Modeling and Measuring Cognitive Load to Reduce Driver Distraction in Smart Cars

by

Tanvi Jahagirdar

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved April 2015 by the
Graduate Supervisory Committee:

Ashraf Gaffar, Chair
Arbi Ghazarian
Robert Gray

ARIZONA STATE UNIVERSITY

May 2015

ABSTRACT

Driver distraction research has a long history spanning nearly 50 years, intensifying in the last decade. The focus has always been on identifying the distractive tasks and measuring the respective harm level. As in-vehicle technology advances, the list of distractive activities grows along with crash risk. Additionally, the distractive activities become more common and complicated, especially with regard to In-Car Interactive System. This work's main focus is on driver distraction caused by the in-car interactive System. There have been many User Interaction Designs (Buttons, Speech, Visual) for Human-Car communication, in the past and currently present. And, all related studies suggest that driver distraction level is still high and there is a need for a better design. Multimodal Interaction is a design approach, which relies on using multiple modes for humans to interact with the car & hence reducing driver distraction by allowing the driver to choose the most suitable mode with minimum distraction. Additionally, combining multiple modes simultaneously provides more natural interaction, which could lead to less distraction. The main goal of MMI is to enable the driver to be more attentive to driving tasks and spend less time fiddling with distractive tasks. Engineering based method is used to measure driver distraction. This method uses metrics like Reaction time, Acceleration, Lane Departure obtained from test cases.

DEDICATION

I would like to dedicate this work to my parents PARIMALA JAHAGIRDAR and JAYESH JAHAGIRDAR, my sisters VAIBHAVI JAHAGIRDAR and ADITI KULKARNI, my grandparents SETURAM JAHAGIRDAR, INDUMATI JAHAGIRDAR, RANGAPPAYYA DESAI and PUSHPA DESAI, my friends and family for their support.

ACKNOWLEDGMENTS

I would like to thank Dr. Ashraf Gaffar for giving me the opportunity to work on this innovative project and for his constant guidance and support. I am grateful to Dr. Robert Gray for his help and support and providing me the means to work on the Driving Simulator. Also I would like to thank Dr. Arbi Ghazarian for readily accepting to be my committee member. I am very grateful to my colleagues and friends Richa Mittal and Paresh Nakrani for constantly motivating and helping me out through the project. It's because of them that I was able to successfully complete my thesis.

TABLE OF CONTENTS

Page

LIST OF TABLES vii

LIST OF FIGURES viii

CHAPTER

1 INTRODUCTION 1

1.1 Why Driver Distraction Is A Major Problem? 1

1.2 Distraction-Affected Crashes 3

1.3 NHTSA 7

1.4 NHTSA Recommendations 9

1.5 Our Perspective On Driver Distraction 12

1.6 State Of Art 12

2 BACKGROUND 17

2.1 What Is Driver Distraction? 17

2.2 Sources Of Driver Distraction 19

2.3 Exposure Assessment 22

2.4 History Of Driver Behaviour Research 24

2.5 Accident Risk Assessment 27

2.6 Cognitive Load 28

2.7 Driver Behavior Detection And Support 40

2.8 Problems In Measurement Of Driver Performance 47

2.9 The Case Of MMI 53

3 METHODOLOGY 67

CHAPTER Page

3.1 Introduction To Multi Modal Interaction 67

3.2 Multimodal In-Car Enhanced Interaction System 68

3.3 MMI User Interface 70

4 THE EXPERIMENT 80

4.1 Scientific Based Approach: Defining Our Metrics 80

4.2 Test Cases 85

5 DATA ANALYSIS & RESULTS 88

5.1 Experiment Details 88

5.2 Experiment Data & Analysis 95

5.3 Results 104

6 DISCUSSION 105

6.1 Conclusion 105

6.2 Future Work 106

REFERENCES 110

APPENDIX

A CONSENT FORM 114

B DRIVING SIMULATOR 117

C DATA COLLECTED 120

D STATISTICAL ANALYSIS 122

LIST OF TABLES

Table Page

1. Fatal Crashes, Drivers In Fatal Crashes, And Fatalities, 2011 3

2. People Killed In Distraction-Affected Crashes, By Person Type, 2011 4

3. Estimated Number Of People Injured In Crashes And D-A Crashes 4

4. Estimated Number Of Drivers And People Injured In D-A Crashes 5

5. Motor Vehicle Traffic Crashes And Distraction-Affected Crashes By Year 5

6. Drivers Involved In Fatal Crashes By Age, 2011 6

7. Drivers Involved In Fatal Crashes By Vehicle Type, 2011 6

8. Comparison Between HCaI And HCI 13

9. Cognitive Distraction By Task Specific Voice Commands 16

10. Hazard Assessment Of Crash Risks Associated With Distraction Factors 23

11. 19 Distraction Indicators 30

12. MMI User Interface 71

13. Sample Data 96

LIST OF FIGURES

Figure		Page
1.	Increase In Drivers Manipulating Hand-Held Devices	8
2.	In-Car Environment Project Scope	15
3.	T.A. 1	16
4.	T.A. 2	16
5.	T.A. 3	16
6.	T.A. 4	16
7.	Driver Distraction Model	21
8.	Relationship Between Cognitive Workload, Distraction And Crash Risk	29
9.	Glances At Hazard Locations	44
10.	Research By AAA Foundation, 2011	63
11.	Cognitive Distraction Scale	64
12.	Architecture Of MMI	70
13.	Home Screen	71
14.	Media Screen	72
15.	Climate Controls	72
16.	Car Controls	73
17.	Windows Screen	73
18.	Wipers Screen	74
19.	Map Controls	74
20.	View MAP Screen	75
21.	Goto Screen	75

Figure Page

22. Search Screen 76

23. Previous Screen 76

24. Favorite Screen 77

25. Phone Screen 77

26. Dial Screen 78

27. Contacts Screen 78

28. Display Contact 79

29. Following Distance At Hazard Locations 82

30. Reaction Times At Hazard Locations 83

31. 4 Icons Landscape 86

32. 4 Icons Portrait 86

33. 8 Icons Portrait 87

34. 8 Icons Landscape 87

35. Route Overview 88

36. Starting Point 89

37. Left Turn 89

38. Curved Road 90

39. Follow A Car 90

40. Left Turn 90

41. Pedestrian Crossing 91

42. Goal 91

43. 4 Icons Landscape Small 91

Figure Page

44. 8 Icons Landscape Small 92
45. 4 Icons Portrait Small 92
46. 8 Icons Portrait Small 93
47. 4 Icons Landscape Large 93
48. 8 Icons Landscape Large 94
49. 4 Icons Portrait Large 94
50. 8 Icons Portrait Large 95
51. Range Of Average Response Time Per Person........ 97
52. Lane Position 98
53. Velocity 99
54. Acceleration 99
55. Brake 100
56. Steer 100
57. Headway Distance 101
58. Lane Position Comparison 101
59. Velocity Comparison 102
60. Acceleration Comparison 102
61. Brake Comparison 103
62. Steer Comparison 103
63. Headway Distance Comparison 104
64. Driving Simulator Setup........ 118
65. Screen Holder 119

Figure Page

66. Statistical Analysis.. 133

CHAPTER 1

INTRODUCTION

1.1 Why Driver Distraction Is A Major Problem?

Driving is the coordinated operation and movement of a vehicle, such as a car, truck, or bus. It's is a common activity for many people, making driving safety an important issue in everyday life. Driving in traffic is more than just knowing how to operate the mechanisms, which control the vehicle; it requires knowing how to apply the rules of the road (which govern safe and efficient sharing with other users). A driver must have physical skills to be able to control direction, acceleration, and deceleration and the mental skills in avoiding or successfully handling an emergency-driving situation. An effective driver also has an intuitive understanding of the basics of vehicle handling and can drive responsibly. Over the 20 years from 1980 to 2000, the number of licensed drivers in the U.S. increased 23.7%, from about 154.0 million to 190.6 million. Total annual mileage traveled annually in the U.S. increased 28.9% from 1990 to 2000 and reached 2,767 billion miles in 2000 (USDOT, 2000).

Since 2009, the U.S. Department of Transportation (USDOT) has launched a variety of creative campaigns to raise awareness about the dangers of distracted driving such as "One Text or Call Could Wreck It All." Despite of all the safety improvements in road and vehicle design, the total number of fatal crashes is still increasing. Motor vehicle-related fatalities increased from 33,186 in 1950 to 42,387 in 2000 (Wang, Knipling, & Goodman, 1995). The growing number of fatalities demonstrates that driving safety represents a persistent and critical issue and would affect millions of people across the world. Although most motor-vehicle crashes are attributed to multiple causes, driver error represents a dominant one because drivers are responsible for operating vehicles and avoiding crashes (Lee, 2006). Compared to 34.9% for roadway factors and 9.1% for vehicle factors, driver errors contribute to 92.9% of crashes (Treat et al., 1977). For example, rear-end collisions that comprise approximately 30% of all crashes and roadway departure crashes, which cause the greatest number of fatalities have been largely attributed to the inability of drivers to detect hazards and control the vehicle properly (The National Safety Council, 1996). Most of these performance breakdowns result from the impairments of driver's attention. Four major categories of attention impairments include Alcohol, Fatigue, Aging, and Distraction (Yulan Liang, 2009). Alcohol contributes to approximately 40% of fatalities in US highway (Lee, 2006). Fatigue is often cited in the accidents involving young drivers and truck drivers because these drivers tend to adopt risky strategies to drive at night and/or lack good-quality sleep (Lee, 2006). Aging results in longer response time to hazards and a more narrow field of attention in old drivers (Ball & Owsley, 1993; Owsley et al., 1998). Compared with the above three impairments, distraction, the fourth impairment, is the impairment that has become increasingly important with the introduction of in-vehicle technology (e.g., navigation systems, cell phones, and internet) and has drawn increasing attention from human factor researchers and policy makers in the area of transportation safety (Yulan Liang, 2009).

Distractions can compromise driver's mental skills. Drivers talking on a phone exhibit greater impairment than drivers who were suffering from alcohol intoxication. Music could also affect driver's concentration adversely. Distracted driving is the act of driving while engaged in other activities—such as looking after children, texting, talking on the phone or to a passenger, watching videos, eating, or reading—that take the driver's attention away from the road. All distractions compromise the safety of the driver, passengers, bystanders and those in other vehicles. According to the USDOT, "text messaging while driving creates a crash risk 23 times higher than driving while not distracted." Despite these statistics, more than 37% of drivers have admitted to sending or receiving text messages while driving, and 18% admit doing so regularly. Driver distraction diverts driver's attention away from the activities critical for safe driving toward a competing activity (Lee, Young, & Regan, 2008). It contributes to 13-50% of all crashes, resulting in as many as 10,000 fatalities and $40 billion in damages each year (Lee, 2006). In the 100-Car Study, driver inattention contributed to nearly 80% of the crashes and 65% of the near-crashes (Klauer et al., 2005). Distraction has been identified as an emerging road safety issue and is also being increasingly ranked by road safety authorities around the world as a significant contributing factor to road trauma alongside speeding, drink-driving and fatigue (Klauer et al., 2005).

1.2 Distraction-Affected Crashes

A distraction-affected (D-A) crash is any crash in which a driver was identified as distracted at the time of the crash (NHTSA, 2013). Table 1 provides information on crashes, drivers, and fatalities involved in distraction-affected crashes.

Table 1. Fatal Crashes, Drivers In Fatal Crashes, And Fatalities, 2011

	Crashes	Drivers	Fatalities
Total	29,757	43,668	32,367
Distraction-Affected (D-A)	3,020 (10% of total Crashes)	3,085 (7% of total Drivers)	3,331 (10% of total Fatalities)

Table 2. People Killed In Distraction-Affected Crashes, By Person Type, 2011

Occupant			Non-occupant			
Driver	**Passenger**	**Total**	**Pedestrian**	**Pedal-cyclist**	**Other**	**Total**
2024(61%)	812(24%)	2836(85%)	408(12%)	58(2%)	29(1%)	495(15%)

In 2011, an estimated 2,217,000 people were injured in motor vehicle traffic crashes (Table 3). The number of people injured in a distraction-affected crash in 2011 was estimated at 387,000 (of which, 17% of all the injured people are from distraction-affected crashes. Over the past five years, the estimated number of people injured in distraction-affected crashes has fallen from 448,000 to 387,000, a 14-percent decline (compared to an 11% decline in the number of people injured overall during this time period). However, the percentage of injured people in distraction-affected crashes as a portion of all injured people has remained relatively constant.

Table 3. Estimated Number Of People Injured In Crashes And D-A Crashes

Year	Overall	Distraction
		Estimate (% of Total Injured)
2007	2,491,000	4,48,000(18%)
2008	2,346,000	4,66,000(20%)
2009	2,217,000	4,48,000(20%)
2010	2,239,000	4,16,000(19%)
2011	2,217,000	3,87,000(17%)

Table 4. Estimated Number Of Drivers And People Injured In D-A Crashes

Distraction-Affected Injury Crashes	Distracted Drivers in Distraction-Affected Injury Crashes	People Injured in Distraction-Affected Injury Crashes
260000(17% of all injury crashes)	266000(10% of all drivers in in injury crashes)	387000(17% of all injured people)

Table 5 provides information for all police-reported crashes from 2007 through 2011 including injury crashes, and property- damage-only (PDO) crashes for the year. During this time period, the percentage of injury crashes that were distraction-affected fluctuated slightly, but remained relatively constant.

Table 5. Motor Vehicle Traffic Crashes And Distraction-Affected Crashes By Year

Crash by Crash Severity		Overall Crashes	Distraction-Affected Crashes
2007	Injury Crash	1,711,000	309,000 (18%)
	PDO Crash	4,275,000	689,000 (16%)
	Total	6,024,000	1,003,000 (17%)
2008	Injury Crash	1,630,000	314,000 (19%)
	PDO Crash	4,146,000	650,000 (16%)
	Total	5,811,000	969,000 (17%)
2009	Injury Crash	1,517,000	307,000 (20%)
	PDO Crash	3,957,000	647,000 (16%)
	Total	5,505,000	959,000 (17%)
2010	Injury Crash	1,542,000	279,000 (18%)
	PDO Crash	3,847,000	618,000 (16%)
	Total	5,419,000	900,000 (17%)
2011	Injury Crash	1,530,000	260,000 (17%)
	PDO Crash	3,778,000	563,000 (15%)
	Total	5,338,000	826,000 (15%)

Table 6 describes 2011 fatal crash data for distraction-affected crashes by driver age. The age group, 15-19 years, is the group with the largest proportion of drivers who were distracted. Both methods of looking at age illustrate the increased prevalence of distracted younger drivers in fatal crashes but spread across all ages and conditions.

Table 6. Drivers Involved In Fatal Crashes By Age, 2011

	Total Drivers		Distracted Drivers		
Age Group	#	% Of total	#	% Total drivers	% Distracted drivers
Total	43,668	100	3,085	7	100
15-19	3,212	7	344	11	11
20-29	10,160	23	790	8	26
30-39	7,401	17	505	7	16
40-49	7,376	17	464	6	15
50-59	6,783	16	434	6	14
60-69	4,144	9	251	6	8
70+	3,815	9	270	9	9

With respect to the vehicles driven by distracted drivers, the distribution of vehicles among distracted drivers is similar to the distribution of vehicles among all drivers (Table 7). The victims of distraction-affected crashes vary little from the victims of crashes overall. Thus Distraction-Affected Crashes are not in particular to vehicle type.

Table 7. Drivers Involved In Fatal Crashes By Vehicle Type, 2011

	Total Drivers		Distracted Drivers		
Vehicle Type	#	% of total	#	% total drivers	%distracted drivers
Total	43,668	100	3,085	7	100
Passenger Car	17,335	40	1,316	8	43
Light Truck	16,643	38	1,235	7	40
Motorcycle	4,741	11	265	6	9
Large Truck	3,568	8	202	6	7
Bus	243	1	20	8	1

In conclusion,

- Ten percent of fatal crashes in 2011 were reported as distraction-affected crashes.
- Seventeen percent of injury crashes in 2011 were reported as distraction-affected crashes.
- In 2011, 3,331 people were killed in crashes involving distracted drivers and an estimated additional 387,000 were injured in motor vehicle crashes involving distracted drivers.
- Of those people killed in distraction-affected crashes, 385 died in crashes in which at least one of the drivers was using a cell phone (12% of fatalities in distraction-affected crashes) at the time of the crash. Use of a cell phone includes talking/listening to a cell phone, dialing/texting a cell phone, or other cell-phone-related activities.
- Eleven percent of all drivers 15-19 years old involved in fatal crashes were reported as distracted at the time of the crashes. This age group has the largest proportion of drivers who were distracted.
- In 2011, 495 non-occupants were killed in distraction-affected crashes.

1.3 NHTSA

The percentage of drivers text-messaging or visibly manipulating hand-held devices increased significantly for a second year in a row from 0.9 percent in 2010 to 1.3 percent in 2011, while driver hand-held cell phone use stood at 5 percent in 2011 (Figure 1). These results are from the National Occupant Protection Use Survey (NOPUS), which provides the only nationwide probability-based observed data on driver electronic device use in the United States. The NOPUS is conducted annually by the National Center for Statistics and Analysis of the National Highway Traffic Safety Administration.

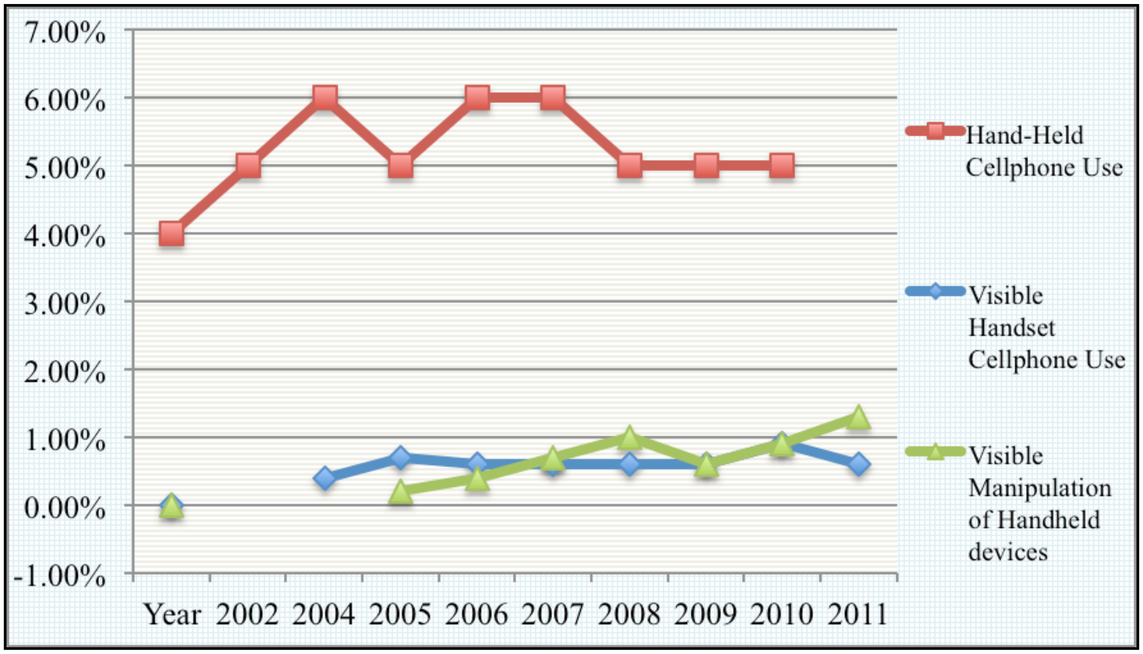


Figure 1. Increase In Drivers Manipulating Hand-Held Devices

Motor vehicle drivers are increasingly using electronic devices while driving for activities such as calling or sending text messages (texting) from cell phones, watching video, or searching the Internet. Automakers are also incorporating electronic devices into standard vehicle design, including dashboard Internet and satellite connections. Because these devices are integrated into everyday life, drivers mistakenly assume they can be used safely while operating a motor vehicle. Despite their dissimilarities, each of the devices distracts a driver's attention (some more than others), posing a highway safety hazard. The National Highway Traffic Safety Administration (NHTSA) reported that 5870 persons died (16% of all fatalities) and an estimated 515 000 individuals were injured in police reported crashes involving driver distraction in 2009. The General Estimates System estimated that 21% of all reported injury crashes involved distracted driving. Using naturalistic driving data (with cameras tracking driving behavior), the Federal Motor Carrier Safety Administration found that while dialing a mobile phone, drivers of light vehicles (cars, vans, and pickup trucks) were 2.8 times as likely as non-distracted drivers to have a crash or near crash, and commercial truck drivers were 5.9 times as likely. This research supports earlier findings that young drivers who text spend up to 400% more time with their eyes off the road than drivers who do not text, have 6-fold greater odds of a collision, and in simulated driving have impaired lateral and forward vehicle control.

Hence, NHTSA has long recognized the potential safety problems associated with driver distraction from use of in-vehicle technologies while driving. As a result, NHTSA has conducted a variety of research activities to examine and understand the implications of various forms of driver distraction and identify appropriate methodologies to assess the safety implications of distraction resulting from the use of in-vehicle technologies. Initial NHTSA research highlighted the complexity of the problem and the difficulties in establishing a direct link between distraction and crashes.

1.4 NHTSA Recommendations

Ongoing and future research will focus on applying NHTSA's research tools and methods to better understand the relationship between in-vehicle technologies, distraction and the increased risk of a crash. NHTSA's efforts are also directed at developing technological solutions for mitigating the potential for distraction-related crashes through systems that ease the workload of distractive tasks and thus prevent drivers of potential crash situations. The prevalence of distraction as a risk factor could increase as new technologies proliferate the market. It is important, therefore, that policies and programs are developed and implemented to manage existing and emerging risks associated with driver distraction. The following are the counter-measures recommended by NHTSA to be taken by future researchers:

- A carefully designed study of the prevalence of driver involvement in distracting activities within the vehicle should be undertaken. This information, combined with the epidemiological data, will enable an initial assessment of the magnitude of the problem to be made.
- An inventory of existing and emerging technologies and services which can be accessed on-board the vehicle or through portable devices within the vehicle should be compiled. The potentially distracting effects of these technologies and services should be established where these have not already been established.
- Research is required to better understand drivers' willingness to engage in potentially distracting tasks while driving, the factors that influence this willingness and under what conditions drivers engage in distracting tasks.
- There is currently little knowledge regarding how drivers use in-vehicle technologies: whether they use them in the manner intended by the designer; and at what point (or threshold) and under what conditions they become a distraction.
- Research needs to be conducted into whether and how individual difference factors such as age, gender, driving skill and experience influences the ease with which drivers are distracted.
- To complement the above activities, research is needed to identify and quantify the distracting effects of objects and events occurring outside the vehicle.

- No research, to the knowledge of the NHTSA, has examined the potentially distracting effects of portable devices used by pedestrians and other road users (e.g., mobile telephones, pedestrian navigators) to access information and services when negotiating their way through the road system.
- The most effective way to minimize technology-based distraction is to design the Human Car Interaction (HCaI) ergonomically. In Europe, North America and Japan, draft standards have already been developed which contain performance based goals which must be reached by the HCaI so that the in-car technologies do not distract or visually entertain the driver while driving (e.g., the European Statement of Principles for Driver Interactions with Advanced In-vehicle Information and Communication systems). It is important that relevant authorities closely monitor the development of these standards and that local vehicle manufacturers and system developers are encouraged to refer to these standards in designing their systems.
- The operation of certain devices including mobile phones and route guidance systems often involves associated tasks such as accessing written information, which can further distract the driver. There is a need for research to develop the HCaI so that it eliminates the need for these associated tasks.

