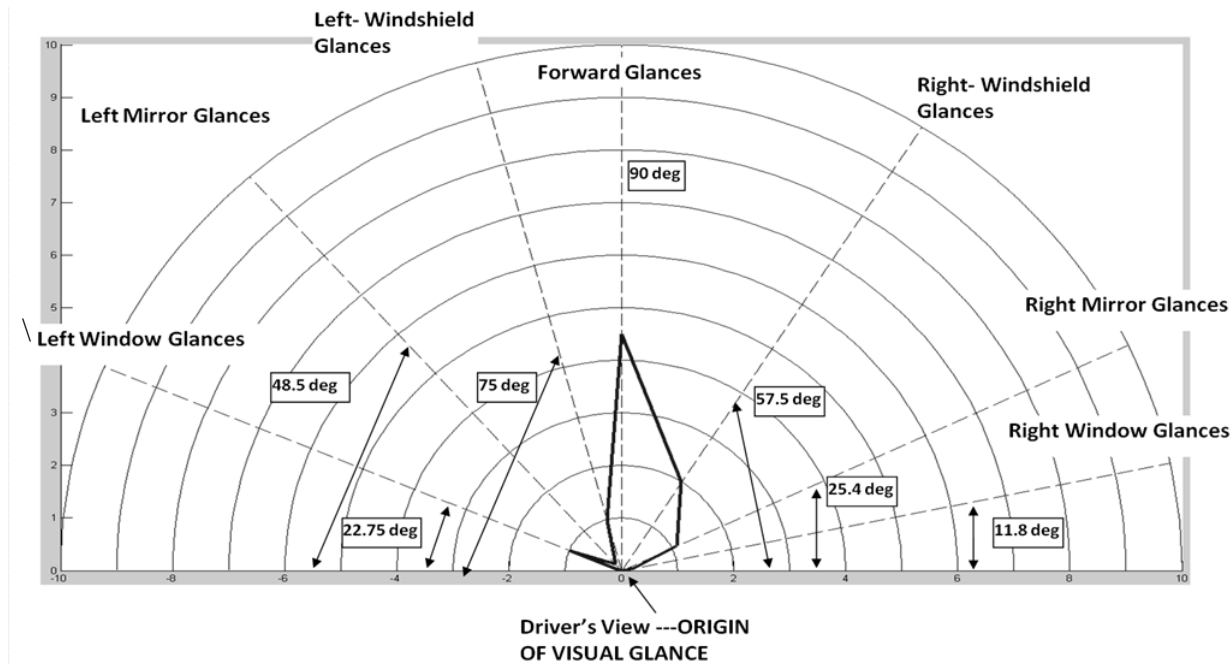
## **7.2 Future implication- Countermeasure Suggestion**

The findings from this study together with other findings in the literature has the potential to contribute to the scientific foundation from which countermeasures could be developed for enhancing driver safety during left turns. One of the many new initiatives towards the Intelligent Transportation System (ITS) is the CAMP initiative, a partnership of automobile manufacturers, who are working on project called the Cooperative Intersection Collision Avoidance Systems (CICAS). This new technology being created as part of this joint initiative is using vehicle-to-vehicle and vehicle-to-infrastructure communication to warn drivers of imminent crash threat. This thesis can be expanded utilizing this new communication technology, which can lead to the creation of new driver assist features. The understanding of gap acceptance, traffic presence in an intersection from this and future research can help in creating new driver assist features which can provide drivers with cues as to when is it safe to make a turn. For example, a vehicle-based countermeasure could be developed to provide a visual display which a driver (of any age) could use to judge the size of gaps in traffic through which a left turn could be executed (and the display-size would change according to the speed of oncoming vehicles).

Even though there were no crashes or near crashes incidents that were noted in this research with regards to negotiating turns at this intersection. Although, in the future a larger naturalistic research like the one captured in SHRP-2 might bring out a crash/near-crash incidents which may be researched using a case study approach. Such an approach may lead to potential problems of driver breakdown with regards to making unprotected intersection turns.

There is also a huge training/assessment component for the crash risk driver groups, namely the older driver and the younger driver. Current driver evaluation and training systems are usually in-class methods which has driver been coached for rule of thumbs. For Older drivers several self-assessment and safety programs exist which teaches them to self-regulate and compensate for age-related changes which effects their driving. For teen drivers initiatives like the Graduate Driver Licensing Program (GDL) has helped in reducing newly licensed teen fatalities. The GDL helps in making adjustments to driving habits during the supervised learning period of the GDL process, but there exists no process which can tell if such corrected driving habits have had a

lasting effect on these young drivers. The methodology and analysis developed in this research has the potential to contribute to this void in driver training. In the future driver coaching can be provided by tracking drivers visual glance spread for a specific driving event and can be represented in a visual format like in figure 27.



**Figure 27:** Driver Visual Glance Model intended to be used for training purpose

From figure 27, it can be seen that, a star plot with the different glance locations are marked on a scale containing the proportion of glances for each of the locations. Now a mathematical baseline driver model can be created for the specific event, which can then be compared to the actual driver's model shape to point out what the drivers were doing wrong. This type of feedback related training can help younger drivers in learning the important driving related glances, while helps older drivers in making adjustments based on limitations brought upon by aging.

This type of modeling can also be incorporated to create countermeasure technologies which can prompt the driver in certain situations to glance such that their glance-model fits better to an appropriate baseline. A lot of countermeasure technology has been developed using collision mitigation logic, and it increases overdependence on technology, perhaps there can be a training component of real-time driving which can help these crash risk age-groups of different ages.

### 7.3 Contribution to the Area

It is in hope that this research will eventually lead to safety benefits for all drivers making left turns. Historically, older drivers have been overrepresented in such turns, and have suffered fatalities from these crashes at twice the rate of other drivers. Thus, specifically reducing this risk for older drivers at left turns is a goal of this work. However, in order to achieve significant reductions in this risk, it will be necessary to prevent crashes at turns – since crash protection has already been largely optimized through technology advances in passive safety over the last three decades. In order to prevent these left-turn crashes using active safety countermeasures in the future, it is essential to identify and understand the factors that contribute to these crashes.

The Naturalistic Driving research paradigm provides an unobtrusive method of observing driver behavior in their natural driving environment. This research utilizes previously collected separate naturalistic data and makes an effort to answer new research questions which were not the original goal of the data collection process.

Finally, this research has resulted in contributions toward two types of engineering applications:

1. **Process applications.** Several new methodologies were developed for mining and analyzing naturalistic data, including: an algorithm for identifying and matching intersection turns, techniques for coding the presence/absence of traffic at a turn, techniques for coding gap acceptance and non-acceptance, new methods for analyzing and displaying the spatial distribution of glances.
2. **Safety countermeasure development.** Given the high crash rate at intersections, particularly for older drivers at intersections of the type studied in this work, the development of possible safety countermeasures is important. Several technology solutions are under development at this time, and there are opportunities for driver education and training solutions as well. Countermeasure features have largely been developed on the basis of need (arising from crash data analyses), rather than research-driven requirements stemming from

in-depth study of drivers making turns at intersections. Therefore, the findings from this thesis are among the few that can be used to inform the further development, refinement, and testing of technology (and training) solutions intended to assist drivers in making successful turns and avoiding crashes at intersections. In particular, the results from this thesis suggest that young drivers could benefit from training on how to strategically scan at an intersection prior to turning. Older drivers, on the other hand, may benefit from technology cues that assist with judgments of gap sizes, which can improve their confidence in proceeding or holding back from a turn, etc. Drivers of all ages may benefit from warnings of traffic approaching an intersection that may be obstructed – and/or from autonomous braking if they proceed when an intersecting vehicle is in close proximity.

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## Appendix A: IRB Protocol

### Older Driver Difficulties at Intersections:

### The Role of Cognitive Changes on Visual Scanning and Their Implications for Countermeasure Approaches

(Data Mining Project Using Existing Data)

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#### **6. DESCRIBE THE BACKGROUND, PURPOSE, AND ANTICIPATED FINDINGS OF THIS STUDY:**

Aging drivers have historically been over-represented in multi-vehicle angled impact crashes (resulting from turns at intersections) and had a higher rate of fatality than younger drivers. For example, Staplin et al (2001) reported that 48-55% of all fatal crashes involving drivers aged 80 years or over occurred at intersections (which was more than twice the rate for drivers under the age of 50 years (23%)). A recent study by IIHS (in 2008) revealed drops in these rates for older drivers (due, it is thought, to self-limiting of driving by older drivers), but this area of crash risk remains a significant one for older drivers.