1.5 Our Perspective On Driver Distraction

- Distraction is very serious and costly problem both in life and in dollar.
- However, Distraction is also a very complex problem to solve as per NHTSA recommendation.
- Chapter 2 will show a small side of this complexity - such as sources of distraction, accident risks, cognitive load and driver behavior detection.

1.6 State Of Art

Traditional Human-Car Interaction was fundamentally a driver maneuvering a car at a given time and no other devices. Now the connected car experience has introduced lot of other features such as Wi-Fi connectivity, Phone connectivity and External GPS. Technically now, the driver is operating a vehicle with one or more devices simultaneously. First and foremost, the driving task can be divided into three classes: primary, secondary and tertiary (Geiser, 1985). Primary tasks describe how to maneuver the car, e.g. control the speed or checking rearview mirror. The steering wheel is the primary controller and the pedals are the earliest control devices introduced in a car. So far, these devices have stayed largely unaffected but the additional controls shortcuts are often mounted on the modern-day steering wheels and that can be considered as a fundamental part of the car. Secondary tasks are functions that increase the safety of the driver, the car, and the environment, e.g. setting turning signals, lane change warning, activating the windshield wipers. Tertiary tasks are all functions concerning entertainment and information systems. Even though the computing power of systems integrated with the car is analogous to current mobile phones or even desktop computers, interacting with these systems is very dissimilar. HCaI is subjected to different constraints that generally do not apply to HCI (Kern, Schmidt, 2009). The comparison between these two is given in Table 8 below.

Table 8. Comparison Between HCaI And HCI

Human-Car Interaction (HCaI)	Human-Computer Interaction (HCI)
Every task has precedence in car: primary task, secondary task, and tertiary task.	There are no such restrictions while interacting with computers.
A driver has to share his attention between the primary task and other non-driving-related activities.	User is able to provide his full attention to a computer system in a desktop environment
Computer input and output devices can’t be used as it demands high attention mental as well as physical.	Devices like mouse, keyboards for input and large information-rich displays for output
If the driver does not pay full attention to the primary task, dangerous situation may arise.	There are no such risk related to user’s safety
A driver is not free to choose body movements as he is buckled up in the driver’s seat.	In a desktop environment, the user is more or less free to choose with which body part he wants to interact with the computer

Two-handed operations are not acceptable; for safety reasons, one hand should always remain on the steering wheel [European Communities 2007].	The environmental conditions while using a desktop computer do not affect human computer interaction in a critical way.
HCaI is always used in context, where the current driving situation greatly affects the interaction. For example, interacting with an infotainment system under high traffic and noisy conditions might result in higher work load for the driver.	A user might be disturbed by environmental noise or light conditions, but it is unheard that this has ever put the user or others in his vicinity in a dangerous situation.
In-car voice interaction has many challenges like environment noise, hardware limitations and response time.	There are no such limitations regarding noise or response time at home while interacting with computer on voice recognition.
HCaI is also affected by outdoor environment use cases such as engine noise, extreme sunlight or extreme dark, vibrations, snow, fog, and rain.	HCI mostly takes place in indoor environment, which controlled and stable.

The discussion in this work centers on the limited areas of in-car environment, which affects the driver in terms of distraction. The areas of the in-car controls can be defined as instrument cluster, steering wheel, infotainment display, climate and media controls, car system controls, rear and front mirror controls, front passenger side auxiliary display controls, and real display controls. The scope area of the work is given in the Figure 2 below. The Figure below was a great influence in designing MMI.

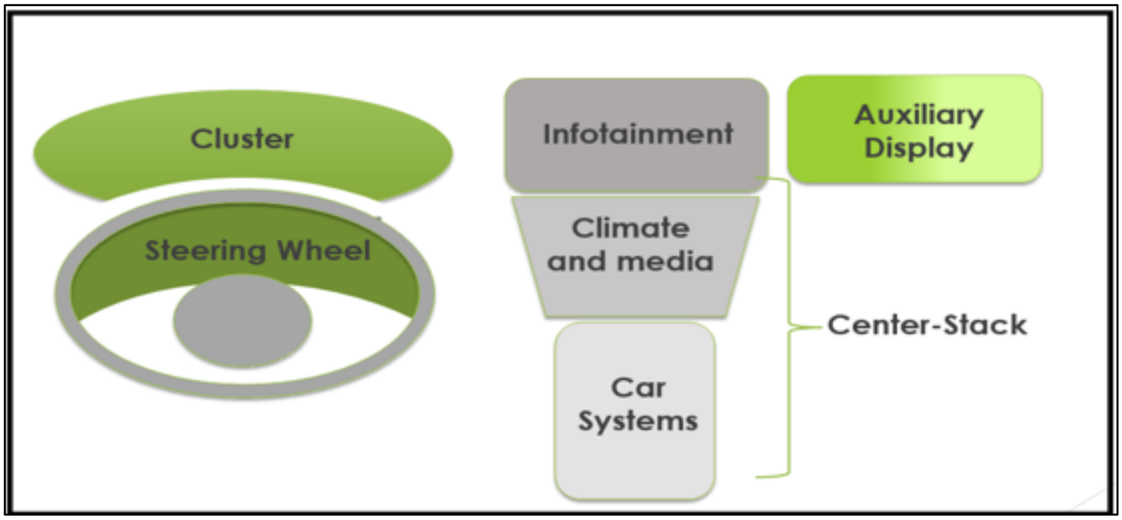
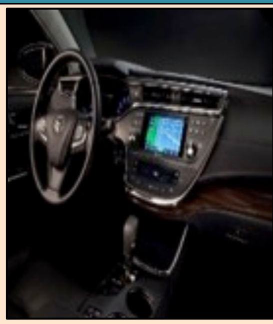


Figure 2. In-Car Environment Project Scope

The 360-degree review is about knowing the automotive domain for HCaI and analyzing the features, technology and interaction design of most of the car categories such as Economy cars, Premium cars, Sports cars and Luxury cars. Toyota Avalon comes under Premium Cars category. This category of cars comes under compact, mid-large, and large-family cars. This class of the cars is very much influenced by technology and it comes overloaded with lots of features and functionality. The consumer is ready to pay for extra feature like ADAS, voice recognition, and fancy instrument cluster or infotainment. So automakers are ready to do more for this segment and outsourcing of the infotainments and ADAS loaded with features has become common. The Table 9 is an example of Toyota Avalon Analysis.

Table 9. Toyota Avalon In-Car Interaction Design Analysis

Figure 3. T.A. 1	Figure 4. T.A. 2	Figure 5. T.A. 3	Figure 6. T.A. 4
			

Analysis-

- Touch display in CS with 2 manual control knobs and 10 small buttons besides.
- Small secondary display for climate controls with preferred grouping but small buttons
- IC with gauges and small digital display containing too much information

CHAPTER 2

BACKGROUND

2.1 What Is Driver Distraction?

The American Automobile Association defines driver distraction as occurring "when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object or person within or outside the vehicle compelled or tended to induce the driver's shifting attention away from the driving task" (Stutts et al., 2001). Crash data analysis reveals that any distraction has the potential to cause or contribute to a crash. Thus, rolling down a window, adjusting a mirror, tuning a radio or dialing a cell phone have all been identified as fundamental factors in crashes. Many distracting activities that drivers engage in can involve more than one of these components (e.g., visually searching for a control to manipulate). Recent concerns about the potential safety implications of technology based distractions focus on the nature and magnitude of demands some of these devices can place on drivers. Based on an analysis of NHTSA crash data, the major components of inattention-related police reported crashes include

- "Distraction" (attending to tasks other than driving, e.g., tuning the radio, speaking on a phone, looking at a billboard, etc.),
- "Looked but did not see" (e.g., situations where the driver may be lost in thought or was not fully attentive to the surrounds)
- Situations where the driver was drowsy or fell asleep.

All together, these crashes account for approximately 25 percent of police reported crashes. Distraction was most likely to be involved in rear-end collisions in which the lead vehicle was stopped and in single vehicle crashes (NHTSA). Crashes in which the driver "looked but did not see" occurred most often at intersections and in lane-changing/merging situations. To provide additional detail about sources of distraction, Wierwille and Tijerina (1996) searched police report narratives for a set of crashes from North Carolina. They identified 2,819 crashes in which the driver's attention was diverted and found that the majority of these (55.5%) involved distraction due to a source inside the vehicle, including objects, interacting with another person or animal, or interacting with instrumentation, including the radio or a wireless phone. The accelerating rate of in-vehicle technological developments has extended NHTSA's interest to incorporate a wider range of these technologies in its planning of research, and public information/outreach. The technological advancement that has taken place has created new alliances and competition among the automotive, computer, World Wide Web and wireless industries. The outcome has been a new generation of pioneering technologies, characterized by portability, convenience and a variety of functionality that can allow a user the broadest access to communications and informational resources in a mobile setting. It is this flexibility that has raised the concern of NHTSA within the context of driving, where cutting-edge technology is being made available to the driving public as well as the commercial driver, either as OEM (Original Equipment Manufacturer) or aftermarket systems and devices. Concern over this subject, among media, states, and the public, has been growing in light of recent announcements of new initiatives to bring computer functionality to the automobile, including access to the world wide web, availability of e-mail services, and the ability to "conduct business" and "e-commerce" while driving. Industry estimates of widespread use of these services imply general availability at reasonable prices in the near future. The potential for unfavorable safety consequences of using these systems and services by drivers emphasizes the significance of understanding the relationship between device design, the associated demands of these systems and how they interact with the elements that influence drivers' inclination to engage in secondary tasks while driving. It is the ambiguity of these relationships and the need to develop effective countermeasures to tackle the problem of driver inattention that serves as a basis for NHTSA's continued efforts in this area.

2.2 Sources Of Driver Distraction

According to the National Highway Traffic Safety Administration (NHTSA) there are four distinct, although not mutually exclusive, forms of driver distraction: visual, auditory, biomechanical (physical) and cognitive. Visual distraction occurs when the driver neglects to look at the road and instead focuses his/her attention on another visual target for a period of time, can be described as "eye-off-road". Auditory distraction occurs when the driver focuses their attention on auditory signals rather than on the road environment, "ears-off-road". Biomechanical distraction occurs when drivers remove one or both hands from the steering wheel to physically manipulate an object, "hands-off-road". Cognitive distraction includes any thoughts that absorb the driver's attention to the point where they are unable to navigate through the road network safely, "mind-off-road". The trend toward increasing use of In-Vehicle Interactive Systems (IVISs) is critical because IVISs induce distraction. And any of the above type of distraction can lead to larger lane variation, slower response to hazards, more abrupt steering control and less efficient visual perception than attentive driving. Moreover, the four types of distraction can occur in combination and interact with each other. Cognitive distraction is the hardest to study. The NHTSA in the United States has attempted to categorize these sources of driver distraction under the following 13 headings:

1. Eating or drinking;
2. Outside person, object or event;
3. Adjusting radio, cassette, or CD;
4. Other occupants in vehicle;
5. Moving object in vehicle;
6. Smoking related;
7. Talking or listening on mobile phone;
8. Dialing mobile phone;
9. Using device/object brought into vehicle;
10. Using device/controls integral to vehicle;
11. Adjusting climate controls;
12. Other distractions; and
13. Unknown distraction

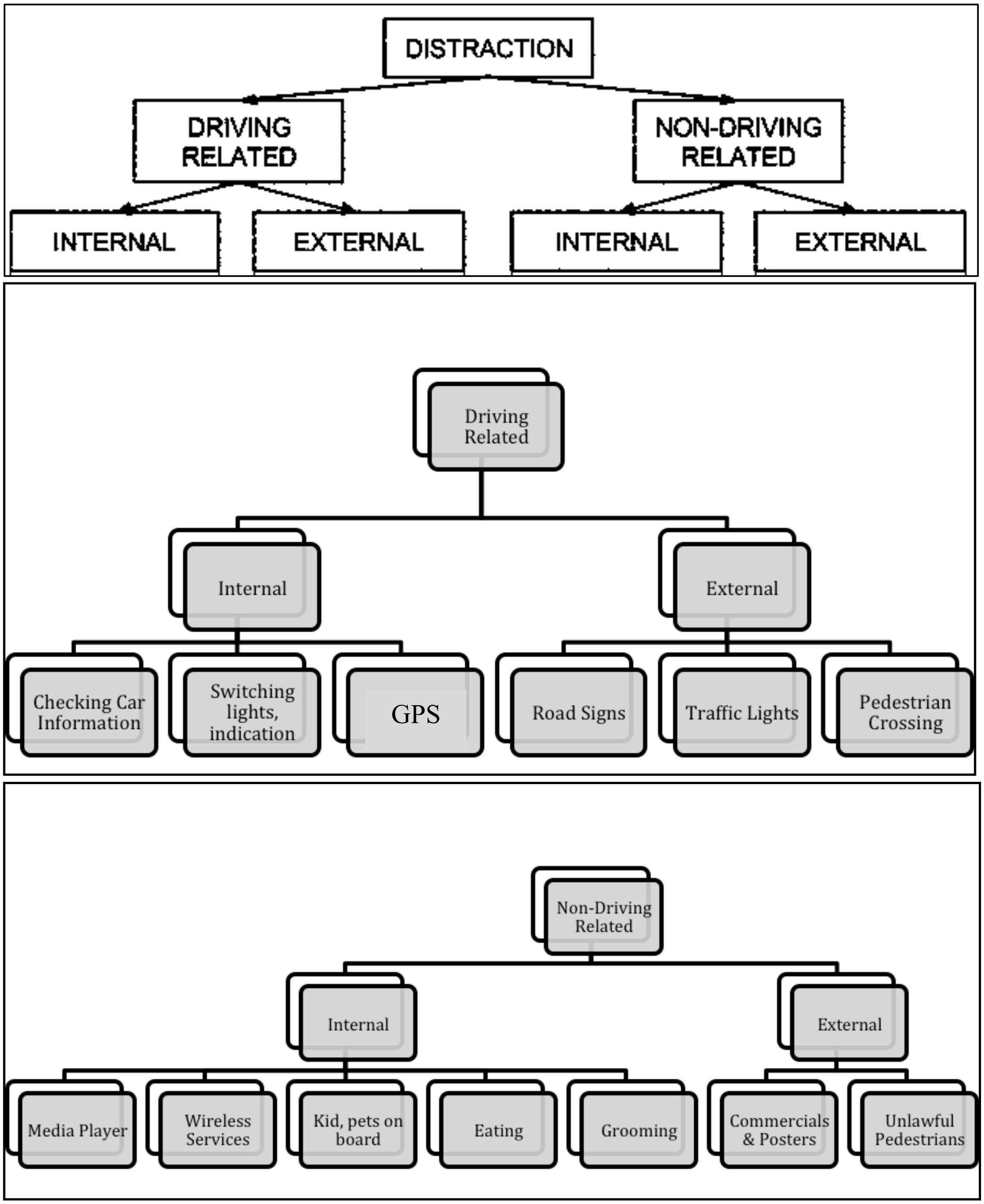


Figure 7. Driver Distraction Model

This model would be developed under 3 states – Stable (Normal driving conditions like a straight road), Dynamic (Taking a turn or Curved road) and Emergency (Accidents).

2.3 Exposure Assessment

According to the US National Highway Traffic Safety Administration (NHTSA), in 2008, nearly 11% of drivers—approximately one million individuals—used a mobile device at some time. Additionally, 35-50% of drivers admit to cell phone use while driving, while 90% of drivers fear those who do. Some foods and drinks can lead to dangerous distractions. McKeel Hagerty, president of Hagerty Classic Insurance Company, did a study to find out which foods were the worst to try to consume while driving. Coffee was the top offender because of its tendency to spill even if in a cup with a travel lid. Hot soup was second followed by tacos and chili. Hamburgers and barbecued food came in fifth and sixth. Eating while driving is not only dangerous, it's messy and it means you're not watching the road. According to a Health Day poll from November 2011(Most U.S. Drivers Engage in 'Distracting' Behaviors: Poll, By Amanda Gardner), most adults who drive admit to engaging in distracted driving behaviors. This poll, which included 2,800 American adults, found that:

- Approximately 86% of drivers have admitted to eating or drinking while driving.
- Approximately 37% of drivers have texted while driving at least once, while 18% of drivers have said they have formed the habit of doing it often.
- Approximately 41% of adult drivers have set or changed a GPS system while driving, and 21% do it "more frequently."
- Approximately 36% of adult drivers have used a map as road guidance while driving.

- At least 1 out of every 5 drivers have admitted to combing or styling their hair while driving.
- Approximately 14% of drivers have applied makeup while driving.
- Approximately 13% of adult drivers have browsed the Internet while driving.

Data from this poll also revealed that younger drivers have a greater tendency to be involved in distracted driving than older individuals. Additionally, males have a greater tendency to engage in distracted driving activities, including driving while drowsy, after drinking alcohol, while reading a map, using a GPS system, or using the Internet.

Hazard assessment - A study in 2013 estimated the following risks of a crash or near-crash among novice drivers:

Table 10. Hazard Assessment Of Crash Risks Associated With Distraction Factors

Activity	Odds ratio
Dialing a cell phone	8.3
Reaching for a cell phone	7.1
Sending or receiving text messages	3.9
Reaching for an object other than a cell phone	8.0
Looking at a roadside object	3.9
Eating	3.0
Interaction with radio (or head unit)	1.0

Among experienced drivers, dialing a cell phone is estimated to increase the risk of a crash or near crash by odds ratio 2.5.

2.4 History Of Driver Distraction Research

In September 2010, the NHTSA released a report on distracted driving fatalities for 2009. The NHTSA considers distracted driving to include the following distractions: other occupants in the car, eating, drinking, smoking, adjusting radio, adjusting environmental control, reaching for objects in car, and cell phone use. The report stated that 5,474 people were killed and 448,000 individuals were injured in motor vehicle crashes involving distracted drivers in 2009. Approximately 995 deaths of those individuals were drivers distracted by cell phones. The report does not state whether this is an under or over representation of the level of cell phone use amongst drivers, or whether there is a causal relationship. The NHTSA states that 80% of accidents and 16% of highway deaths are the result of distracted drivers. The National Safety Council (NSC) estimates that 1.6 million (25%) crashes annually are due to cell phone use, and another 1 million (18%) traffic accidents are due to text messaging while driving. These numbers equate to one accident every 24 seconds attributed to distracted driving by cell phone use. The NSC also reported that speaking on a cell phone while driving reduces focus on the road and the act of driving by 37%, irrespective of hands-free cell phone operation. The US Department of Transportation estimates that reaching for a cell phone distracts a driver for 4.6 seconds, or the equivalent of the length of a football field, if the vehicle is traveling 55 miles per hour. It has been shown that reaching for something inside the vehicle increases the accident risk by 9 times. Texting while driving increases the risk of an auto accident by 23 times.

Driving with a dog or any pet can be very dangerous. An uncaged or unharnessed animal can be a constant distraction. According to a national study by AAA (American

Automobile Association), 31 percent of the people that responded admitted to being distracted by their dogs. Fifty-nine percent of people that were surveyed had participated in at least one distracting behavior while driving with their dog. Eighty percent of respondents said they'd driven with their pets, and only 17 percent said they used any form of pet restraint. The AAA Foundation for Traffic Safety found that looking away from the road for only two seconds doubles a driver's risk of being in a crash.

A 2003 study of U.S. crash data states that driver inattention is estimated to be a factor in 20–50 percent of all police-reported crashes. Driver distraction has been determined to be a contributing factor in estimated 8–13 percent of all vehicle crashes. Of distraction-related accidents, cell phone use may range from 1.5 to 5 percent of contributing factors, according to a 2003 study. "Outside person, object, or event" (commonly known as rubbernecking) is the most reported cause of distraction related accidents, followed by "adjusting radio/cassette player/CD." "Using/dialing cell phone" is the eighth most reported cause of distraction-related accidents, according to the study.

According to the article "NHTSA distracted driving guidelines" in the August 2013 Motor Age magazine issue, the NHTSA released voluntary guidelines covering the use of in-car infotainment and communication devices, that have some bearing on connected car technologies and In-Car Interactive System. "Proposed items include disabling manual text entry and video-based systems prohibiting the display of text messages, social media or Web pages while the car is in motion or in gear. NHTSA heavily relied on the input provided by Alliance of Automobile Manufacturers and drafted Guidelines to eliminate crashes attributable to driver distraction The NHTSA Guidelines recommend that devices be designed so that tasks can be completed by the driver while driving with glances away from the roadway of 2 seconds or less and a cumulative time spent glancing away from the roadway of 12 seconds or less in a series of 1.5-second glances. In 2011, according to the NHTSA, 1/3 of the accidents caused by distracted driving. Driving and eating is very distracting. A correspondent for the Boston Globe, Lucia Huntington, stated, "Distracted driving is the cause of many of today's traffic accidents. In a world of ever-extending commutes and busy schedules, eating while operating a vehicle has become the norm, but eating while behind the wheel proves costly for many drivers. Soups, unwieldy burgers, and hot drinks can make steering a car impossible. Although the danger of eating while driving are apparent and well known, drivers ignore them repeatedly, accounting for many crashes and near-misses." During a study done by NHTSA, the NHTSA blames "inattentive driving" for 80% of all car accidents. 2.1 percent of the total were daydreaming, personal hygiene, and eating. The location of where people live also causes people to eat and drive. Now that people are now living in the suburbs, this has caused a longer commute to work for some. A study done by Toyota found that truck drivers manage their lives out of their trucks. With this fast-paced life style everyone is always on the move, finding time for food can be difficult, but saving time is not worth risking your life or someone else's.

A study by Monash University found that having one or more children in the car was 12 times more distracting than talking on a mobile phone while driving.

According to David Petrie of the Huntington Post, Children in the back seat are the worst distraction for drivers. While the focus on texting while driving is laudable, it has failed to address long-standing issues. In both cases an incoming call and a crying child create a situation where the driver should pull over and not attempt to multitask.

A study by AAA found that talking to a passenger was as distracting as talking on a hands-free mobile phone.

Today's youth is being accused for most of the distracted driving, but really adults are at fault too. More than 600 parents and caregivers were surveyed in two Michigan emergency rooms while their children, ages 1–12 years were being treated for any reason. During this survey, almost 90% of drivers reported engaging in at least one technology-related distraction while driving their children in the past month. The parents who disclosed using the phone—hand held or hands free—while driving were 2.6 times likely to have reportedly been involved in a motor vehicle crash. The escalating annual rate of fatalities from distracted driving corresponds to both the number of cell phone subscriptions per capita, as well as the average number of text messages per month. From 2009 to 2011, the amount of text messages sent increased by nearly 50%.

Distracted driving offenders are more likely to report driving while drowsy, going 20 miles per hour over the speed limit, driving aggressively, not stopping at a red light or stop sign, and driving while under the influence of alcohol. The American Automobile Association (AAA) reports that younger drivers are overwhelmingly more likely than older drivers to text message and talk on cell phones while driving. However, the proportion of drivers aged 35-44 who reported talking on cell phones while driving is not significantly lower than those drivers aged 18-24 who reports doing so.

2.5 Accident Risk Assessment

In 2011, Shutko and Tijerina reviewed a large naturalistic study of in field operational tests on variety of vehicles and concluded that:

- Most of the collisions and near misses that occur involve inattention as a contributing factor.
- Visual inattention (looking away from the road ahead) is the single most significant factor contributing to crash and near crash involvement.
- Cognitive distraction associated with listening to, or talking on, a handheld or hands-free device is associated with crashes and near miss events to a lesser extent than is commonly believed, and such distractions may even enhance safety in some instances.

Distracted driving is responsible for many deaths that could otherwise be prevented, especially in the younger generation of drivers. Throughout the United States, over 3,000 deaths and 416,000 injuries annually can be attributed to distracted driving. To further illustrate the seriousness of this "epidemic," driving while texting is about 6 times more likely to result in an accident than drinking while driving. Not only is distracted driving more likely to result in an accident, but the risk of injury requiring hospital visitation is 3-5 times greater than the rate for other accidents.