Findings from other very recent research have shown that:

1. Visual scanning by older drivers is different from that of other drivers
  - a. At intersections, particularly after turning has been initiated (Romoser et al, 2005; Romoser et al, in press; Bao & Boyle, 2009 )
  - b. When approaching hazards (Fildes et al (2006))
2. Cognitive changes occur with age and may be relevant for these maneuvers, including:
  - a. Slowed processing speed with age

- b. Reduced top-down inhibition (which affects the ability to selectively attend), and slowed top-down facilitation of visual activity with age -- Gazzaley et al (2005), Gazzaley et al (2007)

Applying these findings *together* in the context of driving, particularly in the context of a contemporary understanding of how eye movements are generated from moment-to-moment in an ongoing visual task like driving – permits new hypotheses to be generated about why visual scanning at intersections may change for older drivers – and why visual attention to hazards may be reduced at these locations. In particular, it can now be hypothesized that specific age-related changes in the cognitive process known as top-down modulation (which underlies the ability to *selectively* focus attention, *enhance* visual activity for relevant information, *suppress* distracting input, and *hold* relevant information in mind ) could cause or precipitate the observed changes in visual scanning at intersections. It is the degradation of this system with age that may lead to some of the functional difficulties experienced by older drivers. [Note: Novice drivers have also been reported to show less mirror scanning, and reduced scanning to hazards (e.g., Klauer et al (2008)) – and this may be due to knowledge limitations from inexperience on the same underlying process – leading to an inability to generate appropriate top-down expectation-based facilitation of eye-movements to probable locations of hazards at intersections.]

However, while individual studies have contributed individual findings on age-related changes, it does not appear that these findings have been pulled together as part of an explanatory framework for application to older driver visual scanning and selective attention (or development of visual scanning in novice drivers). Further, some of the key findings come from studies done in driving simulators – so it would be useful to discover whether the findings are replicated in naturalistic driving data. If naturalistic data were to confirm findings on visual scan patterns of older drivers at intersections, and additional work were done to ascertain the causes of change in visual scanning (to confirm “what goes wrong”), it may

facilitate the identification of countermeasure approaches for assisting older drivers with this area of driving difficulty.

#### Approach:

Using previously collected naturalistic data, analyze visual scan patterns of older, middle-age, and teenage drivers during right and left turns at intersections, to test whether naturalistic driving data confirm that scanning of mirrors and scanning for hazards after turn-initiation is reduced in older drivers (and to determine how it may differ for teens). In addition, examine other salient driving data available from naturalistic datasets (e.g., approach speeds to intersections, time through intersection). [Note: Depending upon the outcome of this effort, a second follow-on effort approach is envisioned – which would consist of an experiment done on VTTI’s Smart Road. However, this would be handled under a separate IRB proposal, and would not be initiated until approvals on that IRB proposal were granted.]

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## **7. EXPLAIN WHAT THE RESEARCH TEAM PLANS TO DO WITH THE STUDY**

### **RESULTS:**

The results will be compiled into a report for the sponsor, presented at conferences and may eventually be published in scientific journals.

**8. WILL PERSONALLY IDENTIFYING STUDY RESULTS OR DATA BE RELEASED TO ANYONE OUTSIDE OF THE RESEARCH TEAM? (highlight one)**

*For example – to the funding agency or outside data analyst, or participants identified in publications with individual consent*

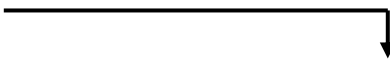
No

Yes, to whom will identifying data be released?

**9. WILL ANY STUDY FILES CONTAIN PARTICIPANT IDENTIFYING INFORMATION (E.G., NAME, CONTACT INFORMATION, VIDEO/AUDIO RECORDINGS)? (highlight one)**

No, go to question 10

Yes, answer questions within table



**IF YES**

**Describe if/how the study will utilize study codes:**

The project requires trained data reductionists and other researchers to view digital video files collected in a previous data collection effort. The original videos files are coded with participant numbers. Those numbers will be used for the current research effort. Some audio information may also be available, as participants could press an incident button to briefly open an audio recording channel.

**If applicable, where will the key [i.e., linked code and identifying information document (for instance, John Doe = study ID 001)] be stored and who will have access?**

**The key is located within a secure digital project folder. Access to this folder can be granted only with the approval of the principal investigator of the original project. The current data effort will use the participant numbers as they were assigned in the original data collection effort. The current project will not require access to the key.**

*Note: the key should be stored separately from subjects' completed data documents and accessibility should be limited.*

## **10. WHERE WILL DATA BE STORED?**

Data will be stored in secure digital project folders on a secure server at VTTI that are only accessible by personnel directly involved in the project, with the principal investigator's approval. Illustrations of representative scanning and head turning patterns at intersections will be provided to the sponsors (who are contributing members of the National Surface Transportation Safety Center of Excellence). This set will contain only unidentifiable data (e.g., parametric vehicle data and reduced video data, or visual scans illustrated by points of fixation on the driving scene, without any driver or identifying vehicle elements in view).

## **11. WHO WILL HAVE ACCESS TO STUDY DATA?**

Other than the principal investigator, who will control access to the data, identifiable video files will only be accessed by trained VTTI data reductionists (none of whom know the participants), the VTTI data reduction manager, and members of the VTTI research team (which includes the

Principal Investigators of the original studies). The sponsor will be provided with an unidentifiable dataset of scanning patterns (head and eye) at intersections.

## **12. DESCRIBE THE PLANS FOR RETAINING OR DESTROYING THE STUDY**

### **DATA:**

The data will be retained indefinitely.

## **13. FROM WHERE DOES THE EXISTING DATA ORIGINATE?**

- The original data to be utilized for this project will be drawn entirely from studies that have already been concluded. Thus, the data will have been previously collected in naturalistic observation studies conducted by VTTI under approved IRB proposals – studies that have now concluded. These studies include: “Preventing Motor Vehicle Crashes Among Young Drivers: Research on Driving Risk Among Novice Teen Drivers” (referred to as the Forty Teen Naturalistic study) (IRB # 05-799), the “100-Car Naturalistic Driving Study” (IRB # 01-432), and the “**Older Driver Naturalistic Observation**” study, IRB #07-187].
- The original consent forms for two these projects indicated that future analysis could be conducted by VTTI researchers, while the “Forty Teen Naturalistic Study” allows for such analysis as long as the original research team is included as part of the new research team (which they have been – Suzie Lee and Charlie Klauer for the “Forty Teen” study).

## **14. PROVIDE A DETAILED DESCRIPTION OF THE EXISTING DATA:**

Existing data contain video of the participant's face, forward and rear-facing views, and an over-the-shoulder view of the vehicle's center stack or console. The video data are synchronized to a stream of vehicle network data (e.g., speed, acceleration/deceleration, machine vision-based lane tracking, and forward facing radar. Further details on the data collection can be found in submissions relating to IRB #07-187.

As of today, there are several databases, each containing in excess of 30,000 data files (where a data file represents an unique trip), and each database covering over 4,000 hours of driving data distributed among its data files. Algorithms will be developed to identify the epochs within data files that represent intersections – and turns at intersections -- so that those segments of the data files pertaining to behavior during turns at intersections can be analyzed. (The focus of this study is specifically on behavior at and during intersections). In addition, other epochs may be selected at random to serve as a baseline sample for comparison and to determine level of exposure to factors of interest.

The focus of this effort is on the visual scanning and driving data. Visual scanning includes both head turning and eye movements. However, we may also relate observed driving data with scores on a variety of driver assessments conducted as a part of the original study on older drivers (IRB #07-187), or as part of the other original studies (on teens and middle-aged drivers) which were covered under separate and previously-approved IRB proposals: IRB # 05-799, IRB # 01-432.