2.6 Cognitive Load

Cognitive distraction is the most challenging of the four sources (visual, physical, audio and cognitive) of distraction to evaluate because of the problems associated with observing what a driver's brain (as opposed to hands, ears or eyes) is doing. Additionally, changes in driving performance coupled with cognitive distraction have been shown to be qualitatively different from those associated with visual distraction (Angell et al., 2006; Engström, Johansson, & Östlund, 2005). For example, visual distraction has been shown to increase the variability of lane position, whereas cognitive distraction has been shown to decrease the variability of lane position (Cooper, Medeiros-Ward, & Strayer, in press). Figure 8 presents a framework for understanding the relationship between cognitive workload, cognitive distraction, and crash risk.

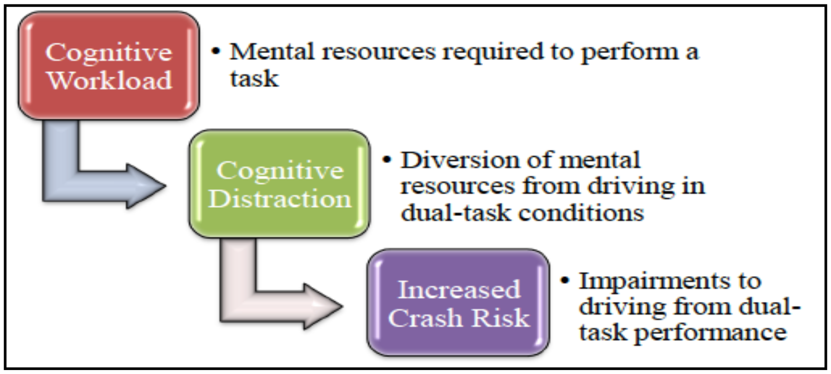


Figure 8. Relationship Between Cognitive Workload, Distraction And Crash Risk

As attention is diverted from the task of driving, the crash risk increases. Proxies of crash risk include increased brake reaction time (Brown, Lee, & McGehee, 2001; Caird, Willness, Steel, & Scialfa, 2008; Horrey & Wickens, 2006), failure to scan for potential hazards in the driving environment (Taylor et al., 2013), failure to notice objects in the line of sight (Strayer & Drews, 2007), and failures to stop at controlled intersections (Strayer, Watson, & Drews, 2011). Logically, the basic measures of most driver distraction research focus on the principal task of driving. These often include analyses of steering, throttle, and brake inputs, as well as their effects on lateral and longitudinal control. Unexpectedly, the effects of cognitive distraction on these primary measures are somewhat subtle and often contradictory. Indeed, two highly cited meta-analyses of cognitive distraction indicated that it does not reliably affect basic lateral or longitudinal control, but that it does reliably degrade reaction time measures (Caird et al., 2008;

Horrey & Wickens, 2006). Driver cognitive distraction (e.g., hand-free cell phone conversation) can lead to unapparent, but detrimental, impairment to driving safety. Detecting cognitive distraction represents an important function for driver distraction mitigation systems. A study (Yulan Liang, John D. Lee, 2014) discovered 19 distraction indicators (continuous measures of driver visual behavior and driving performance summarized) and defined cognitive distraction using the experimental condition (i.e., ‘distraction’ as in the drives with the secondary task, and ‘no distraction’ as in the drives without the secondary task). Table 11 represents these 19 indicators, divided into three groups based on their correlation and meaning—eye movement temporal measures, eye movement spatial measures, and driving performance measures.

Table 11. 19 Distraction Indicators

Groups	Distraction Indicators	
Eye Movement Temporal Measures	Blink frequency	
	Mean and Standard Deviation (SD) of:	Fixation duration
		Pursuit duration
		Pursuit distance
		Pursuit direction
		Pursuit speed
		Percentage of the time spent on performing pursuit movements in each time window
Eye Movement Spatial Measures	Mean and SD of:	Horizontal fixation location coordinates
		Vertical fixation location coordinates

Driving Performance Measures	SD of steering wheel position
	Mean steering error
	SD of lane position

Behavioral studies have shown that engaging in a secondary task, such as talking on a mobile phone, disrupts driving performance (Marcel Just, 2008). There have been previous studies inspecting the impact of concurrent auditory language comprehension on the brain activity associated with a replicated driving task. The results show that language comprehension performed parallel with driving draws mental resources away from the driving and produces deterioration in driving performance, even when it does not involve holding or dialing a phone.

A persistent issue about the human mind concerns the knack to do two things concurrently - multitasking. As technological and informational abilities of our environment rise, the number of available information streams increases, and hence the opportunities for complex multitasking increase. In particular, multitasking of driving and conversing on a cell phone is technologically available, but intuitively seems dangerous in some circumstances (Marcel Just, 2008). Although driving becomes sufficiently cognitively automated (Schneider, 1999) to permit experienced drivers to perform other tasks at the same time, such as carrying on a conversation, a large number of behavioral studies have now shown that performing another cognitive task while driving an actual or virtual car substantially degrades driving performance.

Recent studies have also shown that simulated driving performance is also disrupted by conversations using hands-free devices (Treffner and Barrett, 2004 and a number of research), and epidemiological studies of real-world accidents suggest that users of hands-free phones are just as likely to have an accident as users of hand-held devices (Redelmeier and Tibshirani, 1997; McEvoy et al., 2005). In their meta-analysis of recent dual-task driving studies, Horey and Wickens (2006) concluded that the costs to driving performance resulting from a secondary simulated conversation task were equivalent for hand-held and hands-free devices.

We have developed a 4-level Driver Distraction model (Figure 8) that classifies the various tasks in driving related tasks or not and if it is internal or externally occurring. Normal driving itself can be considered a multi-task (Marcel Just, 2008), requiring the integration of information not only from multiple visual inputs (e.g., the road ahead, the rear-view mirror, the instrument display) and other sensory modalities (e.g., the sound of other vehicles and proprioceptive information about the stability of the vehicle on the road), as well as the coordination of multiple behavioral outputs (e.g., steering, braking, acceleration). The consequences of multitasking on brain activation have been examined in several previous neuroimaging studies and they suggest that two concurrently-performed complex tasks draw on some shared, limited resource, and thus the resources available for performing each component task are diminished in the concurrent situation relative to when the task is performed alone (Marcel Just, 2008).

2.6.1 Driver Workload

NHTSA's first major effort in this area was the Truck Driver Workload Study, conducted between 1992 and 1995 (Tijerina, 1996; Tijerina et al., 1996). Because of the potential for diverting the driver's attention away from the driving task, NHTSA recognized the need for a set of methods that could be used to assess the safety implications of in-vehicle devices. The major objectives of this research program were to establish the relationship between workload and safety and to develop workload assessment methods for determining the safety implications of the use of in vehicle technologies while driving. One major conclusion of this work was that the development of a quantitative model to predict crash incidence as a function of driver workload measures was not feasible. Among the difficulties are the complexity and multiplicity of factors involved in determining driver workload and crash causation and the limitations of existing crash databases with respect to identifying crashes that were caused by driver distraction associated with in-vehicle technologies. Because of these difficulties, it was concluded that workload assessment is best considered as a relative assessment made in comparison to other tasks or baselines. Open-road driving was considered to be a baseline in terms of driving task workload, while tuning a radio was considered to be the upper boundary of acceptable workload for a secondary task since it is a well established and accepted "distraction." A second conclusion of this work was the demonstration that visual allocation measures, including glance duration, number of glances, and total glance time away from the road scene can be used to assess the driver's workload associated with in-cab devices. In addition, lane-keeping measures, such as lane exceedance frequency were also introduced as safety-relevant performance measures. This study found that 2- and 4-line messages such as those used in their testing could have a substantial effect on visual scanning behavior (e.g., increased time looking away from the road scene, shortened glances to the road while reading text) and on lane keeping performance (greater incidence of unplanned lane exceedences). Drivers involved in cell phone dialing tasks were observed to have lane exceedences on 27% of the trials. Finally, results indicated that visual scanning, as measured by mirror sampling, was cut by almost 50 % on average when the driver was engaged in dialogue as compared to open road driving without dialogue. The tools developed in this project are widely used by many researchers as the most appropriate way to assess workload and the consequent potential for distraction associated with the use of in-vehicle technologies. Following that, NHTSA published "An Investigation of the Safety Implications of Wireless Communications in Vehicles," (Goodman, et al., 1997). The report assessed the current state of knowledge with respect to the impact of wireless phone use while driving and explored the broader safety implications of phone use while driving. With respect to the question of whether wireless phone use while driving increases crash risk, the report concluded that the use of wireless phones did increase the risk of a crash, "at least in isolated cases. And the outcome of this project was to encourage changes in data collection methods to improve our ability to estimate the magnitude of the safety problem and to assist the public, the states, and industry in making informed decisions about how and when to combine wireless phone use with driving.

Most recently NHTSA has conducted three experimental studies addressing questions relating to the distraction potential associated with route navigation systems. These included a destination entry study and an individual differences study, which at the time was being considered as a "recommended practice" for evaluating the acceptability of navigation systems.

There was another research on Individual Driver Differences. The objective of this study was to determine whether individual differences in driver abilities would influence the speed with which they interact with in-vehicle technologies. The results were interpreted as support for the conclusion that drivers who differ in temporal (i.e., time dependent performances) and spatial (i.e., ability to visualize and manipulate objects in space) abilities will respond differently to in-vehicle technologies along safety-relevant dimensions.

Research by Horberry and colleagues (in press), however, failed to reveal any interaction between the complexity of the driving environment (by increasing the number of billboards and advertisements placed on the roadside and the number of buildings and on-coming traffic.) and two in-vehicle distracter tasks: operating an in-car entertainment system and conversing on a hands-free mobile phone. Results revealed that interacting with the entertainment system and mobile phone affected driving performance, by decreasing mean speed, increasing speed variability and decreasing responses to a pedestrian hazard. However, no interaction between the distracter tasks and environment complexity was revealed, suggesting that driving performance while interacting with the in-car devices was not further degraded by increased complexity in the traffic environment. It is possible that increasing the number of objects that are not central to the driving task has little effect on increasing the demands of the driving task because drivers simply ignore anything not essential to the driving task when under increased load (e.g., when performing a secondary task). Lee et al. (2001) used a driving simulator to examine the effects of a speech-based email system (in which email messages were accessed, read and replied to using only voice commands) on drivers' attention and their reaction time to a braking lead vehicle. When interacting with the speech-based email system, regardless of the complexity of the system, drivers' reaction time to the braking vehicle was 30% longer than when not interacting with the system. Moreover, this 30% increase in reaction time translated into a 3.5 to 38.5% increase in collisions and 27.3 to 80.7% increase in collision velocity. Interaction with the speech-based email system also increased drivers' self-reported workload levels and this was highest for the complex email system. Another research suggests that simply listening to radio broadcasts while driving can impair driving performance, resulting in more lane deviations, particularly under complex driving conditions (Jancke et al., 1994). Also, while several studies have found that tuning the radio is less distracting than dialling or talking on a mobile phone (McKnight & McKnight, 1993; Strayer et al., 2002) or operating a navigation system (Tijerina et al., 1998), numerous other studies have found that tuning a radio degrades driving performance more than holding a simple conversation on a mobile phone, particularly when driving in adverse conditions (Briem et al., 1995; Wikman et al., 1998).

The automotive industry is actively working to adopt speech recognition technology into in-vehicle devices to allow true hands free operation, including the capability to control the numerous functions of these systems. At the same time text-to-speech processing is also becoming available for automotive use. The safe operation of these technologies is predicated on the assumption that voice-activated and speech-based interfaces will be sufficient for preventing significant distraction for drivers performing increasingly complex transactions while driving. However, this assumption is not well tested and some studies even suggest the opposite (as elaborated earlier in Chapter 1 section 3 and later explained in section 9 of this chapter).

2.6.2 Compensatory Behavior

One fundamental question concerning the influence of in-vehicle devices on driving performance is whether and how drivers self-regulate their driving to compensate for any decrease in attention to the driving task. Surprisingly, very little research has been conducted to exclusively address this issue. It is important to identify, however, that not all changes in driving performance associated with non-driving tasks are indicative of driver impairment, and research suggests that drivers do engage in a range of deliberate and unconscious compensatory behaviors in order to attempt to maintain an adequate level of safe driving (Haigney et al., 2000). Compensatory or adaptive behavior can occur at a number of levels ranging from the strategic (e.g., choosing not to use a mobile phone while driving) to the operational level (e.g., reducing speed) (Poysti, Rajalin & Summala, 2005). At the highest level, drivers can choose to moderate their exposure to risk by preferring not to engage in a potentially distracting task while driving. Research has shown, for example, that older drivers' driving performance is impaired to a greater degree than younger drivers when using a mobile phone and this results in compensatory behavior at the highest level; many older drivers choose not use a mobile phone while driving (Alm & Nilsson, 1995; Lamble, Rajalin & Summala, 2002). At the operational level, several studies have shown that drivers attempt to lessen workload and moderate their exposure to risk while interacting with in-vehicle devices. They do this through a number of means: decreasing speed (Alm & Nilsson, 1990; Burns, Parkes, Burton, Smith & Burch, 2002; Haigney et al., 2000; Rakauskas, Gugerty & Ward, 2004), increasing inter-vehicular distance (Jamson, Westerman, Hockey & Carsten, 2004; Strayer & Drews, 2004; Strayer, Drews & Johnston, 2003), changing the relative amount of attention given to the driving and non-driving tasks in response to changes in the road environment (Brookhuis, de Vries & de Waard, 1991; Chiang Brooks & Weir, 2001), and accepting a temporary degradation in certain driving tasks (e.g., by checking mirrors and instruments less frequently) (Brookhuis et al., 1991; Harbluk, Noy & Eizenmann, 2002).

Several on-road and simulator studies have found that drivers tend to decrease their mean speed and the standard deviation of accelerator travel decreased when engaging in a secondary task (Young, K. & Regan, M. (2007)). An increase in following distance by 12 percent (Strayer and Drews 2004) is another compensatory behavior that has been displayed by drivers while they are interacting with in-vehicle devices.

Generally, based on the above research, the potential for an in-vehicle device to distract drivers can be induced by the design of the interface for the device. With respect to mobile phones, there is proof that the task of having to physically manipulate the phone does adversely affect driving. However, the task of speaking on the phone has also been indicated to have a significant negative impact on driving performance irrespective of the phone type used. In addition, the use of voice input technology to enter destination information into route guidance systems appears to have a lesser effect on driving performance than does the use of visual-manual entry systems to perform this task. Similarly, guidance systems that present navigation instructions using audio output appear to be more usable and less distracting than systems that present information via a visual display, especially if the display is a intricate map.

Another factor, often closely related to interface design, which can influence the distraction potential of a secondary task, is the complexity of the task. For example, the familiarity of a destination address, or the level of difficulty or emotionality of a phone conversation can affect the cognitive demands that the task places on the driver and hence its potential to distract the driver from the driving task. Rakauskas and colleagues (2004) examined the relationship between level of conversation difficulty and driver distraction using a naturalistic conversation task And the results indicated, although the use of the phone degraded driving performance, the level of conversation difficulty did not differentially affect driving performance in terms of mean speed, speed or steering variability, or subjective mental workload. One explanation why this study failed to demonstrate an effect of conversation difficulty when numerous other have done so, may be that naturalistic conversations require less cognitive effort than the verbal reasoning and mathematical tasks used in previous studies and, thus, are less sensitive to effects of increasing difficulty.

2.6.3 Conclusion

Research has shown that the design of a device, the complexity of the driving environment and driver characteristics, such as age and driving experience level, the emotionality and/or complexity of the secondary task being executed can all influence the potential for non-driving tasks to distract drivers. Hence it was recommended that research should attempt to determine how frequently drivers engage in certain distracting activities, how long they typically engage in them, and under what conditions they usually engage in them. Further research is needed to obtain information about drivers' subjective assessments of the degree of distraction imposed by particular devices and their perceived ability to cope with these distractions. Studies examining whether and how practice and training can reduce the interference associated with performing secondary tasks while driving are urgently required and to establish the most ergonomic way to design In-Vehicle Interactive Systems so that they decrease distraction.

2.7 Driver Behavior Detection And Support

Although drivers benefit from these devices, it is also critical for drivers to avoid distraction and direct an acceptable level of attention to the road. A promising strategy to minimize the effect of distraction is to develop intelligent in-vehicle systems, namely adaptive distraction mitigation systems, which can provide real-time assistance or retrospective feedback to reduce distraction based on driver state/behavior, as well as the traffic context (Lee, 2009; Toledo et al., 2008). Such systems must accurately and non-intrusively detect whether drivers are distracted or not. Detecting driver distraction depends on how distraction changes driver behavior compared to the normal driving without distraction, which can depend on the type of distraction. Visual distraction relates to whether drivers look away from the road (i.e., on-road or off-road glances) and can be determined by momentary changes of drivers' eye glances. A general algorithm that considers driver glance behavior across a relatively short period could detect visual distraction consistently across drivers. Detecting cognitive distraction is much more complex than visual distraction because the signs of cognitive distraction are usually not readily apparent, are unlikely to be described by a simple linear relationship, and can vary across drivers. Detecting cognitive distraction likely requires an integration of a large number of indicators (e.g., eye gaze measures) over a relatively long time and may need to be personalized for different drivers (Liang et al., 2007b). The challenge is how to integrate performance measures in a logical manner to quantify complex, even unknown, relationship between drivers' cognitive state and distraction indicators. Data mining methods that can extract unknown patterns from a large volume of data present an innovative and promising approach to this end.

There are five types of measures for driver inattention detection:

1. Measures e.g., SSS (Stanford Sleepiness Scale), KSS (Karolinska Sleepiness Scale)
2. Driver biological measures e.g., EEG (Electroencephalogram), ECG (Electrocardiogram)

3. Driver physical measures e.g., PERCLOS (proportion/percentage of time in a minute that the eye is 80% closed), Gaze direction

4. Driving performance measures/ Engineering based e.g., steering wheel angle, yaw angle, reaction times etc.

5. Hybrid measures.

2.7.1 Driver Biological Measures

Cognitive distraction can be measured through a variety of physiological techniques. Among these, direct measures of brain activity may be the most compelling. One approach that shows high promise is to use time-locked signals of Electroencephalographic (EEG) activity, referred to as Event-Related Brain Potentials (ERPs). This technique provides a window into the brain activity that is associated with responses to imperative driving events (e.g., brake lights on a lead vehicle). Using this technique, Strayer & Drews (2007) found that the brain activity associated with processing the information necessary for the safe operation of a motor vehicle was suppressed when drivers were talking on a cell phone. However, this method is frowned upon, as it is very intrusive and is impossible to incorporate in real life.

2.7.2 Driver Physical Measures

The most commonly used driver physical data for driver cognitive distraction are eye movements. Azman et al. found that mouth and eyes are correlated to each other when a person is thinking or cognitively distracted and they could be used to detect driver' s cognitive distraction. In human science and psychology studies, it has been proved that mouth movement is a good indicator of a human' s state of mind and when a person is thinking, his/her mouth and eyes are moving together. Mouth movement can also be thought of a form of body language. Body language can be used to obtain information about whether a person is distracted or not. Two important conclusions from their study are: (1) mouth and eye movements are highly correlated to each other; and (2) right eye is more correlated to mouth movement either from eye' s height or width compared to the left eye. Victor et al. found that cognitive distraction causes drivers to concentrate their gaze in the center of the driving scene, as defined by the horizontal and vertical standard deviation of gaze distribution, and diminishes drivers' ability to detect targets across the entire driving scene. Fletcher and Zelinsky obtained information such as eye gaze direction, eye closure, and blink detection, as well as head position. Figure 9 shows glance frequency of drivers performing various distractive tasks at hazard locations.

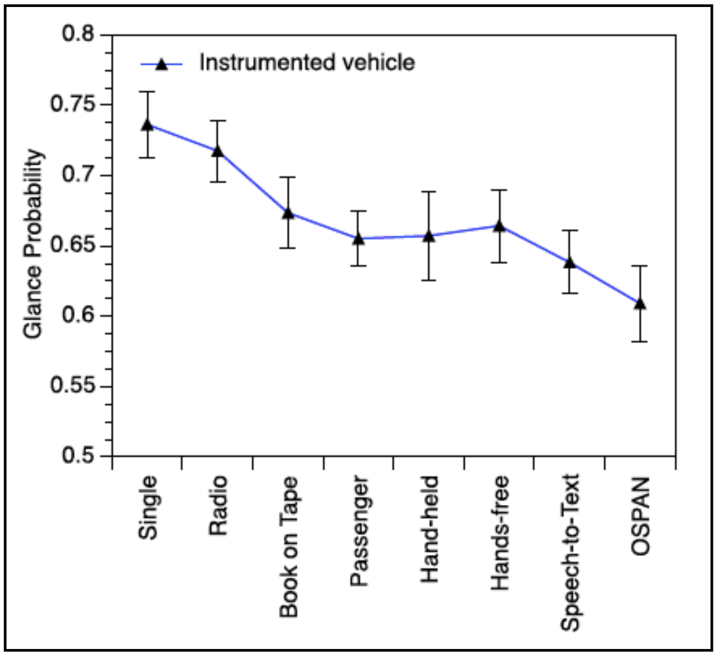


Figure 9. Glances At Hazard Locations

2.7.3 Driving Performance Measures/ Engineering Based

A change in the mental state can induce the change in driving performance. Many studies prove the fact that compared to the attentive drivers the distracted ones steer their car in a different way; the same applies for throttle use and speed. Some lines of evidence show that drivers adjust their behavior according to cognitive demand of secondary tasks.

Drivers tend to increase the distance to the leading vehicle in the car-following scenario when they engage in cognitively demanding secondary tasks. This suggests that drivers may compensate for the impairments that secondary tasks have imposed as elaborated earlier. Wollmer et al. introduced a technique for online driver distraction detection that used LSTM (Long Short Term Memory) recurrent neural nets to continuously predict the driver's state based on driving and head-tracking data. The measured signals include steering wheel angle, throttle position, speed, heading angle, lateral deviation, and head rotation. These links between driving performance and cognitive state show that driving performance measures are good candidates to predict cognitive distraction. This method will be explained in detail later in this report.

2.7.4 Hybrid Measures

In one of the above study, driver physical measures and driving performance measures were combined to detect driver distraction in real time. Comparing support vector machines SVM to traditional logistic regression models, the results showed that the SVMs models performed better. Machine-learning techniques were used to detect driver cognitive distraction based on the standard deviations of eye gaze, head orientation, pupil diameter, and average heart rate RRI (R-R Interval). The eye and head parameters were obtained using faceLAB, whereas the RRI data came from ECG. Sathyanarayana et al. detected distraction by combining motion signals from the leg and head with driving performance signals using a k-nearest neighbor classifier, the driving performance signals adopted including vehicle speed, braking, acceleration, and steering angle.

Among all of these measures, eye movements are one of the most promising ways to assess driver distraction. While most of the eye movements parameters were obtained by faceLAB or SmartEye, these systems are not common in vehicles today, owing to their higher price for installation into a vehicle. At the same time there are limits in the process of extracting eye movements' parameters. The limitations are -

1. Complex calibration: Before each experimental drive, the calibration of the gaze vector with the simulator screen must be verified. After that, in the process of the experiment eye tracker must be calibrated to every participant and the calibration takes 5 to 15 min. After the complex calibration, the tracking error was approximately 5% of visual angle for most participants.

2. Driver restriction: The participants cannot wear glasses or eye make-up because these conditions can negatively affect tracking accuracy.

3. Environmental restriction: Eye trackers may lose tracking accuracy when vehicles are traveling on rough roads or the lighting conditions are variable.

4. Time delay: The Seeing Machines' faceLAB eye tracking system takes approximately 2.6 s to transfer camera image to numerical data.

These requirements limit the application of cognitive distraction system using eye movements parameters obtained from faceLAB or SmartEye; therefore, up till now, this scheme is only for research offline. More robust and real-time eye tracking techniques are needed to make these detection systems become a reality. While driving performance parameters could be obtained in real time from CAN-Bus directly, driving performance measures are used in this study for cognitive distraction detection. In this method, the characteristic parameters could be directly extracted without depending on other sensors, and system real-time performance and robustness are improved. A significant finding of this study is that even though subjects preferred distinct alarms for different driver warning systems, their objective performance showed no difference in reaction times and accuracy of responses to a single versus multiple alarms for the different driver warning systems. This is an important finding since it implies that if performance is unaffected, automotive manufacturers can customize the alerting schemes of driver warning systems to the customers' desires, or use a simple master alerting scheme for vehicles where cost savings are important. However, these results are only applicable to aural alerting schemes and this work should be extended to include integration with visual and haptic alerts. While not unexpected, the results that demonstrate that low reliability can dramatically (and negatively) influence human performance further highlight the need for the development of highly reliable intelligent warning systems. While intelligent driving warning systems can serve as an additional protection to drivers in times of urgent or emergent events, as demonstrated in this study, decreased system reliability can dramatically increase incorrect responses to these systems. If there is a high incidence of false alarms for intelligent warning systems, drivers might be better served by not having such intelligent aids at all.

2.8 Problems In Measurement Of Driver Performance

1. The misuse of the term distraction (and possible misdirection of effort),
2. Driving performance measures and statistics that are either undefined or poorly defined (to be resolved by an SAE practice),

3. The workload of the driving task is not quantified,
4. The demand characteristics of in-vehicle tasks are not quantified,
5. Too often, standards specify only measurement methods, not compliance criteria.

These are the problems derived from the study by Green A. Paul, 2010.

2.8.1 The Misuse Of The Term Distraction

Driver distraction and workload are often used interchangeably, but are not the same. Part of the problem is defining what is the problem. As has been stated before (Oberholtzer, Yee, Green, Eoh, Nguyen, and Schweitzer, 2007; Green, 2008), in the popular press but also in the scientific literature, the term "distraction" is often used to describe the topic addressed here. Distraction generally refers to something that attracts and retains attention, whereas workload or overload refer to the individual and aggregate demands of the tasks a driver performs. In practice, sometimes the consequences of both are the same, but nonetheless distraction persists as the label for both phenomena, probably because it is easier to get attention and funding. The naming/identification of the problem is important because of its implications for what one thinks the problem is and which performance measures should be collected. Keep in mind that there is just something compelling about answering a ringing phone, keeping a phone conversation going, responding to a text message, or completing an in-vehicle task such as entering a destination. When these tasks are conducted while driving, they become a safety issue.

2.8.2 Driving Performance Measures And Statistics That Are Either Undefined Or Poorly Defined

Richard P. Feynman, the Nobel prize-winning physicist at Caltech, in his well-known textbook Feynman Lectures on Physics (volume 1, page 2-1), said, "Observation, reason, and experimentation make up what we call the scientific method." Following the scientific method involves creating a hypothesis to explain a phenomenon, collecting observable, quantifiable data in experiments to test the hypothesis, and using reasoning to interpret the results. Those quantifiable data, measurements, must be repeatable and reliable. The lack of such measures has been a major problem for driving research and engineering, especially for work on distraction/overload. A few examples from Savino (2009), his master's thesis, make the point. Savino reviewed the refereed human factors literature relating to driving, with the goals of determining the names used to identify common driving performance measures and statistics and how they were defined. He examined every issue of Human Factors and Ergonomics from 2000 to 2005, as well as the HFES and Driving Assessment Conference Proceedings, and other references. He did not examine SAE or ISO standards, as those interested in the research were familiar with their content. Overall, Savino examined 498 references, of which 111 were relevant to his research. The terms initially being considered for driver performance measurement are: accelerator response time, accelerator to brake transition time, brake response time, steering wheel reversal, distance gap, time gap, headway time, headway distance, time to collision, lane departure, lane change, lateral lane position, and time to line crossing. However the problem of undefined or inconsistently defined measures is quite serious, making automotive human factors engineering and research appear second-rate, and makes it difficult to consistently assess the effects of distraction. What would chemistry be like if there were ten different names for acidity, the pH value could be computed three different ways, and when used, the authors did not identify how the acidity/pH characteristic, or whatever they called it, was determined?

2.8.3 The Workload Of The Driving Task Is Not Well Quantified.

To date, the demand of the primary driving task in most studies is typically described in general terms, for example, as demanding, or in some studies, as low workload and high workload. Other times, it is measured, but no single or even small set of measures or statistics is consistently used in the majority of studies. As an example, one of the author's studies (Tsimhoni, Green, and Watanbe, 2001) evaluated the effects of workload on Head Up Display (HUD) use in a driving simulator. Workload was manipulated by varying the radius of the curve driven, with the implication being that smaller radius curves represented a higher workload. However, there was no direct measurement of workload. Keeping in mind that what is low, moderate, or high workload is relative. For example, at a certain place, moderate traffic is when a driver sees another vehicle and in another, it is when traffic is moving. Fortunately, ISO is developing a procedure for peripheral detection. This lack of consistent and reliable measures to quantify test conditions also does not reflect favorably on automotive human factors work. Workload depends primarily on road geometry, traffic, visibility, and the road surface condition, each of which can be quantified. Commonly, traffic volume is described in terms of Level of Service, which maps traffic volume into letter grade categories of A through F, where A corresponds to excellent driving conditions and F to failing conditions.

2.8.4 The Demand Characteristics Of In-Vehicle Tasks In Question Are Not Well Quantified.

A topic of significant debate in the literature is what levels of task demands (especially visual, cognitive, and psychomotor) are excessive. However, because tasks are only described qualitatively, a quantitative answer is unlikely to appear. However, there are few tasks used as benchmarks consistently across experiments. The Alliance of Automobile Manufacturer guidelines uses manual radio tuning as a benchmark, but across studies, the total time for that task varies by a factor or six, hardly a stable value (Shah and Green, 2003). Furthermore, it is unknown how much demand is too much, either on a single scale or in combination. Under what circumstances is a visual demand of 6.0 excessive? That of course will depend on the workload of the primary task, the duration of the secondary tasks, and the cognitive, auditory, and psychomotor demands of the task as well. Of course, since these have yet to be quantified in a common manner in the automotive literature, there is no direct, quantitative answer to the excessive visual demand question just posed.

2.8.5 Too Often, Standards Specify Only Measurement Methods, Not Compliance Criteria

Standards, guidelines, rules, and regulations fall into two categories, design oriented and performance oriented. Design oriented specifications identify specific physical characteristics for some feature and may specify values for it, such as a bumper height, a minimum acceptable contrast ratio for a letter, or a minimum intensity for a sound, say a warning. Performance specifications identify how well a system should do in a test, such as the maximum load on some body part in a crash, or the maximum allowable time for drivers to perform certain tasks while driving. There are numerous standards, guidelines, rules and regulations that relate to driver distraction. This is a reflection of the complexity of producing a product that is manufactured internationally and sold in many jurisdictions, where many organizations have a rightful say in safety. Of all the specified criteria what is excessively distracting, a performance characteristic, is left for the manufacturer or supplier to determine. Not providing criteria, leaving up to the user to determine what is distracting, has some interesting consequences. The major automakers with a human factors staff have the capability to decide what is excessive, but where there is no performance criterion, there is no incentive to conduct these tests, so they may not do it. In the organizations with few or no human factors staff, they lack appropriate performance criteria, and accordingly will not perform the evaluation unless required to do so. To put it plainly, if there is no performance criterion for distraction testing, tests for distraction will not be conducted.

2.8.6 Conclusion

There is a need to develop a unified model/theory of driver distraction that encompasses the different sources of distraction emanating from within and outside of the vehicle. A set of standardized experimental protocols is needed to allow for more accurate comparisons of results across studies to be made and to facilitate communication between researchers. Research is needed to establish what methods and measurement techniques are most sensitive to the differential effects of in-vehicle technologies on driving performance. Research is needed to identify and quantify the distracting effects of objects and events occurring outside the vehicle and further examine whether and how external events combine with internal events to distract the driver.

2.9 The Case Of MMI

Mobile phones are but one example of portable devices that provide a wide range of features that are carried into automobiles. They supplement information and driver assistance systems are now becoming common. Each of these systems and their functionalities is being provided for a valid purpose, and together, they increase complexity of vehicle operation. With recent advancement in vehicle safety systems, transforming vehicles from human-controlled passive devices into human-centric intelligent/ active systems is possible. With many more tasks for the driver to do, these systems could also collectively reduce safety and usability. The function of these added systems is something drivers must now learn and will use while driving. These systems can be distracting and their use overwhelming if improperly designed. Those doing the work of designing are sometimes so close to those evaluations that they may not be aware of the larger problem of growing total vehicle complexity. (Green, 2004) Moreover, because of the focus on very specific interface issues, engineers are not aware of the larger shortcomings of current work, which may fall below the quality of research and engineering being done in other industries.

2.9.1 According To The Crash Literature, Has In-Car Interactive System Use Led To Crashes?

There are numerous predictions concerning when various In-Car Interactive System systems will achieve various levels of market penetration in motor vehicles (Cole and Londal, 2000; Richardson and Green, 2000; Green, Flynn, Vanderhagen, Ziomek, Ullman, and Mayer, 2001; Frost and Sullivan, 2002). Although such predictions tend to be a bit optimistic, widespread use of In-Car Interactive System has occurred for some systems and will occur for others. At the present time, the use of cell phones while driving is common, with about 3% of all drivers being on the phone at any given time. Similarly, navigation systems are also becoming more common. It is only a matter of time before text messaging, email, and Internet access become widespread. In-Car Interactive System can have significant benefits, allowing drivers to make better use of their time and to support driving in a variety of ways. However, the concern is that some tasks, when performed under some situations, can pose a significant risk to drivers, passengers, and other road users. There is a growing body of evidence that the use of In-Car Interactive System is associated with crashes. Surprisingly, distraction-related crashes tend to be relatively more likely during the daytime, in good weather; conditions which are favorable to safe driving. When compared with all other crashes in which the driver is not impaired by alcohol or fatigue, rear-end collisions of all types tend to be much more common. In some analysis, intersection and run-off road crashes become relatively more common. The crash literature makes three key points:

1. There are crashes in which In-Car Interactive System use has been a contributing factor.
2. In crashes where In-Car Interactive System use is a contributing factor, drivers become so engrossed in the in-vehicle task that they lose sight of the driving task.
3. Crashes associated with In-Car Interactive System use are relatively more likely to occur in benign conditions (in good weather on good roads).

2.9.2 According To The Human Performance Literature, Why And How Do In-Car Interactive System-Related Crashes Occur?

Numerous studies in the literature examine multitasking while driving. Of these, at least 50 concern the use of phones, although many others concern navigation systems and with abstract tasks. There are a significant number of on-the-road studies (e.g., Brown, Tickner, and Simmonds, 1969; Brookhuis, de Vries, and de Waard, 1991; Tijerina, Johnston, Parmer, Winterbottom, and Goodman, 2000; Nunes and Recarte, 2002; Zylstra, Tsimhoni, Green, and Mayer, in preparation), though most have been conducted in the controlled context of a driving simulator (e.g., Nilsson and Alm, 1991; McKnight and McKnight, 1993; Nowakowski, Friedman, and Green, 2001; Strayer and Johnston, 2001; Tsimhoni, Smith, and Green, 2002; Uchida, Asano, and Hashimoto, 2002). (See Goodman, Bents, Tijerina, Wierwill, Lerner, and Benel, 1997, for a partial summary of the phone-related studies.) Although one can always pick at individual studies and find occasional flaws, the overwhelming abundance of evidence is irrefutable. Depending on the study, using In-Car Interactive System can increase following distance and variability, lane variance, lane departure, response time to a lead vehicle braking, steering entropy, and so forth. In a study about driver overload, referring to Wickens' multiple resource theory (Horrey and Wickens, 2003) as the scientific basis for what occurs. They suggest that driving demands visual, cognitive, and manual resources of specific types to process specifically coded information. In-vehicle tasks also have resource demands and those demands can exceed the capacity of the resources available, leading to overload. Unfortunately, this quite elegant explanation does not predict what drivers will do in response to that overload. All too often, drivers allow the primary task, driving, to degrade. Other explanations refer to cognitive capture, where drivers get locked into a task until it is completed (though some switching between tasks may occur in the process). Capture clearly occurs within secondary tasks. For example, if a person is talking on a phone and hears a call-waiting signal, they might ask the first person to hold, connect the second person, ask them to hold, and then complete the first call. They do not switch back and forth continuously. Similarly, if a person is working on a computer, say editing a document, and they receive an incoming email message, they might, if it was high priority, stop to answer the email message, but they will not type a line in the document, then a word in the email message, etc., switching back and forth. This is because the task-switching restart costs are high in much of the same way there are costs associated with an interrupt service routine for a multitasking computer. Task capture is accentuated by interfaces with short time outs. So, if the driver does not continue to interact with the secondary task for a short period of time, they must start the task over from the beginning. When drivers are engaged in performing these combined tasks, their scanning behavior is disrupted and they fail to look where they should for the desired duration. For visual manual tasks, such as destination entry, drivers spend too much time looking inside the vehicle and not looking at the road. In the case of cell phone conversations, drivers are observed to be looking at the sky much more often, not at the road, traffic, or road signs (Recarte and Nunes, 2000; McCarley, Vais, Pringle, Kramer, Irwin, and Strayer, 2001; Harbluk, Noy, and Eizenman, 2002; Strayer, Drews, and Johnston, 2003). As is commonly observed, the more difficult the thought, the more people shut off visual input because input processing interferes with the cognitive operation. In conversation, people look away from others, and sometimes even close their eyes. This is counterproductive to driving safely. This loss of road-related visual input may occur because of inappropriate prioritization of the secondary task, with drivers giving that task inordinate attention. For example, in an UMTRI laboratory study, drivers would answer a ringing phone in 1 to 4 seconds after it began to ring, even in situations where the workload was nontrivial and driving safety was emphasized in the instructions (Nowakowski, Friedman, and Green, 2001). There is something about a ringing phone that compels people to immediately answer it, even though in many cases it could be a telemarketing call. The behavior to answer a ringing phone and engage in a conversation is so ingrained that is extremely unlikely that any amount of public awareness, education, or training will alter that highly reinforced behavior. For other tasks such as destination entry, there are similar problems. Again, once people initiate a task, they try to continue to perform it until completion. That does not mean they never look back at the road, but it is extremely rare for people to abandon the secondary task. Good design considers not how people should behave, but how they actually behave, whether or not is it desired, good, or even logical. The human performance literature makes these key points:

1. The many studies of how people multitask when they drive consistently find that multitasking while driving does not promote safety.

2. Use of In-Car Interactive System can lead to problems in one of three ways:

    a. Drivers need to look at the device a great deal to use it, so they have less time to devote to the road and either do not see hazards or see them too late.

    b. The act of thinking about the in-vehicle task changes driver-scanning patterns, pulling their gaze away from the road.

c. Completing in-vehicle tasks is very compelling, so drivers initiate and continue in-vehicle tasks even at their peril, and experience momentary overload when they do so.

2.9.3 Why Are In-Car Interactive System Different From Other In-Vehicle Tasks?

The aggregate risk of using a In-Car Interactive System device is the product of duration of each use times the frequency of use (Wierwille, 1995; Wierwille and Tijerina, 1996); that is, exposure. Task completion times for non-In-Car Interactive System devices such as headlights, windshield wipers, and so forth are quite short, about 3-5 seconds (Wierwille, Hulse, Fischer, and Dingus, 1988). In contrast, task times for In-Car Interactive System devices can be 20, 40, or 60 seconds or more (Green, 1998), which is an order of magnitude increase. Furthermore, creeping functionality has significantly increased task times for systems such as climate control and entertainment. Operations in some cases no longer require a single button press, but navigation through a menu hierarchy. What makes these tasks particularly egregious is the amount of time that drivers seemed to be preoccupied by them. One could argue this is not a smart (or crash-risk minimizing) way for drivers to behave, but it is nonetheless how drivers behave.

2.9.4 If There Is An In-Car Interactive System Related Crash, Who Is Responsible?

Automobile design and operation has a long history of regulation. According to the principle of strict liability, “people are responsible for damages their actions or products cause, regardless of any fault on their part… Those engaged in the stream of commerce with respect to products should reasonably foresee that some people will misuse the product and should design the product so that injury does not occur.” Thus, In-Car Interactive System devices can create risk to drivers and other road users and in some cases should not be used while driving. Although it is ultimately the driver’s decision when to use In-Car Interactive System devices, legally, many, including OEMs and suppliers, under the principle of strict liability, share responsibility for driver safety.

2.9.5 For Whom Should In-Car Interactive System Be Designed?

The legal literature refers to the “ordinary, prudent person”, not engineers or computer techies. This is particularly important when considering usability, so that a first-time user can successfully complete a desired task without assistance. In terms of safety, ISO guide 51 (International Standards Organization, 1997) talks about design for expected use and misuse. Engineers need to design systems for how people actually use them, not how the engineers would like them to be used. It is well known that people often do not read the owner’s manuals. Many are not computer literate, and phone and car literacy may be issues as well (Thimbleby, 1993). Although a vehicle might be targeted to a particular market segment, it must be operable by drivers of all types. Vehicles are designed to suit a wide anthropometric range, should accommodate well-known variants in age and need to suit both the manual and intellectual capabilities of drivers. A vital element of the legal discussion is what constitutes foreseeable use and misuse. Using a lawnmower as a ceiling fan is not foreseeable. However, people will participate in phone calls and use GPS in almost any circumstances if left free to do so.

2.9.6 Motivation Behind MMI

A meta-analysis of 125 studies confirmed that cell phone conversations while driving were associated with impaired reaction time and showed no differences in risk between hands-free and handheld phones. According to the Highway Loss Data Institute, the benefits of banning the use of handheld phones are outweighed by the increased use of similarly distracting hands-free devices. The institute found no significant reductions in traffic crashes in states that enacted handheld cellular phone bans relative to states that had not. In a recent NHTSA study, it was found that glance frequency and duration were smallest for the voice-activated system and that the percentage of time the eyes were off the road was smallest for the voice-activated system. The results suggested that using voice commands to enter information or select device functions is less distracting than visual/manual destination entry while driving. Subjective assessments also favored voice over visual/manual methods. Older drivers were no more distracted than younger drivers by the voice input, while the visual/manual interface was more distracting for older than for younger drivers.

The current technology in market for speech recognition has reached its peak and is perfect but for quiet environments where there is minimal disturbance. Such is not the case in vehicles, but it is improving and may someday achieve perfect fidelity. In cars, the environment is brutal. There are a number of disturbances like engine noise, traffic noise, passengers talking, and media player. And hence, it’s still hard to incorporate speech recognition in cars. Other recent reports (by Forbes, J.D. Power, AAA) have shown that voice recognition in the car is one of the biggest complaints, Anyone who has ever used voice recognition in a car knows that it can range from frustratingly inconsistent to utterly useless and concluded that automotive voice-recognition technology should receive a "failing grade." The most recent annual Initial Quality Study, which focuses on problems new car buyers experience in the first 90 days of ownership, found that 23 percent of reported issues were related to infotainment, and a third of these problems were caused by voice recognition. This was because, unlike voice recognition on portable devices, the technology has to contend with lots of road and engine noise inside a moving car.

While some argue, voice recognition can be frustratingly inconsistent, when it works it's great to be heard. It is the UI that is distracting and not the speech recognition per se. And its not that people do not want speech recognition in vehicles, they do not want speech recognition that fails or a bad UX design. Modifying individual behavior is often difficult, especially when the public gains satisfaction from mobile communications. Design changes can often more effective because they do not simply rely on individual compliance. Manufacturers, therefore, have a obligation to improve safety and improving their in-vehicle devices User Interface.

(AAA Foundation for Traffic Safety, 2011) After new speech-based in-vehicle technologies and infotainment systems proliferated, there were prevailing assumptions that: "hands-free" = safe and,

- Public: 66% say driver use of hand-held devices is unacceptable; 56% say hands-free is acceptable
- Policymaker: 41 States + DC ban texting while driving; 0 ban hands-free devices
- Industry: In-vehicle speech-based technologies and infotainment systems are often marketed as safe by virtue of being hands-free.

Figure 10. Research By AAA Foundation, 2011

The AAA Foundation for Traffic Safety set out in 2011 to study this issue and investigate potential sources of cognitive distractions for drivers. And the results indicated:

- There are significant impairments to driving that stem from the diversion of attention from the task of operating a motor vehicle, and that the impairments to driving are directly related to the cognitive workload of these in-vehicle activities.
- Moreover, compared to the other activities studied (e.g., listening to the radio, conversing with passengers, etc.) we found that interacting with the speech-to-text system was the most cognitively distracting. This clearly suggests that the adoption of voice-based systems in the vehicle may have unintended consequences that adversely affect traffic safety.

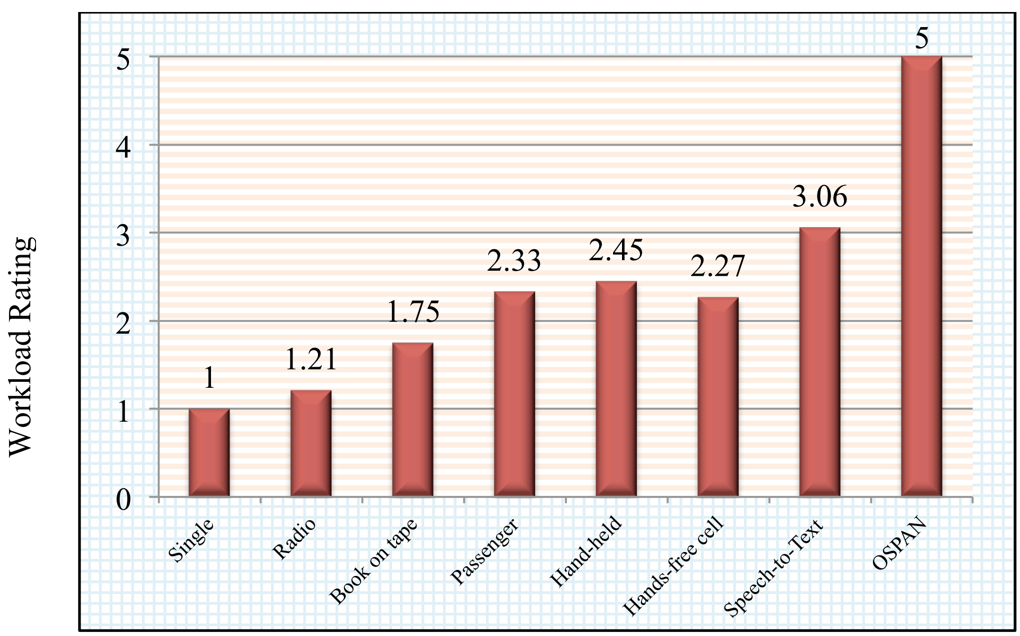


Figure 11. Cognitive Distraction Scale

There are 5 categories of Cognitive Distraction ranging from 1 to 5. Radio handling, book on tape, etc. are recognized as Category-1 level of cognitive distraction. Category-2 is passenger talking, operating handheld and hands-free cell phone. Category-5 is for complex Math problems. The speech-to-text based system that was evaluated in the research was associated with a Category-3 level of cognitive distraction. And the system used was perfect fidelity speech-recognition system and there was no requirement to review, edit, or correct garbled speech-to-text translations. Given the current trends toward more voice commands in the vehicle, this Category-3 level of cognitive distraction is troubling. The belief that if the eyes were on the road and the hands were on the steering wheel then voice-based interactions would be safe appears to be unjustified.