**15. IS THE SOURCE OF THE DATA PUBLIC? (highlight one)**

**No**, go to question 16

**Yes**, you are finished with this application

**16. WILL ANY INDIVIDUAL ASSOCIATED WITH THIS PROJECT (INTERNAL OR EXTERNAL) HAVE ACCESS TO OR BE PROVIDED WITH EXISTING DATA CONTAINING INFORMATION WHICH WOULD ENABLE THE IDENTIFICATION OF SUBJECTS:**

▪ **Directly** (e.g., by name, phone number, address, email address, social security number, student ID number), or

▪ **Indirectly through study codes** even if the researcher or research team does not have access to the master list linking study codes to identifiable information such as name, student ID number, etc

or

▪ **Indirectly through the use of information that could reasonably be used in combination to identify an individual** (e.g., demographics)

**HIGHLIGHT ONE**

**No**, collected/analyzed data will be completely de-identified

**Yes**,

**If yes,**

*Research will not qualify for exempt review; therefore, if feasible, written consent must be obtained from individuals whose data will be collected / analyzed, unless this requirement is waived by the IRB.*

**Will written/signed or verbal consent be obtained from participants prior to the analysis of collected data?**

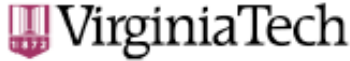
*This research protocol represents a contract between all research personnel associated with the project, the University, and federal government; therefore, must be followed accordingly and kept current.*

*Proposed modifications must be approved by the IRB prior to implementation except where necessary to eliminate apparent immediate hazards to the human subjects.*

*Do not begin human subjects activities until you receive an IRB approval letter via email.*

*It is the Principal Investigator's responsibility to ensure all members of the research team who collect or handle human subjects data have completed human subjects protection training prior to handling or collecting the data.*

## Appendix B: IRB Approval Letters



Office of Research Compliance  
Institutional Review Board  
2000 Kraft Drive, Suite 2000 (0497)  
Blacksburg, Virginia 24061  
540/231-4991 Fax 540/231-0959  
e-mail moored@vt.edu  
www.irb.vt.edu

FWA00000572( expires 1/20/2010)  
IRB # is IRB00000667

DATE: October 19, 2009

### MEMORANDUM

TO: Linda Angell  
Jonathan Antin  
Charlie Klauer

Grant Compared 10/19/2009

Approval date: 10/19/2009

Continuing Review Due Date: 10/4/2010

Expiration Date: 10/18/2010

FROM: David M. Moore 

SUBJECT: **IRB Expedited Approval:** "Older Driver Difficulties at Intersections", IRB # 09-872

This memo is regarding the above-mentioned protocol. The proposed research is eligible for expedited review according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. As Chair of the Virginia Tech Institutional Review Board, I have granted approval to the study for a period of 12 months, effective October 19, 2009.

As an investigator of human subjects, your responsibilities include the following:

1. Report promptly proposed changes in previously approved human subject research activities to the IRB, including changes to your study forms, procedures and investigators, regardless of how minor. The proposed changes must not be initiated without IRB review and approval, except where necessary to eliminate apparent immediate hazards to the subjects.
2. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.
3. Report promptly to the IRB of the study's closing (i.e., data collecting and data analysis complete at Virginia Tech). If the study is to continue past the expiration date (listed above), investigators must submit a request for continuing review prior to the continuing review due date (listed above). It is the researcher's responsibility to obtain re-approval from the IRB before the study's expiration date.
4. If re-approval is not obtained (unless the study has been reported to the IRB as closed) prior to the expiration date, all activities involving human subjects and data analysis must cease immediately, except where necessary to eliminate apparent immediate hazards to the subjects.

#### Important:

If you are conducting **federally funded non-exempt research**, please send the applicable OSP/grant proposal to the IRB office, once available. OSP funds may not be released until the IRB has compared and found consistent the proposal and related IRB application.

As indicated on the IRB application, this study is receiving federal funds. The approved IRB application has been compared to the OSP proposal listed above and found to be consistent. Funds involving procedures relating to human subjects may be released. Visit our website at [www.irb.vt.edu](http://www.irb.vt.edu) for further information

cc: File

*Invent the Future*

VIRGINIA POLYTECHNIC INSTITUTE UNIVERSITY AND STATE UNIVERSITY

*An equal opportunity, affirmative action institution*





**MEMORANDUM**

**DATE:** September 28, 2010

**TO:** Linda Angell, Jonathan Antin, Charlie Klauer, Suzanne E. Lee

**FROM:** Virginia Tech Institutional Review Board (FWA00000572, expires June 13, 2011)

**PROTOCOL TITLE:** Older Driver Difficulties at Intersections

**IRB NUMBER:** 09-872

Effective October 19, 2010, the Virginia Tech IRB Chair, Dr. David M. Moore, approved the continuation request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at <http://www.irb.vt.edu/pages/responsibilities.htm> (please review before the commencement of your research).

**PROTOCOL INFORMATION:**

Approved as: Expedited, under 45 CFR 46.110 category(ies) 5  
Protocol Approval Date: 10/19/2010 (protocol's initial approval date: 10/19/2009)  
Protocol Expiration Date: 10/18/2011  
Continuing Review Due Date\*: 10/4/2011

\*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

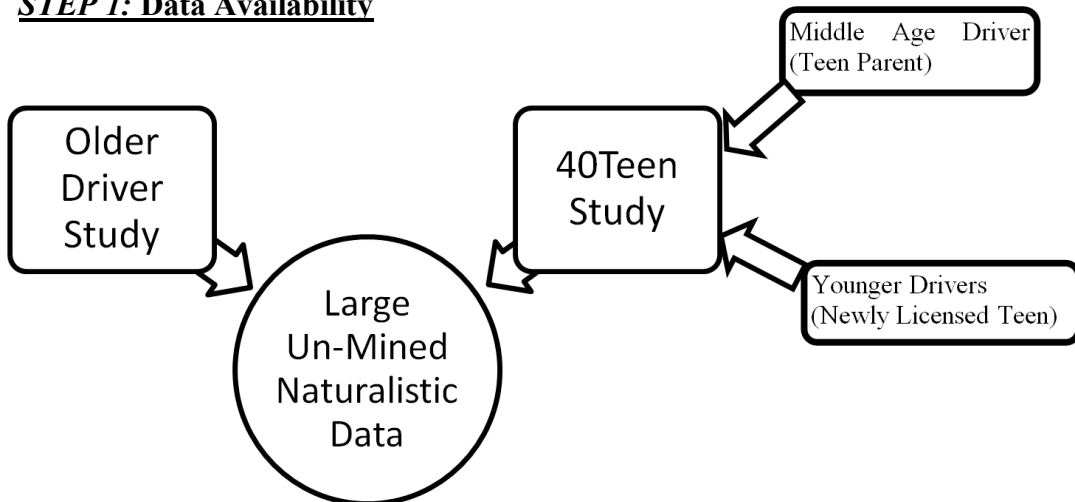
**FEDERALLY FUNDED RESEARCH REQUIREMENTS:**

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals / work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

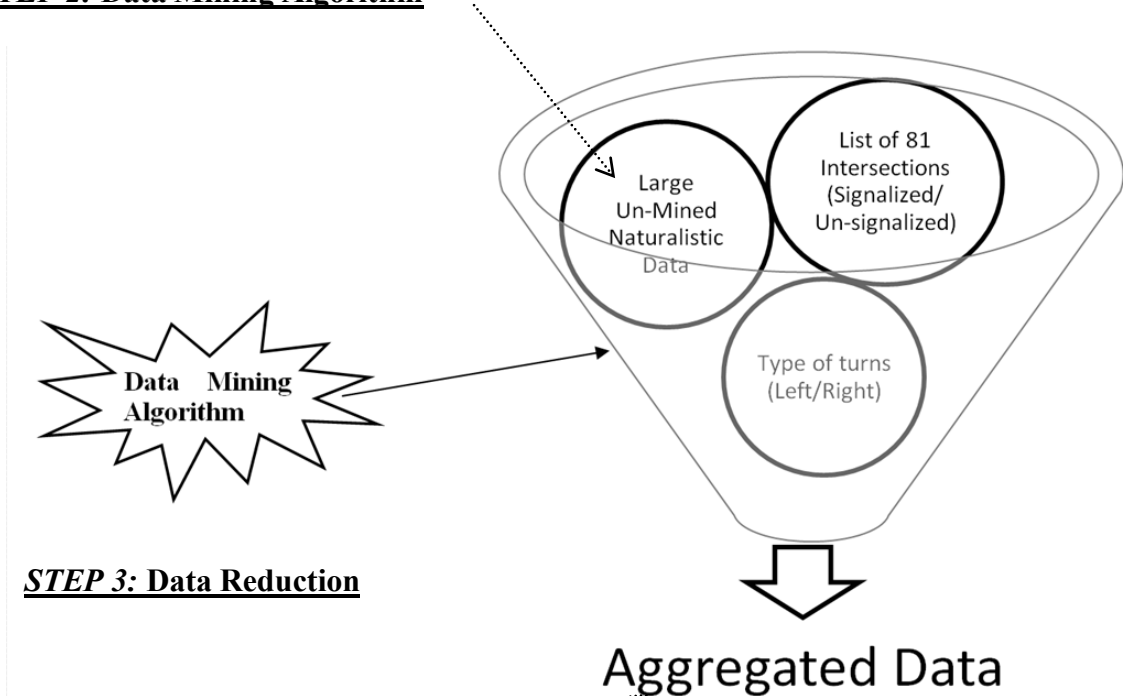
The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