Thus, speech is not the solution as there are 2 problems:

1. It's too difficult and expensive to implement.
2. Even if it is implemented perfectly it's still a distraction, as elaborated above.

Hence, there is a need for other modes for Human-Car-Interaction, which can be used when speech is a distraction or an impediment.

Another study by Shinar and colleagues (2005), focused on whether repeated experience conversing on a mobile phone led to a learning effect, whereby drivers became better able to share the phone and driving tasks, thus reducing the effects of the secondary task on driving performance. The research argued that participants are not given the opportunity to interact with the device over a number of trials and, therefore, any learning effects, whereby drivers learn to effectively time-share the non-driving and driving tasks, are not assessed. Over the course of the five sessions, the negative effects of the phone tasks on driving performance diminished, such that, on several of the driving measures, there was no difference between performance in the distraction and no-distraction conditions. The results of this research suggest that those studies which examine the effects of mobile phone use over a limited number of trials and/or use artificial and demanding phone tasks, such as math solving tasks, may be overestimating the detrimental effects of mobile phone use on driving performance. Clearly, further research is needed in this area before any firm conclusions can be drawn.

And thus as another mode, we have decided to introduce “Learning mode” where the driver will get acquainted to the in-car interactive system.

CHAPTER 3

METHODOLOGY

3.1 Introduction To Multimodal Interaction

Human Voice Interaction also known as Natural Language Interaction does not solely involves speech as the source of sharing information. There is an intertwined cooperation of various other modalities that can be characterized as verbal, para-verbal and non-verbal. The modality includes a variety of communication methods for the expression of intent, the implementation of action and perception to the feedback, such as speech, eye contact, facial expressions, lips movements, hands movements, gesticulation, heads movements, body's posture, touch etc. Researchers have proven that speech-based interaction with in-vehicle information systems demands attention and can distract drivers and degrade safety (AAA, 2011). Designers should recognize that speech-based interaction draws upon some of the same cognitive resources as driving does and, so, can distract drivers just as visual displays and manual controls can. Subjective measures of workload and distraction suggest that increasing the complexity of a speech-based interface may impose a greater cognitive load. In-Car Infotainment System is becoming a standard feature in today's cars. When designing cars, automotive engineers need to consider including infotainment system for navigation, communication and entertainment purposes. However, it can be argued that attaining perfection in speech-recognition is not the answer but what we need is a Multi-modal Interaction. Multimodal interfaces are a natural and safe means of communication and can help in preventing and recovering from speech recognition errors due to inaccurate speech recognition. Multimodal interfaces are recognized to be inherently flexible, and to provide an especially ideal interface for accommodating both the changing demands encountered during mobile use and also the large individual differences present in the population – a clear requirement for universal access. These interfaces can be designed to support simultaneous use of input modes, to permit switching among modes to take advantage of the modality best suited for a task, environment, or user capabilities, or to "translate" information from one mode to another in order to expand accessibility for users with selective limitations. Since it is important that any mobile interface serving field tasks be flexible and to minimize demands on users' attention, one major theme explored in the present paper is whether a flexible multimodal interface may be well suited for assisting users in self managing their cognitive load and improving overall performance as the complexity of field tasks and related communications increase.

3.2 Multimodal In-Car Enhanced Interaction System

Multimodal Interaction is a new term when used in context of automobiles but has been widely used in HCI. Identifying new modes of interaction is different than human computer interaction modes due to the cognitive and environment challenge with automobiles.

The identified modes are as follows:

- Visual
- Touch
- Speech Input
- Learning Text
- Learning Voice

The first mode “Visual” can be simply understood as exact virtualization of hardware on the infotainment screen. User is allowed to give input as speech or touch the application icon, based on that either the action is performed or hardware image is displayed. This gives user the flexibility to use any car system without taking eyes off the road for too long and hence, minimizing distraction.

The second mode “Touch” allows user to physically touch an icon present on the infotainment screen.

The third mode “Speech Input”, as the literal meaning suggests is nothing but interaction with the car using speech. For a speech input user can expect to have a speech output. As mentioned before researchers have proved that speech recognition increases the cognitive load, the solution would be to keep the grammar as simple as possible. Providing all the necessary commands but not natural language speaking.

Fourth mode “Learning Text” allows user to get trained with regards to placement of icons and recognizing every icon by sight. Below every icon is a one word descriptive text that will give the user an idea of what the icon does and the command used in speech recognition.

Fifth mode “Learning Voice” allows user to get trained with respect to the multimodal functionality and experiencing less cognitive challenge. For example: The user said play track 15 by Enrique but this command is not acceptable by the dialogue system but system will check all possible options and will speak back to the user. IF user touches any icon then system will echo the speech command corresponding to that icon. This way user will get to learn the commands. This mode can be turned on and off as per the user convenience. Figure 12 represents the architecture of MMI.

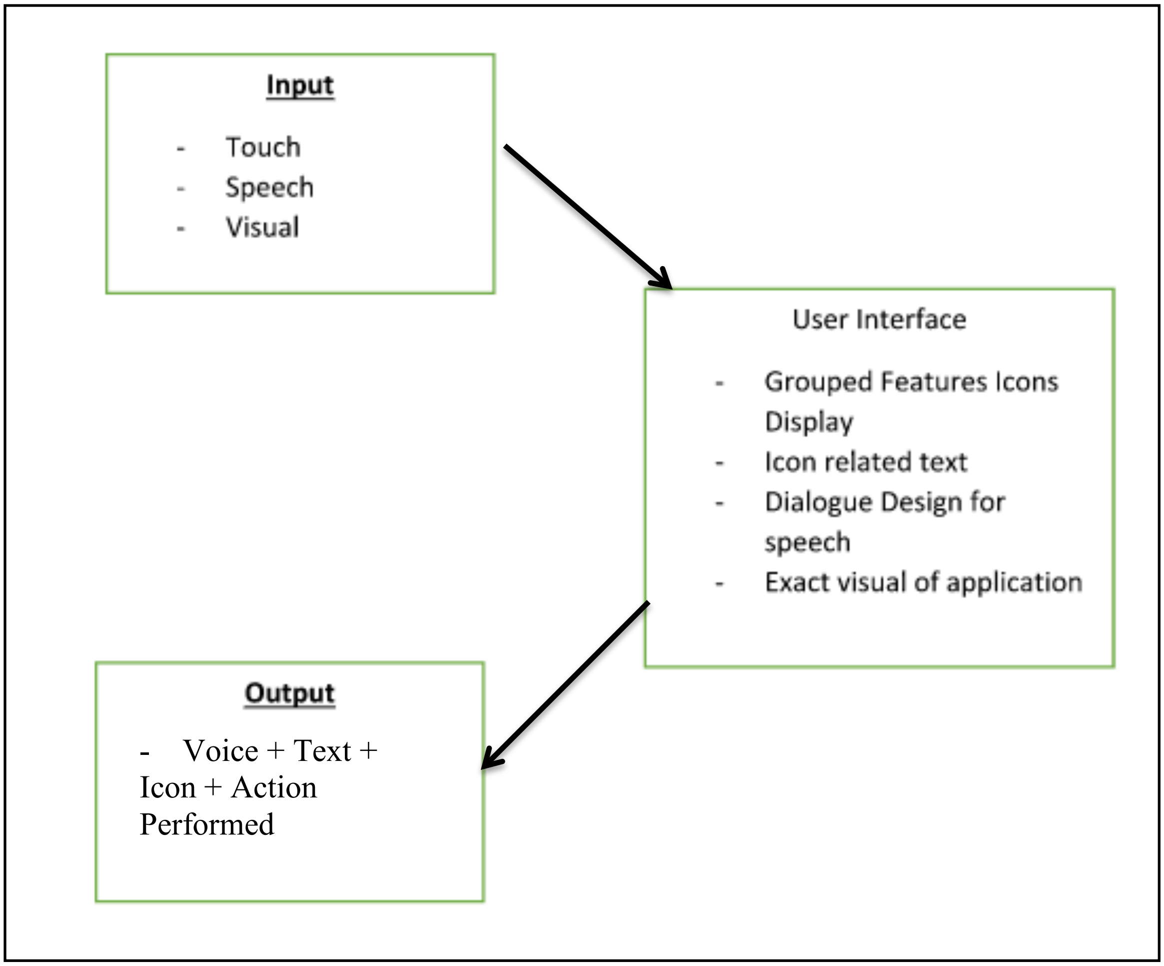


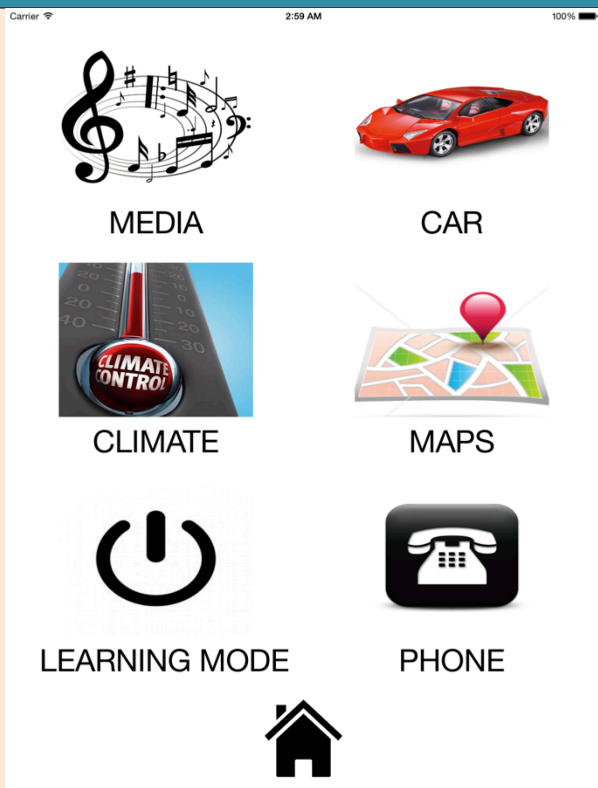
Figure 12. Architecture Of MMI

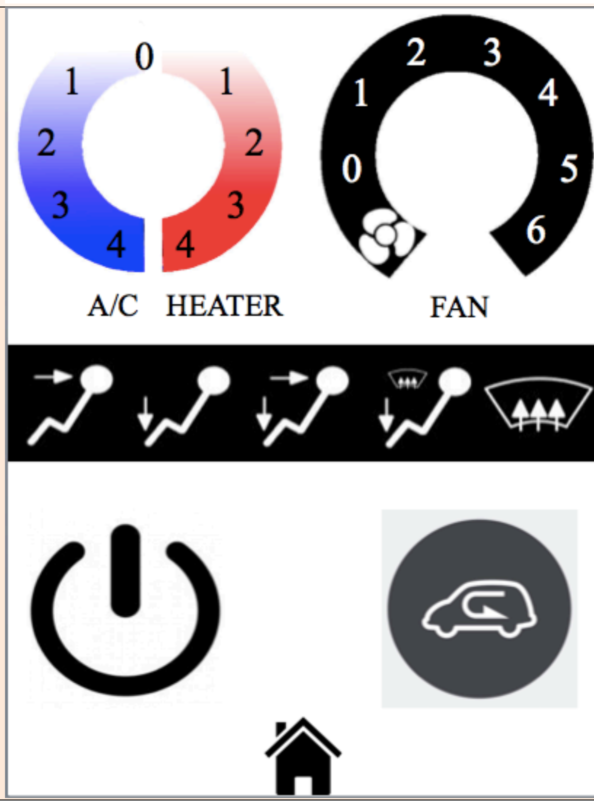
3.3 MMI User Interface

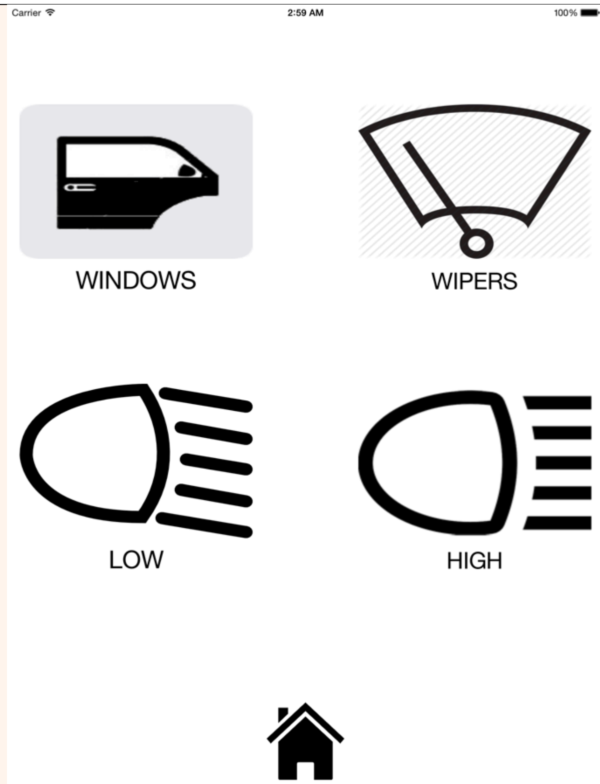
Our main goal is to reduce distraction by minimizing driver's time interacting with the car system. Hence our MMI System is a hierarchical structure that requires 1 click per screen and at most 4 clicks to perform an operation correctly (except for data entry which can be limited to when the car is not moving). As the human eye perceives images faster than text, we have designed an easy-to-eyes icon layout, that is – large size, clear meaning and supporting text if needed, that requires minimum thought process.

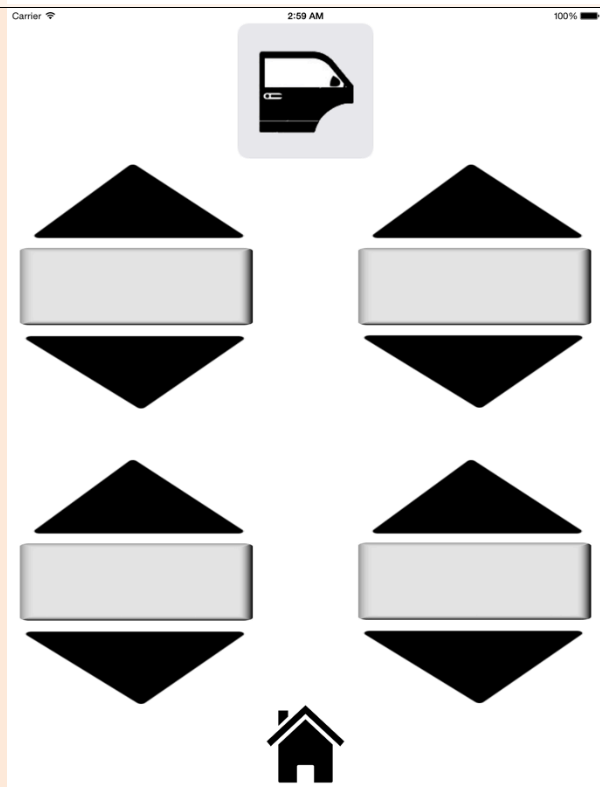
There is a Home icon at the bottom of every screen. In actuality, this icon would be implemented as a built-in button in the hardware itself. On clicking on the home button, the screen will go back to the home screen. We can have a similar Interface for Landscape Orientation.

Table 12. MMI User Interface

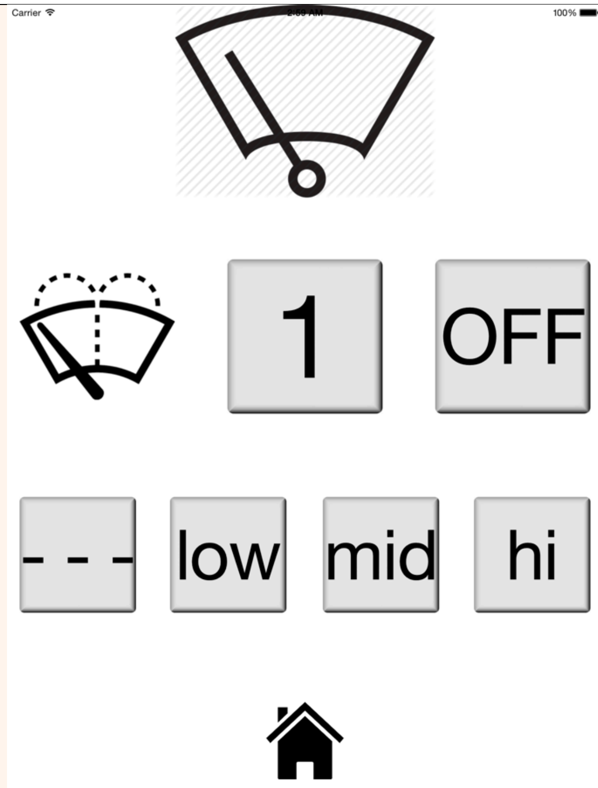
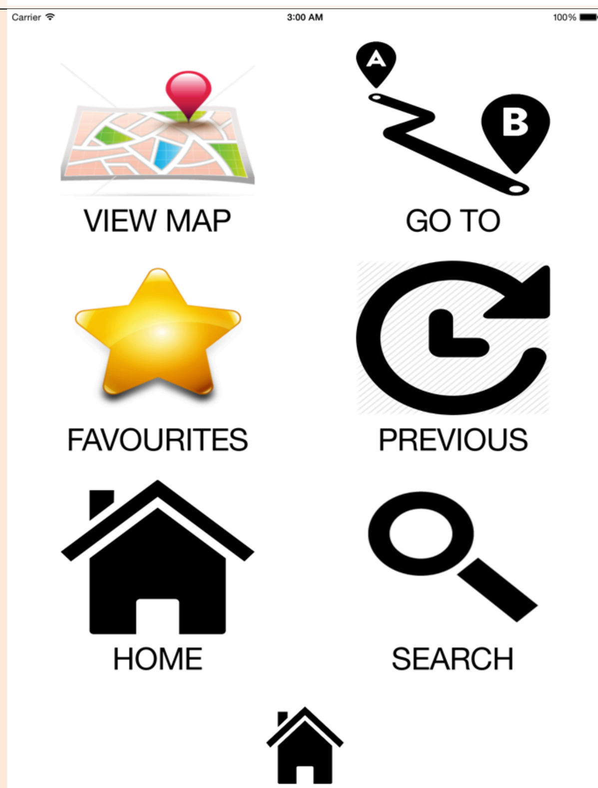
No.	Figure	Description
1		Figure 13. Home Screen This is the landing screen of the application. Driver can choose any of the icons: Media, Car, Climate, Maps, Phone for specific functionality. Learning mode button is to enable or disable learning mode. When learning mode is on, you get talkback and icon titles as features. This can be easily turned off.

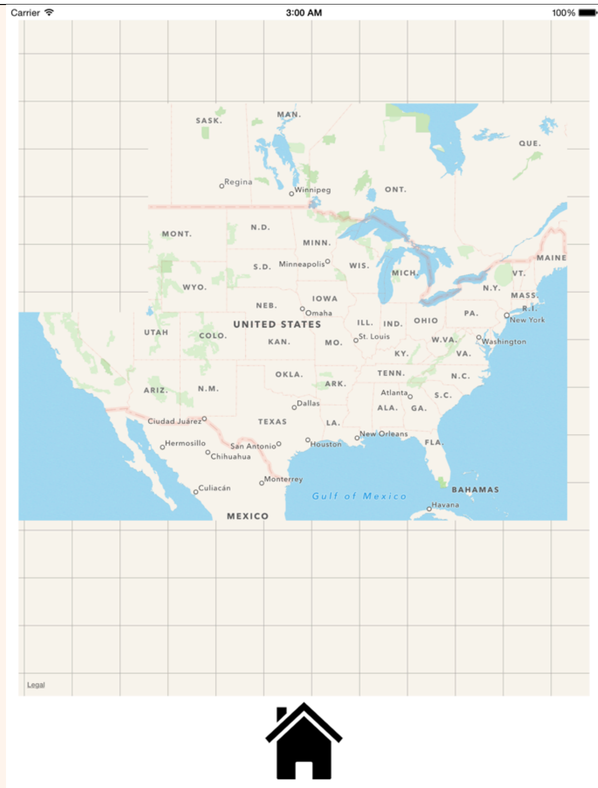
2		Figure 14. Media Screen Displays the almost exact replica of the actual radio system in the car. It will same functionality as the one below.
3		Figure 15. Climate Controls Displays the car climate controls as represented in the car. There are controls for A/C, Heater, FAN and air circulation modes.

<table>
<tr>
<td>4</td>
<td>
</td>
<td>Figure 16. Car Controls

Icons Windows and Wipers lead to another screen with their respective functionality. Low and High buttons are for low and high beam lights of the car.</td>
</tr>
<tr>
<td>5</td>
<td>
</td>
<td>Figure 17. Windows Screen

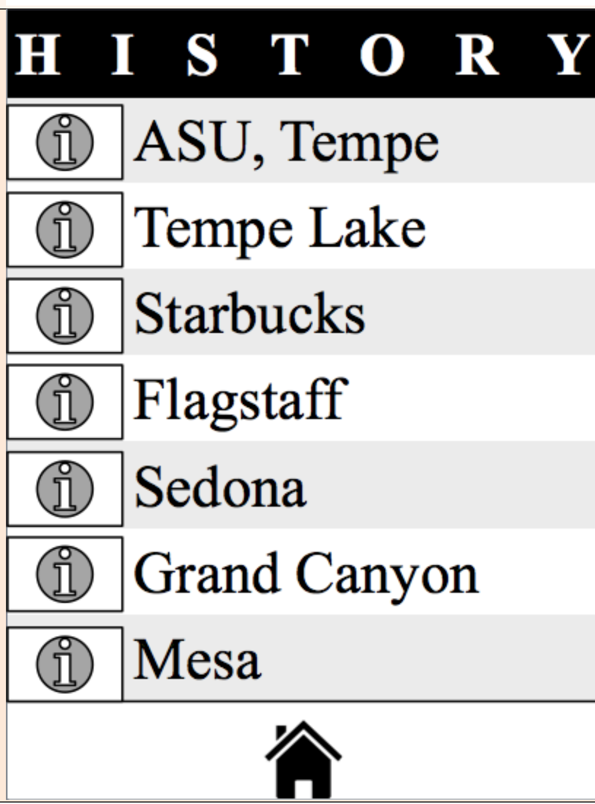
Displays the 4 sets of up and down controls of the windows in the car.</td>
</tr>
</table>

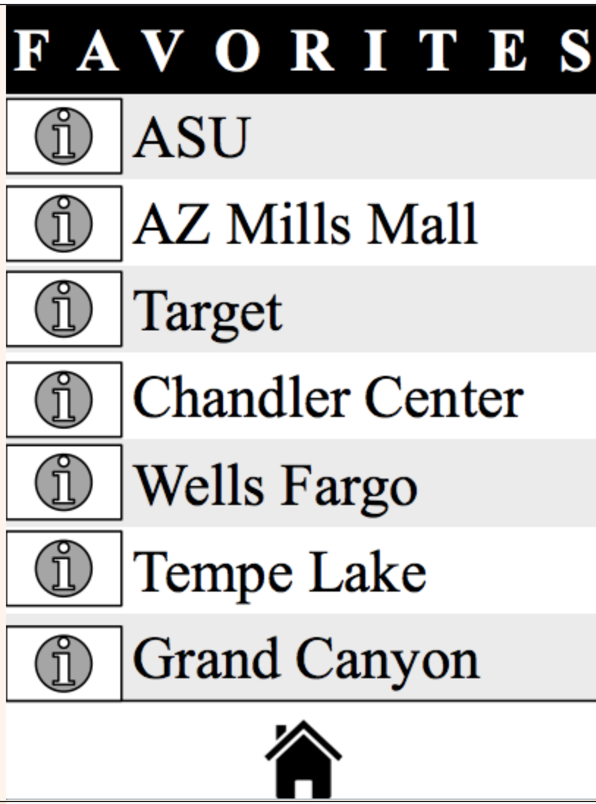
6		Figure 18. Wipers Screen Displays various functions related to wipers like water mode, 1, intermittent, low mid high and OFF.
7		Figure 19. Map Controls Displays icons to screens for View Map (Map), Go To (Route guidance from current location to given address), Favorites (All favorite locations by driver), Previous (History), Home (Route guidance from current location to initially set home address) and Search (Displays another screen with options to search).

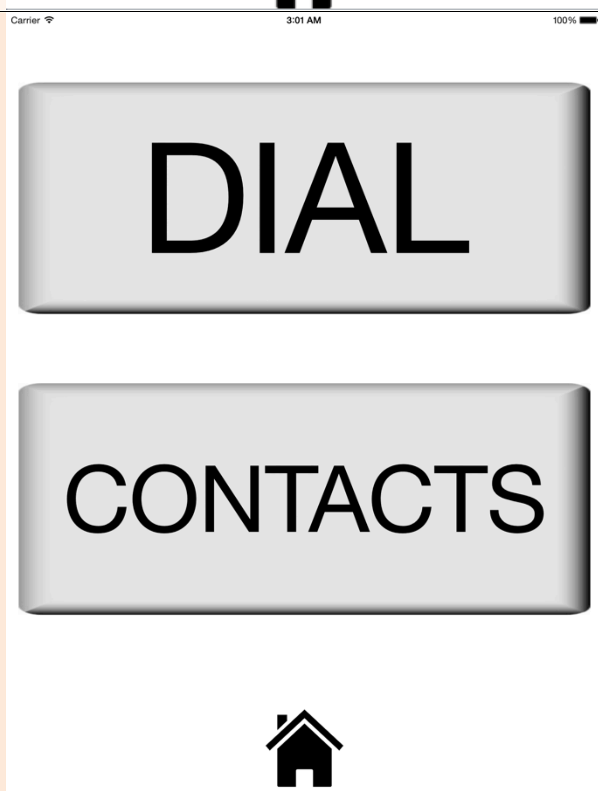
<table>
<tr>
<td>8</td>
<td>
</td>
<td>Figure 20. View MAP Screen

Displays the map with your current location.</td>
</tr>
<tr>
<td>9</td>
<td>
</td>
<td>Figure 21. Goto Screen

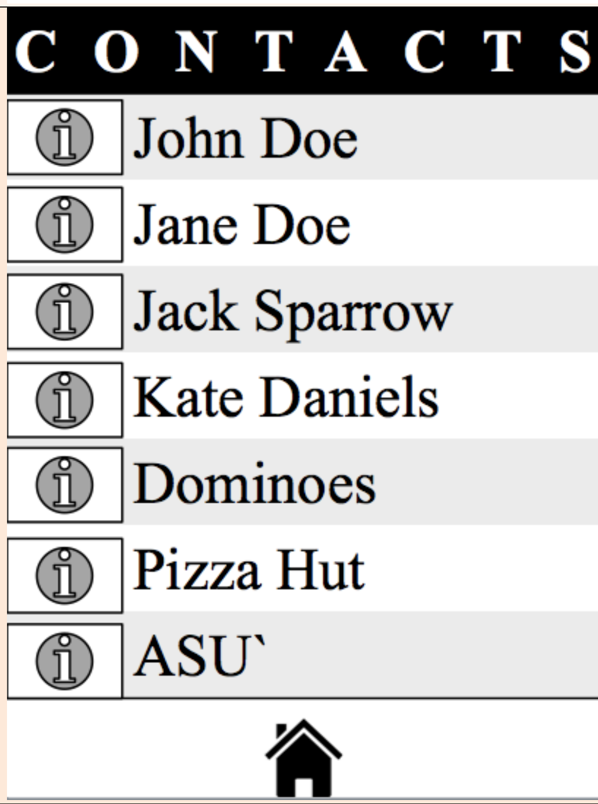
Displays interface to enter the destination address in street #, name, city and state format. The text field at the top displays the address being set. And on clicking go, the screen shown will be the map with route guidance.</td>
</tr>
</table>

10	 	Figure 22. Search Screen Displays 4 options to search – Restaurants, Café, Shopping and Gas Stations. On clicking any of these icons, the map screen will be shown with the selected type of places nearby.
11	 	Figure 23. Previous Screen Displays the history, that is all previously visited, searched or used locations.

<table>
<tr>
<td>12</td>
<td>
</td>
<td>Figure 24. Favorite Screen

Displays list of all locations marked as favorite by driver. The favorite locations can be marked by visiting the view map screen.</td>
</tr>
<tr>
<td>13</td>
<td>
</td>
<td>Figure 25. Phone Screen

This screen has 2 options – Dial and contacts. One can either dial or select a contact from the list to call.</td>
</tr>
</table>

14		Figure 26. Dial Screen Displays a number pad with text field at the top displaying the currently typed phone number. You can call the number and to end the same call click on end.
15		Figure 27. Contacts Screen Displays all contacts present in the directory.

<table>
<tr>
<td>16</td>
<td>
</td>
<td>Figure 28. Display Contact Screen
Displays details like – Full Name, Image, Phone number and email id of the person selected. There is an option to call the person and the end the call here as well.</td>
</tr>
</table>

CHAPTER 4

THE EXPERIMENT

4.1 Scientific Based Methods: Defining Our Metrics

4.1.1 Lane Departures

The number of lane departures per unit of time or trial is a very common safety statistic. If drivers are distracted, they are more likely to depart the lane (Zhang and Smith, 2004). However, what is most critical is that this measure was rarely defined and when it was, the definition was imprecise. Contrast the definition of Jenness, Lattanzio, O'Toole, and Taylor, 2002 (page 594) of a lane departure beginning when “the automobile crossed the white sidelines on the roadway,” with that of Blanco, Hankey, and Chestnut, 2005 (page 1977) as beginning “when the vehicle's tire came into contact with the lane marker.” So, there are two aspects that need to be defined, what part of the lane is considered the boundary and what part of the vehicle is considered to have departed. Thus, there are at least two candidate criteria for a lane departure, (1) the outer edge of the exterior mirror passes over the midline of the lane marking, and (2) the front tire touches the inside edge of the lane marking. The first criterion is the most crash relevant. The second is easier to detect (when using a side-mounted camera). Simple math suggests there is a one to four inch difference between the two criteria.

4.1.2 Time-To-Line Crossing

Time-to-line crossing, a key safety measure, reflects the safety margin for lateral control. When drivers are distracted, the minimum time-to-line crossing over a time window decreases (Jamson, Westerman, Hockey, and Carsten, 2004). Time-to-Line is basically how long it takes the vehicle to reach the lane boundary. There are actually at least three different ways time-to-line crossing can be defined: (1) as lateral distance divided by lateral velocity, (2) as an expression that includes lateral acceleration, and (3) as the complete trigonometric solution that considers the radius of curvature of the vehicle's path and the radius of curvature of the road. Of the values provided by the three expressions, the first two of which are approximations, and all three can differ considerably. (See Godthelp, 1984; Van Winsum, Brookhiuis, and de Waard, 2000).

4.1.3 Headway

The more closely the driver follows a vehicle ahead, the more likely a crash (Ervin, Sayer, LeBlanc, Bogard, Mefford, Hagan, Bareket, and Winkler, 2005). Of the various types of crashes, rear-end collisions are much more likely when drivers are distracted (Wang, Knipling, Goodman, 1996). The Highway Capacity Manual (Transportation Research Board, 2010), headway refers to the time difference between when two successive vehicles pass by the same point on a road. Generally, it is the front bumper to front bumper difference. However, the problem is not just that the name headway is inconsistently used, but the intended use is uncertain because it is not defined. Savino (2009) found 10 definitions for distance headway and 18 definitions for time headway in the literature. The definition of Strayer, Drews & Crouch, 2003, page 27, is typical. Following distance as “the distance between the pace car and the participant's car.” Not specifying the points on the vehicle leads to ambiguity. Figure 29 shows the following distance at hazard locations for different distractive tasks. The figure below shows the drivers indulged in compensatory behavior while performing distractive tasks by increasing following distance to avoid accidents. Distractions that are of “mind/ear-off-road” nature show significantly larger headway than the other 2 (visual, manual).

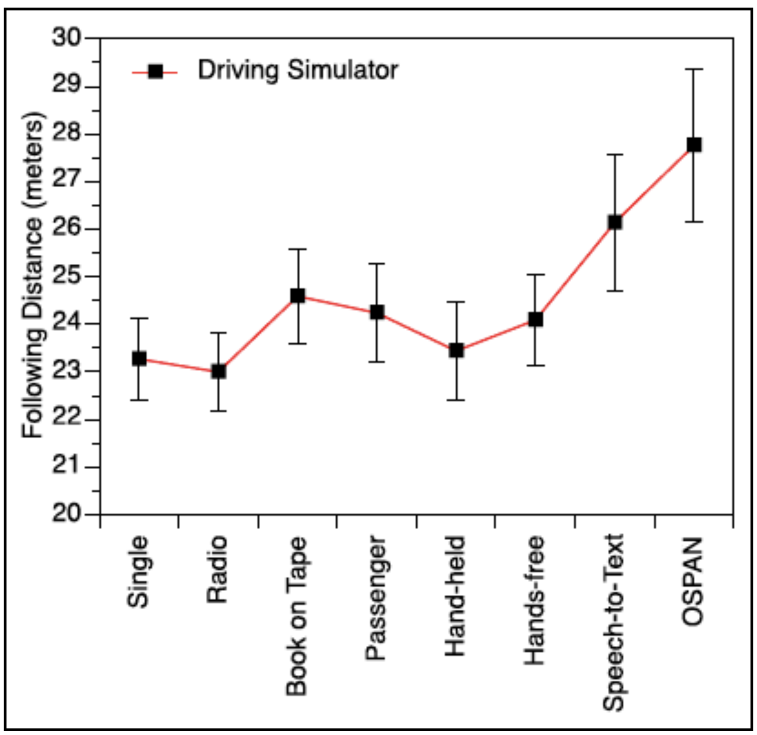


Figure 29. Following Distance At Hazard Locations

4.1.4 Acceleration, Velocity, Brake

As previous studies indicate, if the driver is distracted, then there is an abrupt change in brake, acceleration and velocity. The driver compensates by reducing his speed and after completing the distractive tasks, aligns back to the speed achieved prior to the distraction. This can also indicate the duration of distraction.

4.1.5 Steering Wheel

As stated previously, if the driver is distracted, the occurrence of lane departure is prominent. And after the distractive task is over, the driver will adjust his position in the lane again. In case of no distractions, except for turns, drivers have been observed to maintaining their lane position and requiring minimum steering wheel adjustment. Hence deviations from the baseline value would suggest the need for driver to compensate.

4.1.6 Response Time

We measure this metric manually. The Driver is asked to click a certain numbered icon on the screen while driving at normal conditions. This step is repeated 5 times for each UI. And, any deviation in those readings without any other modifications in the experiment should indicate distraction occurrence and larger the response time, longer the distraction. All the readings can be analyzed by taking average of all readings for each case. Figure 30 shows reaction times at hazard locations for various distractive tasks.

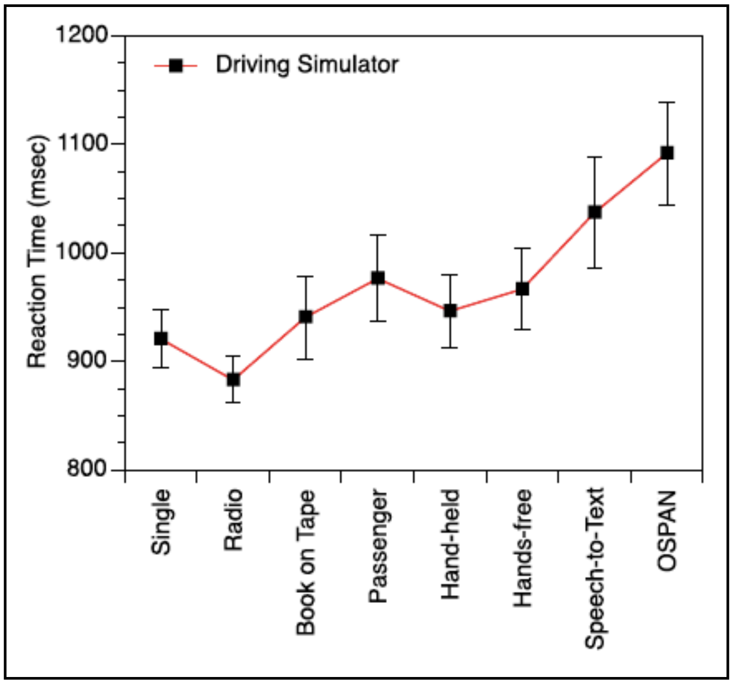


Figure 30. Reaction Times At Hazard Locations

4.2 Test Cases

4.2.1 User Interface

For this study, to test the User Interface of the in-car Interactive System, we tested an abstract layout of icons of varying sizes, orientation and number of icons while driving, to effectively calculate driver response time. Our goal was to evaluate the effect of our minimalist design on driver distraction as well as to measure the effects of icon size and number, screen size and orientation.

Our Null hypothesis: Minimalist design has no effect on driver distraction.

Alternate hypothesis: A minimalist design has minimum distracting effect on the driver.

And our secondary hypothesis:

1. There is no difference between Portrait and Landscape orientation
2. There is no difference between 8 icons and 4 icons
3. There is no difference between small screen and larger screen size

A combination of the above dimensions will be tested in the driving environment. That is:

1. Portrait, Small screen size, 4 icons
2. Portrait, Small screen size, 8 icons
3. Portrait, Large screen size, 4 icons
4. Portrait, Large screen size, 8 icons
5. Landscape, Small screen size, 4 icons
6. Landscape, Small screen size, 8 icons
7. Landscape, Large screen size, 4 icons
8. Landscape, Large screen size, 8 icons

The figures below represent the above user interfaces.

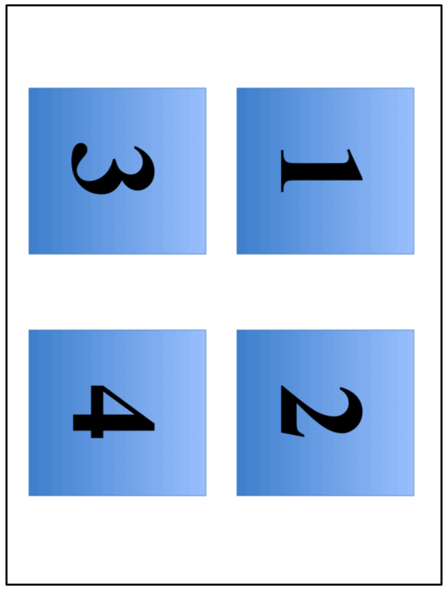


Figure 31. 4 Icons Landscape

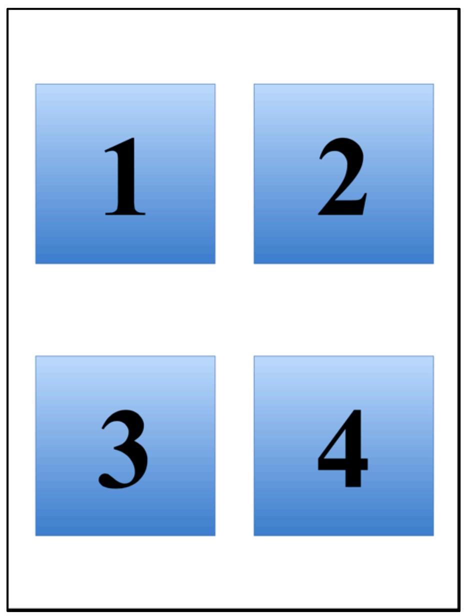


Figure 32. 4 Icons Portrait

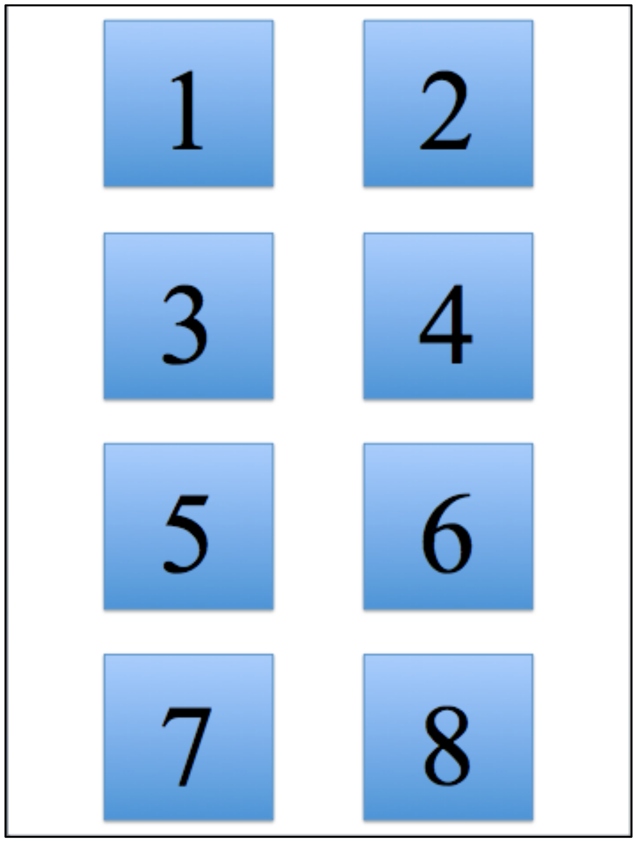


Figure 33. 8 Icons Portrait

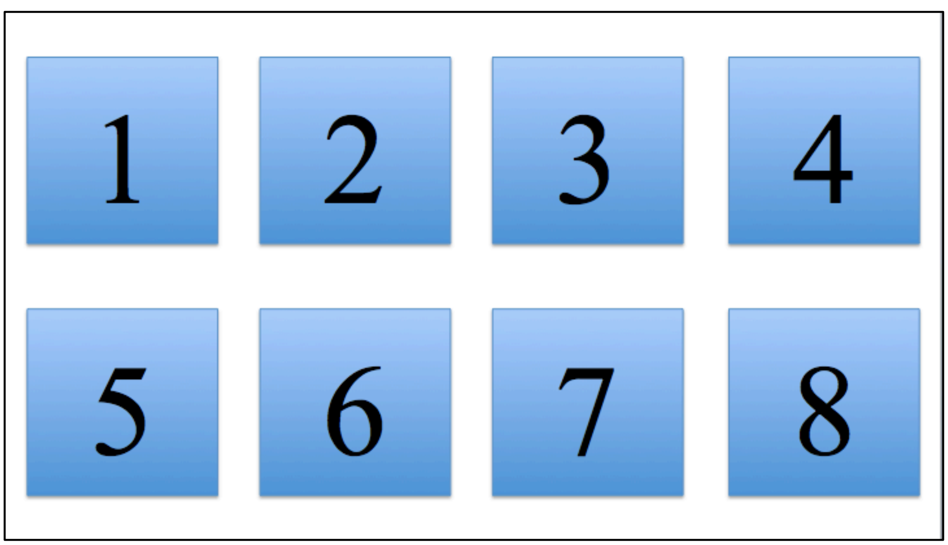


Figure 34. 8 Icons Landscape

CHAPTER 5

DATA ANALYSIS & RESULTS

5.1 Experiment Details

The HyperDrive Simulator was used for this experiment. It is explained in details later in the Appendix Section. The volunteers (within the development team) were asked to drive on a previously programmed route, with possible driving tasks like left turns at a signal, pedestrians crossing, curved road and following a car.

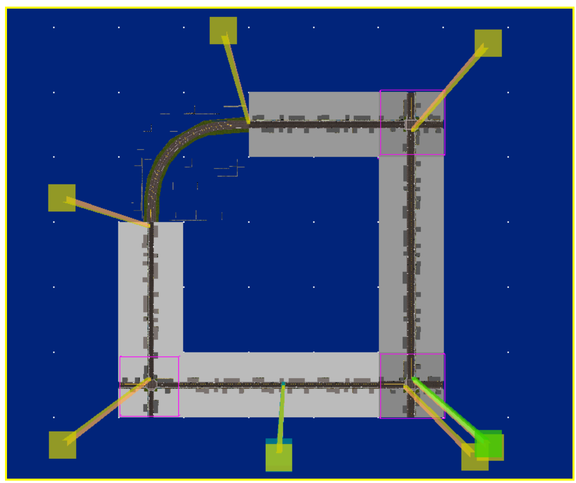


Figure 35. Route Overview

The driver was asked to maintain speed between 40–50mph (for better analysis of results), maintain lane when they are not distracted, to follow any preceding car without overtaking and follow all traffic rules. At the starting point, the user would start from the lane to the right of the centerline. The volunteers were given few minutes to get acquainted with the driving environment. Then the 2 drives – with smaller screen size and larger screen size were monitored closely. The volunteers' reaction time (from the number being said to the driver clicking the number) was also noted for both. For each UI, the driver was asked to click a specific icon 5 times.

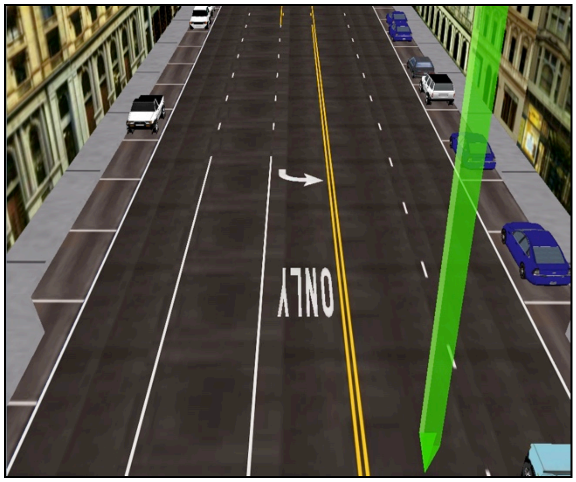


Figure 36. Starting Point

The first complex driving task was a left turn. The driver would have to stop at the intersection and wait for the green light and then make a turn while following another car also making the same turn. There were other cars at the intersection, all following traffic rules.

Figure 37. Left Turn

The curved road is the 2nd complex driving task. At the start of this path, the preceding vehicle is taken out and another car joins the roadway.

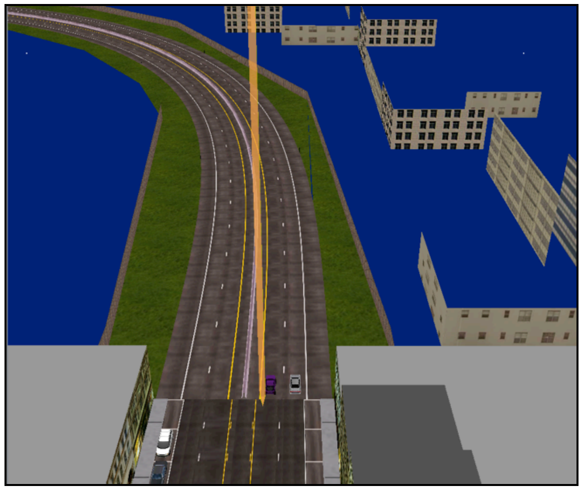


Figure 38. Curved Road

Following a car is the 3rd task. The driver will have to follow the red car. There is also another left turn for the driver, whereas the red car will opt to go straight.