## Appendix C: Process Chart for Data Aggregation and Reduction

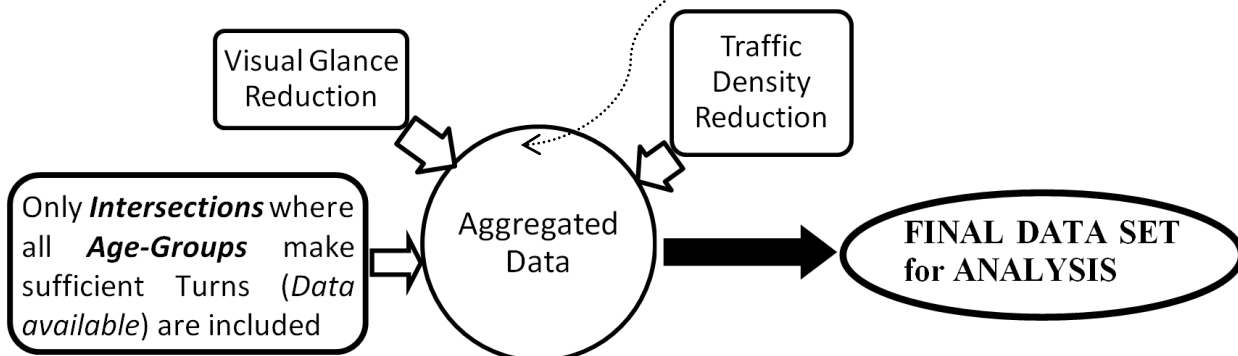
### STEP 1: Data Availability



### STEP 2: Data Mining Algorithm



### STEP 3: Data Reduction



## **Appendix D: DATA ACQUISITION SYSTEM**

The data acquisition system (DAS) utilized in both the 40Teen Study and the OlderDriver Naturalistic Study have a basic characteristic which includes the following:

- Compatible with the vehicle (e.g., power obtained from vehicle battery, data from in-vehicle network).
- Unobtrusive and non-invasive:
  - Not distracting.
  - Does not limit driver visibility.
  - No permanent modifications to the vehicle.
  - Minimal space requirement (e.g., for data storage unit).
  - Automatic start-up, shut-down, and continuous operation.
  - No subject tasks required for operation or data downloading.
- Ruggedness: Reliable performance in the often harsh operational environment of driving.
- Crash survivability & Minimal data loss and automatic detection of failures
- Continuous multi-camera video recording system (30 Hz) to capture driver's face, over-the-shoulder, wide-angle rearward, forward scene; a passenger camera will provide a

snapshot of the vehicle's cabin , allowing researchers to determine the presence of a passenger but filtered, to conceal their identity.

The main unit is mounted on the floor of the trunk using Velcro under the “package shelf” depicted in Figure 28. The vehicle network box is located under the front dashboard. The incident box will be mounted above the rearview mirror. Wiring will be run through the normal wire chases on a vehicle to all the various network nodes, as well as to the cameras. The cameras will be mounted unobtrusively to facilitate naturalistic driving behavior.