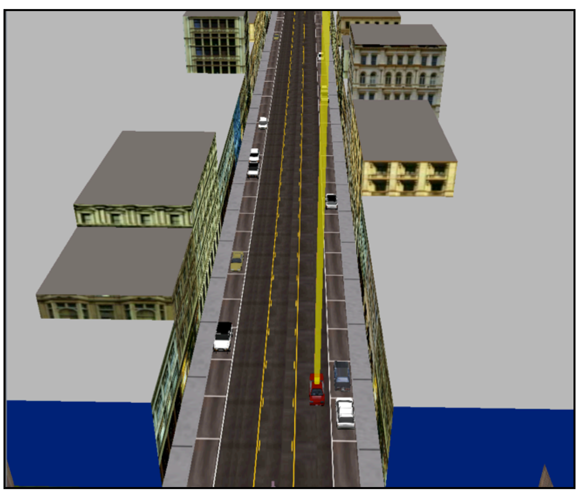
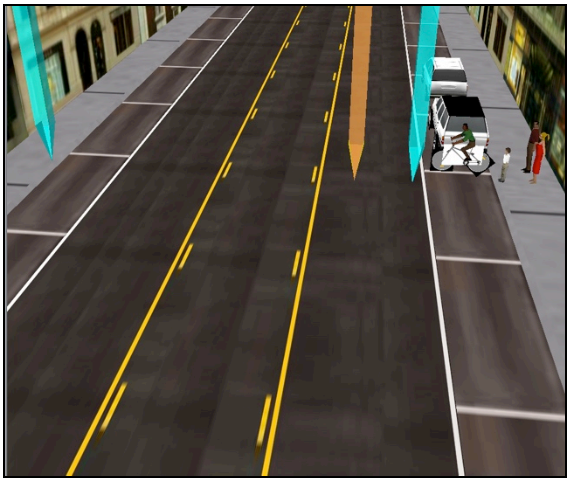


Figure 39. Follow Car Figure 40. Left Turn

Pedestrian crossing is the last task. Here to measure reaction time more effectively, we have pedestrians crossing the road suddenly. The driver then proceeds forward and reaches the goal.



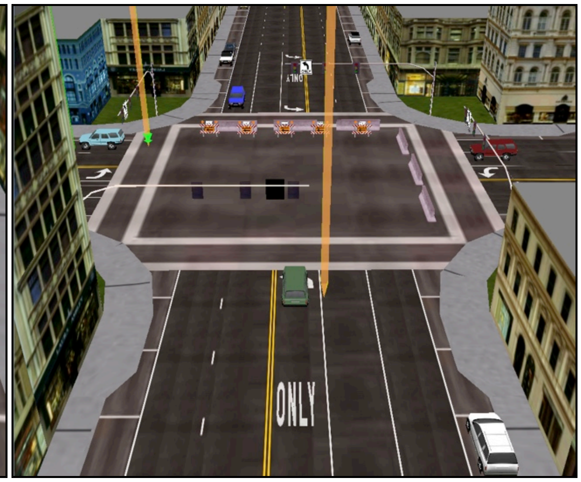


Figure 41. Pedestrian Crossing Figure 42. Goal

The Driving Simulator is an important part of this project. The images below are the various UI’s of our application in their actual setup inside the simulator dashboard.

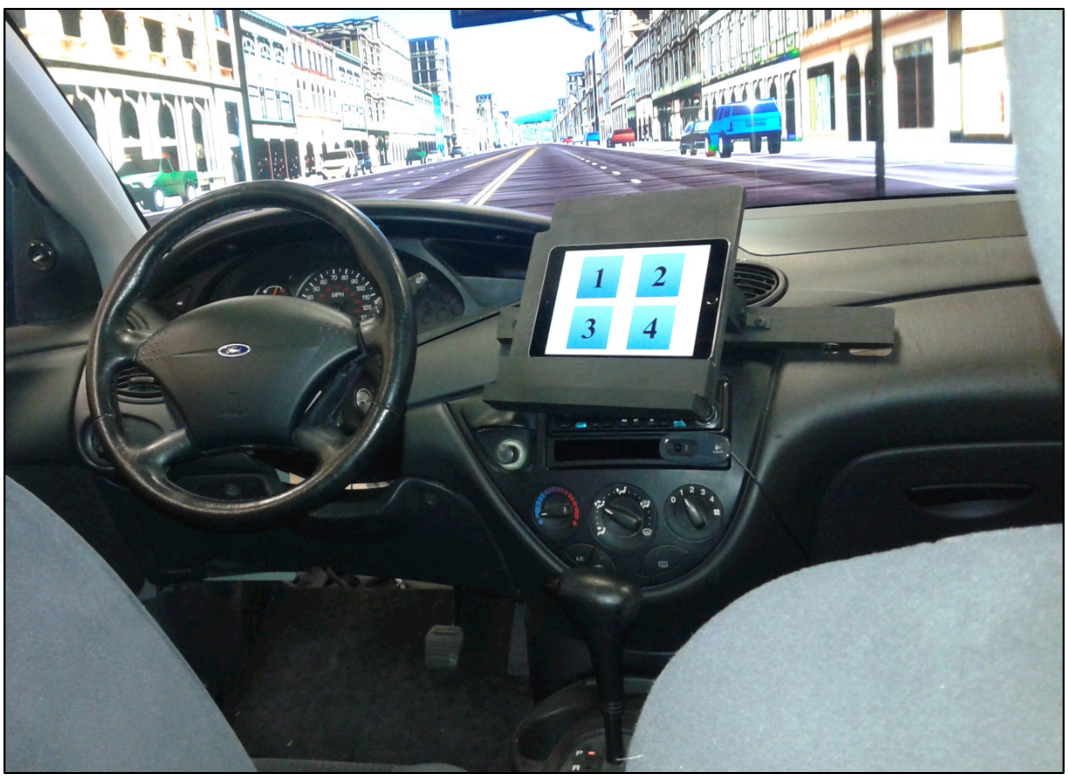


Figure 43. 4 Icons Landscape Small

Figure 44. 8 Icons Landscape Small

Figure 45. 4 Icons Portrait Small

Figure 46. 8 Icons Portrait Small

Figure 47. 4 Icons Landscape Large

Figure 48. 8 Icons Landscape Large

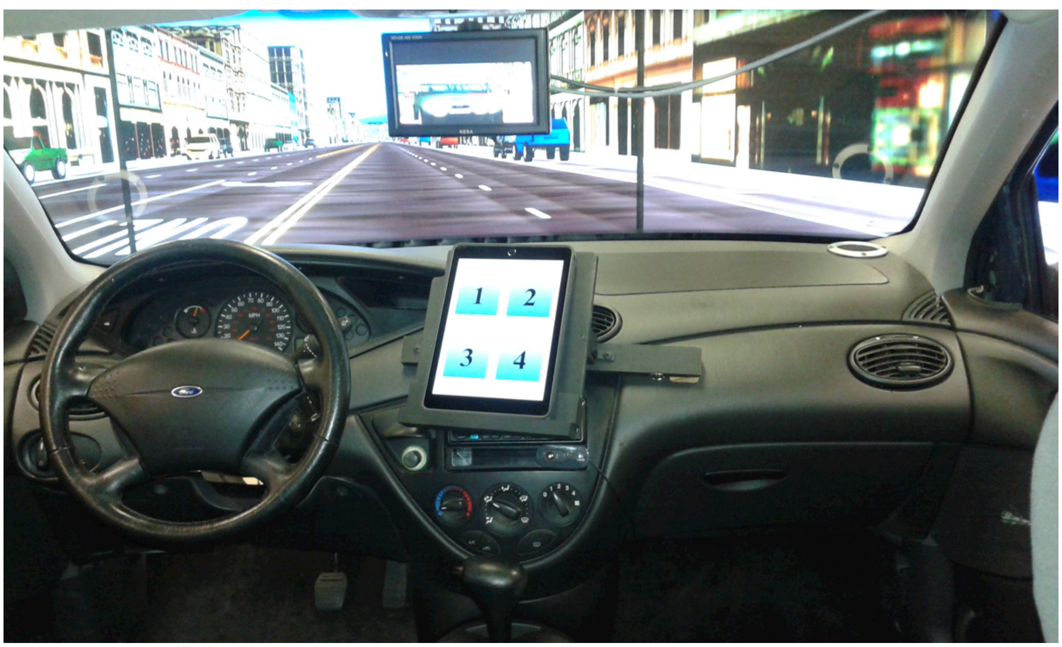


Figure 49. 4 Icons Portrait Large

Figure 50. 8 Icons Portrait Large

5.2 Experiment Data & Analysis

Our experiment data shows that our minimalist design was well within the NHTSA's criteria. That is, each screen should take less than 2 seconds and the cumulative task time should be no more than 2 x 6 screens = 12 seconds. The data thus proves our design causes minimal driver distraction, disproving our null hypothesis, with distractive task time as low as 0.71 seconds per screen to 0.98 seconds.

After the set of experiment we analyzed, the data shows there is no significant difference between the different orientations, screen and icon sizes and number of icons and all of them fall within the NHTSA norms. There were 2 types of data obtained – Driver Response Time and Driving Simulation metrics. The response times were closely monitored and noted manually using a stopwatch and excel spreadsheet to note the values. The order of UI's tested was same as the order of the figures above from Figure

43 – 50. The driving simulation metrics was recorded by the Simulation system by programming it prior to the experiment. All possible metrics which could be used in identifying distraction and its risk factor was separated out in an excel spreadsheet. Since the simulator records every data and action per microsecond, we are unable to display all of the data and only specific parts will be shows. Rest of the data and statistical analysis is included in the Appendix or as attachments.

Table 13. Sample Data

#	Average Response time
1	0.71175
2	0.7675
3	0.79625
4	0.80875
5	0.8235
6	0.86425
7	0.88925
8	0.9295
9	0.931
10	0.985

The above table shows that for each person the response time can very minutely, depending on how attentive and how quick the driver was. But every user's average was in the same range for all UI's. Refer figure 51 for the comparison of some of the drivers' response times.

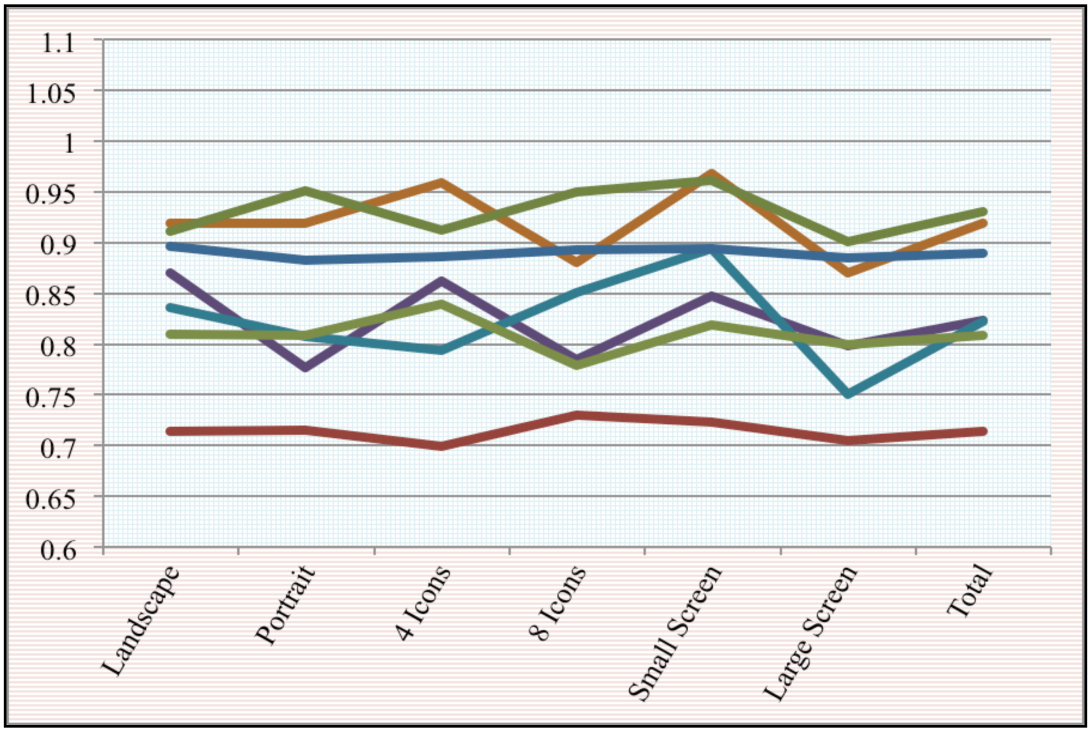


Figure 51. Range Of Average Response Time Per Person

The Figures 52 - 57 below represent a snippet of the Driving Simulation Records in regards to various metrics – Lane Position, Velocity, Acceleration, Brake, Steer, Subject Engine RPM, Headway Distance and Time-to-Collision. The above metrics data are displayed for each driver – comparing their drive using Small screen size (Blue) and Larger screen size (Red). And a comparison of a select few drivers with regards to each metrics depicting how different their driving is from others. The small screen UI was first tested and the large screen later. Hence the Red curve might show less variances and more controlled and steady driving than the blue curve.

Figure 52 shows the comparison of lane position values between small screen and large screen UI's throughout both drives. The deviation from the center of the lane was recorded in this sample. And both the graphs are quite matching.

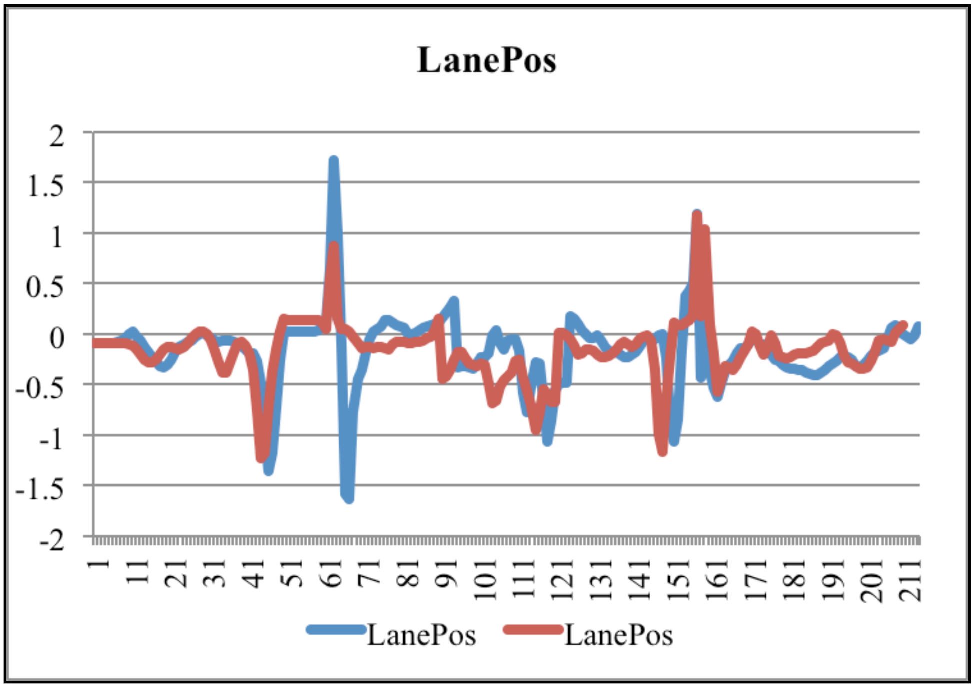


Figure 52. Lane Position

Figure 53 shows velocity variations in the experiment. And the graph below shows that the change or distraction does not affect the velocity significantly. However, in the 2nd drive, it seems that the driver was comfortable enough to go on a higher speed than the previous one. And the figure below also shows that the driver was cautious in the 1st drive and hence there aren't many sharp changes.

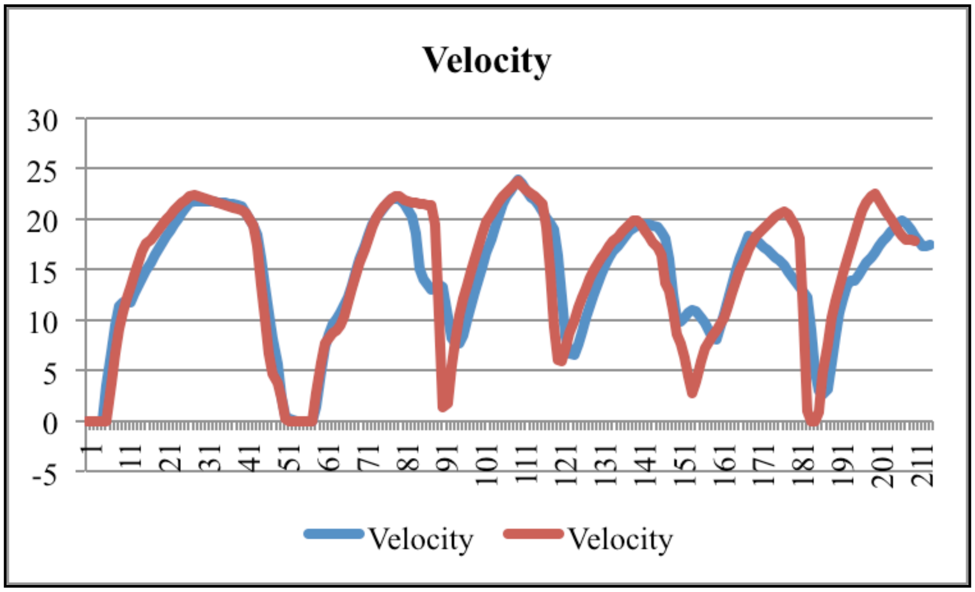


Figure 53. Velocity

Figure 54 is a comparison between the acceleration values recorded. Again, acceleration being related to velocity shows a same tendency and both the curves are quite similar.

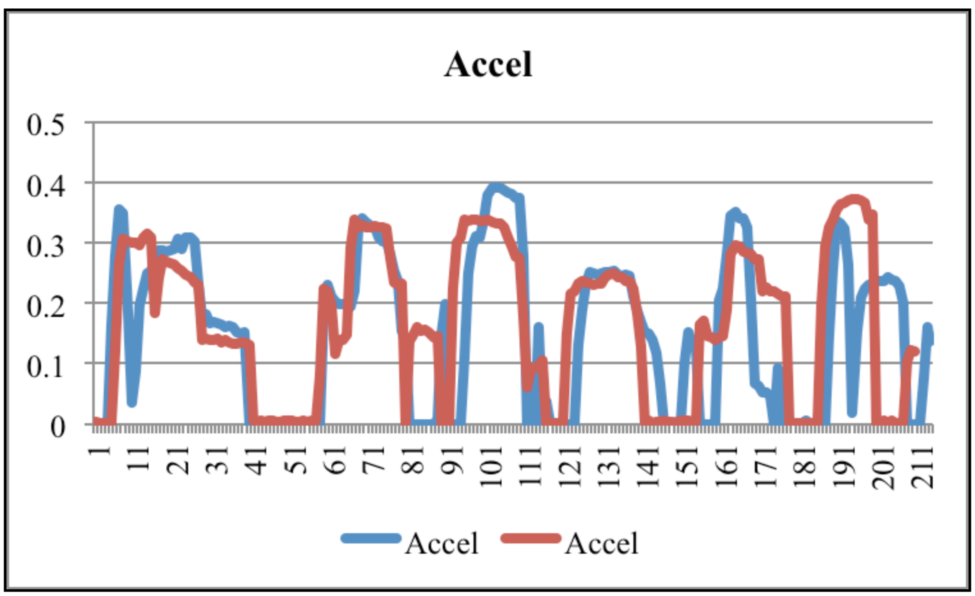


Figure 54. Acceleration

Brake also being related to acceleration and velocity, Figure 55 shows the same result. Also proves that during the 2nd time the driver drove less carefully.

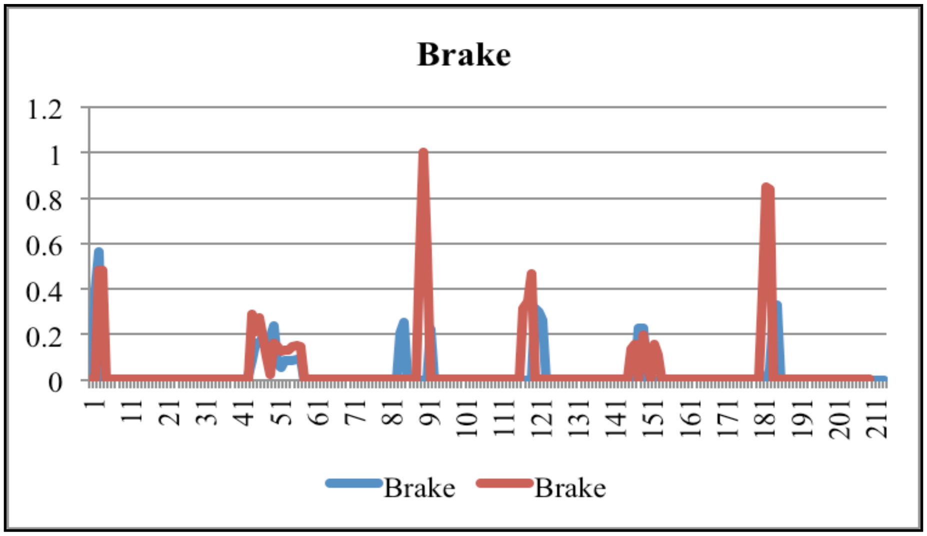


Figure 55. Brake

Figure 56 is a comparison of the steering angle recorded in the experiment. This graph shows the closest match of curves. Thus the change in UI's didn't affect driver's ability to be consistent in steering. Even the curved road section, from 91 – 131 approx. on the horizontal axis, and the 2 left turns show the almost same variation.

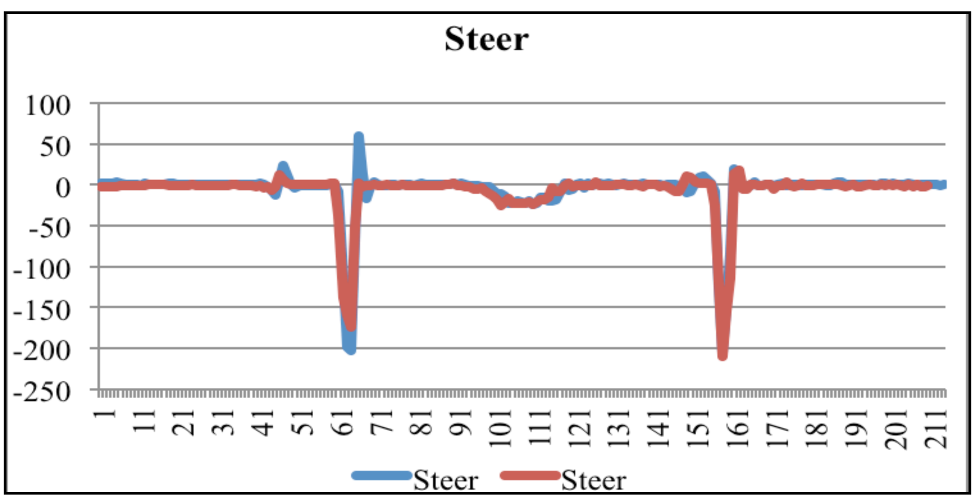


Figure 56. Steer

Figure 57, metric - headway, is also an exact match except for the last part. Since the driver was going on a faster speed than the 1st drive, they would have completed their experiment a bit sooner. Hence the lag between the 1st and 2nd curves.