**Figure 28:** Data Acquisition System mounted under the package shelf in the trunk of a vehicle (*Photo by Author, 2011*)

## **DATA ACQUISITION SENSORS**

The following sensors will be unobtrusive and non-visible to participants:

### **Global Positioning System (GPS)**

The Global Positioning System (GPS) data output includes measures of latitude, longitude, altitude, horizontal and vertical velocity, heading, and status/strength of satellite acquisition.

### **Lane Tracker**

A VTTI-developed lane tracker, called the “Road Scout,” is included in the DAS. The Road Scout consists of a single analog black and white camera, a PC with a frame grabber card, and an interface-to-vehicle car network for obtaining ground speed.

### **Yaw Rate**

A yaw rate (gyro) sensor is included in the DAS and provides a measure of steering instability (i.e., jerky steering movements).

### **X/Y Accelerometer**

Accelerometers instrumented in the vehicle are used to measure longitudinal (x) and lateral (y) accelerations.

### **Vehicle Network**

The data set from the network will contain measures of the following:

Vehicle speed

Distance since vehicle start-up

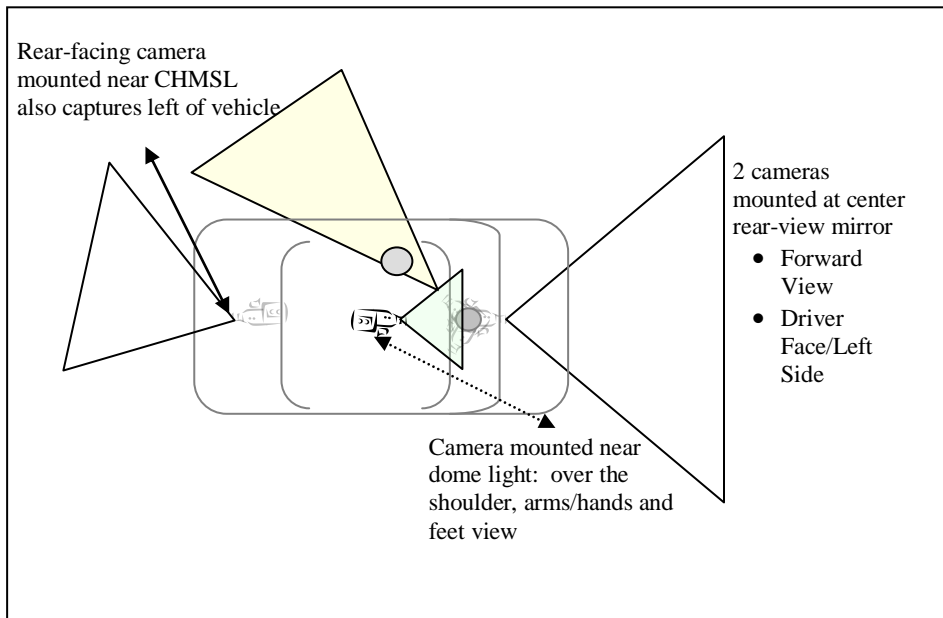
- Ignition signal
- Throttle position
- Brake pressure

Outside of the vehicle network measures available, other driver input measures that are collected with sensors include the following:

- Right and left-turn signal
- Headlights on/off
- Brake pressure (if not available from the network)

### Video Cameras

Digital video cameras are used to record continuous video of the driver and the driving environment. Four video cameras will be used and will be multiplexed into a single image. The four camera views are: (1) forward roadway view, (2) driver's face camera, (3) over-the-shoulder, and (4) wide-angle rearward. The forward and rearward camera views provide good coverage of the driving environment. The face view provides coverage of the driver's face and



**Figure 29:** Diagram showing Camera location and range

will allow researchers to conduct eye glance analyses. The four camera images are multiplexed into a single image. A timestamp (mpeg frame number) is also included in the mpg data file but

is not displayed on the screen. The frame number is used to time-synchronize the video (in mpeg format) and the vehicle/performance data (in binary format).