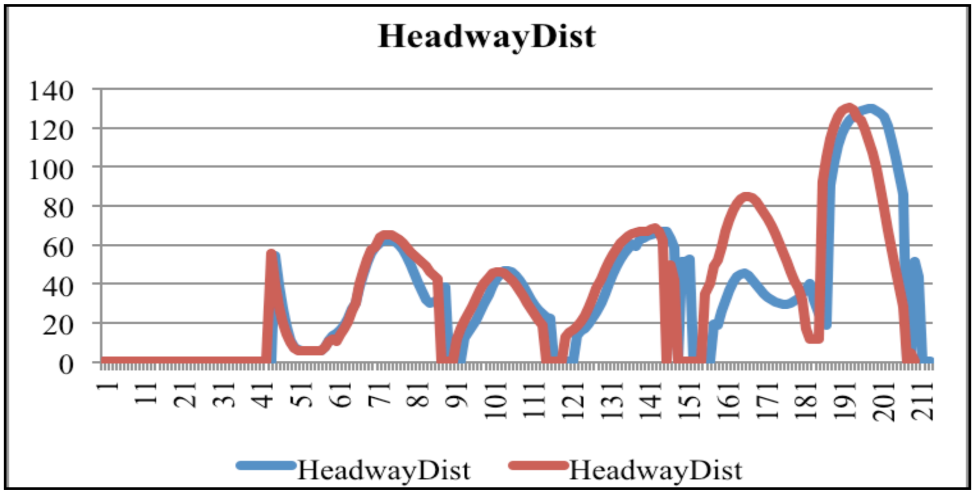


Figure 57. Headway Distance

The figures from 58 – 63 are combination of select 4 drivers' complete records for each metric. The graphs show more similarities than differences in the curves. Some of the differences might be a result of personal preference and drivers' own judgment.

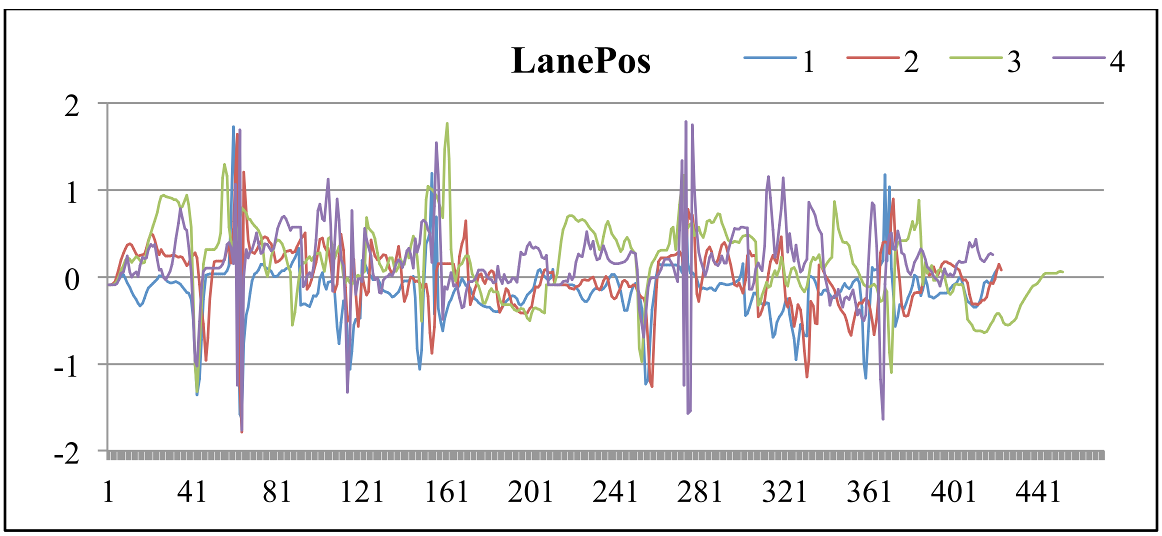


Figure 58. Lane Position Comparison

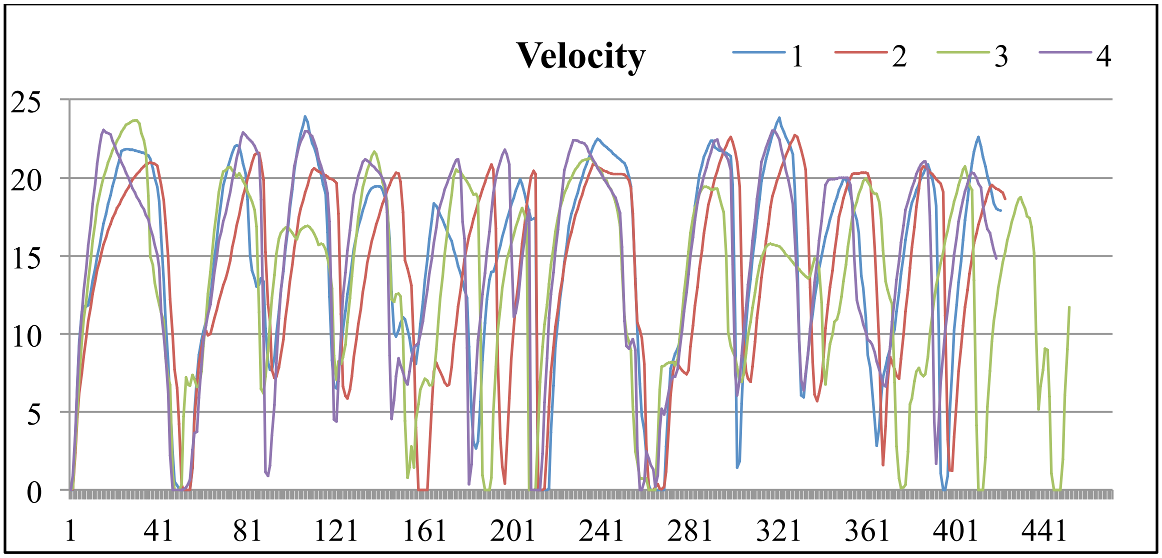


Figure 59. Velocity Comparison

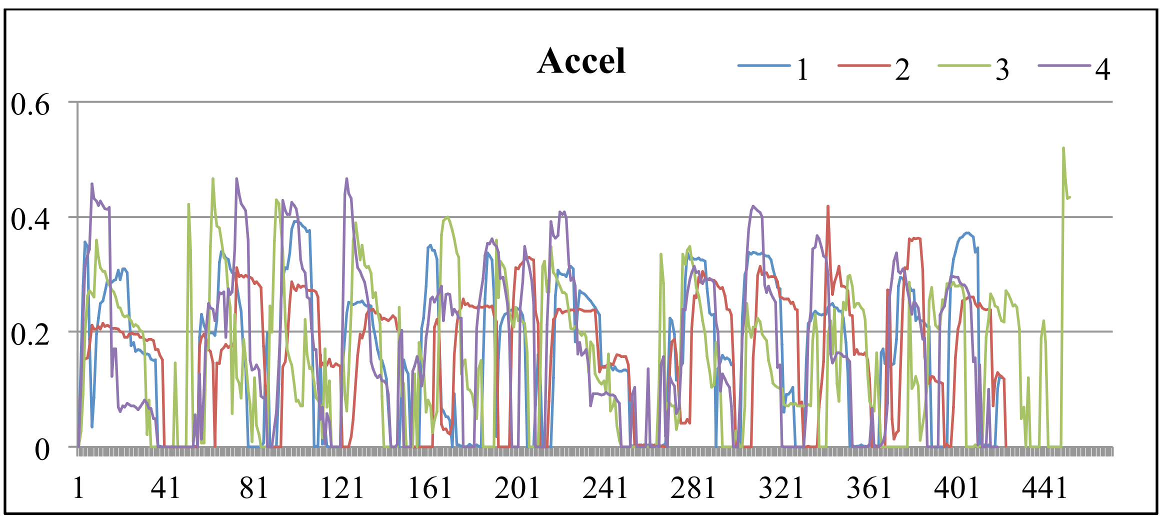


Figure 60. Acceleration Comparison

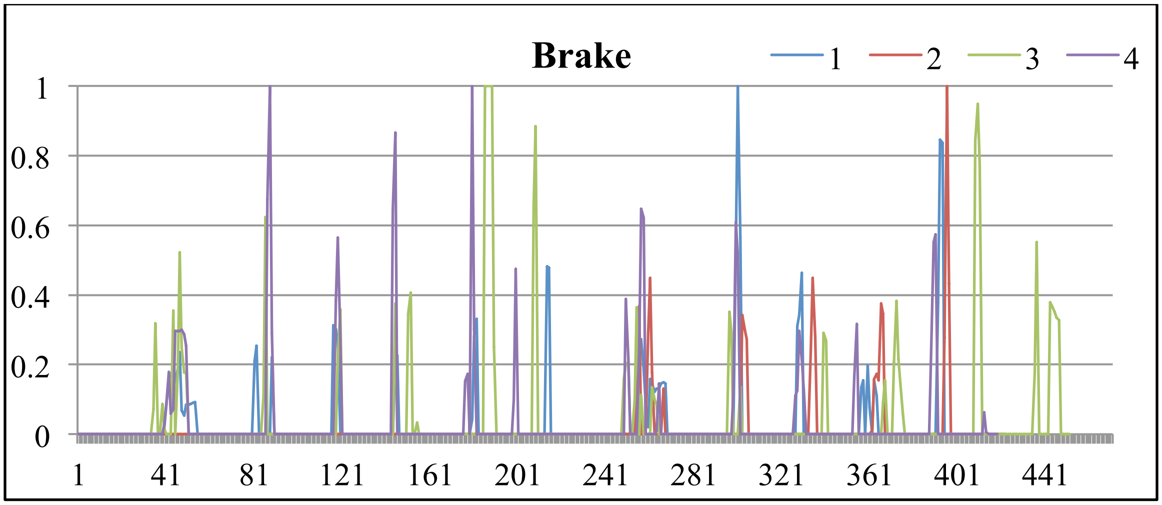


Figure 61. Brake Comparison

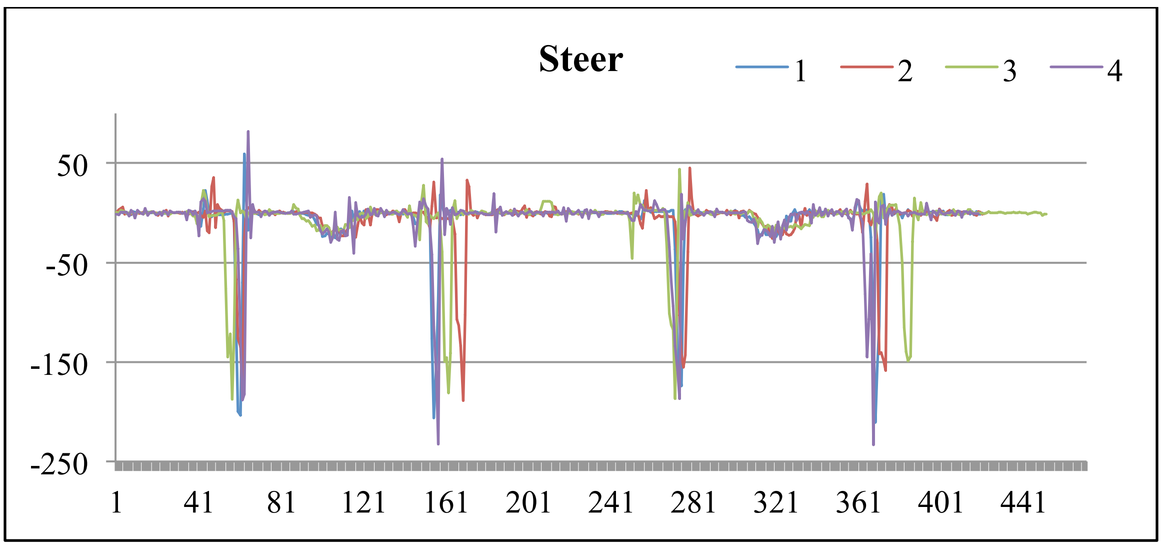


Figure 62. Steer Comparison

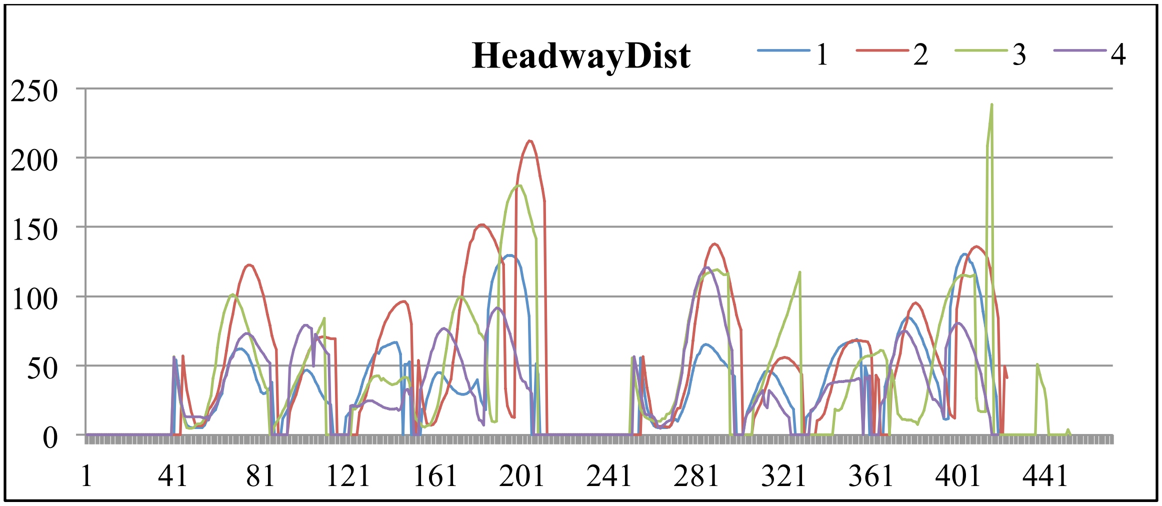


Figure 63. Headway Distance Comparison

5.3 Results

The above data and analysis clearly show the average response of time of most drivers for any icon is below 2 seconds and ranging from as low as 0.71 seconds to 0.98 seconds. Hence we have achieved a minimalist design with least driver distractions and conforming to NHTSA's Guidelines. Also, there is no significant difference in the 4 icons or 8 icons, Large screen size or smaller screen size and between Landscape and Portrait orientation. There are certain variations in the above data but otherwise they are similar. Most prefer Landscape to Portrait, Large screen size to small screen size and 4 icons to 8 icons.

CHAPTER 6

DISCUSSION

6.1 Conclusion

The above results clearly show there is hardly any difference between the screen sizes 7” and 10”. Some drivers did not even notice the difference. Thus, the screen sizes of 8” + / - 2” hardly shows any difference.

There was no change in the reaction times between portrait or landscape. However, many people personally preferred Landscape orientation. It may because in the past all the screen orientations of technology have been landscape. For e.g. Computers, Television, Radio and Media Players. Hence this preference might stem out from the drivers own experience and comfort rather than its effect.

There was also no significant change in using 4 icons or 8 icons. Though some drivers preferred 4 icons because it was easy to concentrate on just 4 icons and others preferred 8 since it didn’t affect their reaction and they could fit more icons on the screen. Hence, 6 +/- 2 number of icons is an effective design with an average of less than 2 second response time per screen and even less than a second with more experience.

We can effectively conclude that 8” +/- 2” screen size with either or portrait or Landscape with an adjustable screen holder and 6 +/- 2 number of icons per screen will reduce the distraction time. Also it was observed that the driver hardly took their eyes of the road as the screen was placed in such a position that could be seen from the corner of our eyes and not obstructing road view. Thus the driver can perform tasks while having their eyes on the road most of the time.

6.2 Future Work

- This above work was conducted only on a limited small number of participants. More test cases and more participants should definitely show more accurate results.
- Comparing 8 icons and 24 icons can further extend this study. This should show a significant change if not huge. 24 icons can delay the response time a lot than just 8. Also in this work, the order of icons was serialized. Hence the drivers had prior idea where the icons were located and could focus on the particular area, for e.g. if 4 was said then they would immediately look at the bottom right corner where they expect 4 to be. Thus this shows learning the positions or experience helps in reacting faster. Future research can also be done on 5 times vs. 20 times the UI was tested. This should show a slight, gradual reduction in the response time that depicts the use of learning mode and the effect of experience. However to check that further experimentation should be done by randomizing the order each time, a comparison between novice and expert drivers in using the In-Car Interactive System.
- There is also a need to check the difference between normal and emergency conditions. This work focused on considering normal situations where there was no need for special attention. The commands were not given when the user was taking a left turn, stopping or such emergency and complex situation. This study could also bring to light as to how many opt to do the distractive task even with the possibility of crashing and who all choose to delay their response time to be safe.

- The position we placed our screen was right next to the steering wheel. However there could be further research concerning to this case. Future researchers can change the position by placing it at the bottom or angling it more to the driver. There is further scope for many such test cases to be considered and tested before implementing MMI.
- The Driver Distraction model previously described shows 2 levels of driver distraction – internal & external and Driving-related and Driving-nonrelated. We can further extend it by having another level emergency and normal mode. Depending on that the drivers can be tested in various situations.
- The UI we presented is based on a concept called Minimalist design. The term minimalism is also used to describe a trend in design and architecture, wherein the subject is reduced to its necessary elements. Minimalistic design has been highly influenced by Japanese traditional design and architecture. Architect Ludwig Mies van der Rohe adopted the motto "Less is more" to describe his aesthetic tactic of arranging the necessary components of a building to create an impression of extreme simplicity—he enlisted every element and detail to serve multiple visual and functional purposes; for example, designing a floor to also serve as the radiator, or a massive fireplace to also house the bathroom. Designer Buckminster Fuller adopted the engineer's goal of "Doing more with less", but his concerns were oriented toward technology and engineering rather than aesthetics. The concept of minimalist architecture is to strip everything down to its essential quality and achieve simplicity. The idea is not completely without ornamentation; but that

all parts, details and joinery are considered as reduced to a stage where no one can remove anything further to improve the design.

- We can further extend the design by considering its Golden Ratio - A ratio within the elements of a form, such as height to width, approximating 0.618. The golden ratio is found throughout nature, art and architecture. Pinecones, seashells, and the human body all exhibit the golden ratio into their paintings. Stradivari utilized the golden ratio in the construction of his violins. The Parthenon, the Great Pyramid of Giza, Stonehenge, and the Chartres Cathedral all exhibit the golden ratio. While manifestations of the golden ratio in early art and architecture were likely cause by processes not involving knowledge of golden ratio, it may be that these manifestations result from a more fundamental, subconscious preference for aesthetic resulting from the ratio. A substantial body of research comparing individual preferences for rectangles of various proportions supports a preferences for the ratio in past experiments resulted from experimenter bias, methodological flaws, or other external factors. Whether the golden ratio taps into some inherent aesthetic preference or is simply an early design technique turned tradition, there is no questions as to its past and continued influence on design. Consider the golden ratio when it is not at the expense of other objectives. Geometrics of a design should not be contrived to create golden ratios, but golden ratios should be explored when other aspects of the design are not compromised.
- By implementing such standards, which might seem farfetched, we can achieve a level of comfort and familiarity between the Driver and In-Car

Interactive System. As previously stated, more drivers preferred Landscape orientation simply because it was a more familiar concept to perceive than portrait, we can achieve a perfect design by combining MMI, Minimalist design and Golden Ratio in our HCaI.

REFERENCES

Addario, Pamela Maria D. 2014. “Perception-Response Time to Emergency Roadway Hazards and the Effect of Cognitive Distraction by Perception-Response Time to Emergency Roadway Hazards and the Effect of Cognitive Distraction.”

Ahlstrom, Christer, and Katja Kircher. 2010. “Review of Real-Time Visual Driver Distraction Detection Algorithms.” *Proceedings of the 7th International Conference on Methods and Techniques in Behavioral Research* 2010: 310–13. doi:10.1145/1931344.1931346.

“Automakers Could Learn From Apple's Siri: Faulty Voice Recognition Is No.1 Complaint Among New Car Owners,” Forbes, accessed January 20, 2015, http://www.forbes.com/sites/matthewdepaula/2014/08/31/faulty-voice-recognition-no-1-problem-cited-by-car-owners-in-jd-power-study/

Beirness, Douglas J, Herb M Simpson, and Anita Pak. 2002. “Driver Distraction,” 7–8.

Brown, Timothy, Shannon Roberts, Chris Schwarz, and Eric Nadler. n.d. “Detection of Driver Distraction Using Vision-Based Algorithms John Lee.”

Daly, Angela, and Patti Pena. 2009a. “MLA Research Paper (Daly),” 1–7.

“Driving,” Wikipedia, accessed January 20, 2015, http://en.wikipedia.org/wiki/Driving

“Distracted Driving,” Wikipedia, accessed January 20, 2015, http://en.wikipedia.org/wiki/Distracted_driving

“Distraction.Gov,” Distraction, accessed January 20, 2015, http://www.distraction.gov/index.html

General, Solicitor, and Motor Vehicles. n.d. “Discussion Paper Addressing the Problem of Distracted Driving and Its Impacts to Road Safety Ministry of Public Safety and Solicitor General.”

Gordon, Craig. 2005. “Driver Distraction : An Initial Examination of the ‘ Attention Diverted by ’ Contributory Factor Codes from Crash Reports and Focus Group Research on Perceived Risks,” no. code 350: 1–14.

Gostin, Lawrence O. 2010. “Reducing Distracted Driving : Regulation and Education to Avert Traffic Injuries and Fatalities Reducing Distracted Driving : Regulation and Education to Avert Traffic” 1420.

Gray, Rob. 2011. “Looming Auditory Collision Warnings for Driving.” Human Factors 53 (1): 63–74. doi:10.1177/0018720810397833.Green, P. 2010. “Driver Distraction/Overload Research and Engineering: Problems and Solutions.” *SAE Int. J. Passeng. Cars-Electron. Electr. Syst*. doi:10.4271/2010-01-2331.

Green, Paul. 2004. “Driver Distraction , In-Car Interactive System Design , and Workload Managers : Safety Issues and Solutions.” *Proc. Int. Congr. Transp. Electron*, 165–80.

Hanowski, Richard. 2011. “The Naturalistic Study of Driver Distraction.” *Transportation*, 1–15.

Ho, Angela W L, M L Cummings, Enlie Wang, Louis Tijerina, and Dev S Kochhar. 2006. “TRB 2006 Annual Meeting CD-ROM Paper Revised from Original Submittal.,” no. 617.

Hs, D O T. 2010. “Research Note Distracted Driving 2009.” *Methodology*, no. September: 1–8. doi:DOT HS 811 379.

“Implications of Distracted Driving on Driver Behavior in the Standing Queue of Dual Left-Turn Lanes: An Empirical Study.” n.d.

Iterature, L, and Mike Hammer. 2003. “Driver Distraction : A Review of the.” *Building*, no. 206: 66. http://www.monash.edu.au/miri/research/reports/muarc206.pdf.

“J.D. Power confirms auto voice-recognition tech is as lousy as we think,” AutoBlog, accessed January 20, 2015, http://www.autoblog.com/2014/08/08/jd-power-confirms-auto-voice-recognition-tech-lousy/

Jin, Lisheng, Qingning Niu, Haijing Hou, Huacai Xian, Yali Wang, and Dongdong Shi. 2012. “Driver Cognitive Distraction Detection Using Driving Performance Measures.” *Discrete Dynamics in Nature and Society* 2012. doi:10.1155/2012/432634.

Just, Marcel Adam, Timothy a. Keller, and Jacquelyn Cynkar. 2008. “A Decrease in Brain Activation Associated with Driving When Listening to Someone Speak.” *Brain Research* 1205: 70–80. doi:10.1016/j.brainres.2007.12.075.

Klauer, Sheila G., Feng Guo, Bruce G. Simons-Morton, Marie Claude Ouimet, Suzanne E. Lee, and Thomas a. Dingus. 2014. “Distracted Driving and Risk of Road Crashes among Novice and Experienced Drivers.” *New England Journal of Medicine* 370 (1): 54–59. doi:10.1056/NEJMsa1204142.

Landau, Ld. 1937. “NHTSA Guidelines.” *Zhurnal Eksperimental’noi I Teoreticheskoi Fiziki*. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:No+Title#0.

Laws, Primary, Fine Levels, and Are Associated. 2010. “Raffic Ech,” no. 400: 2007–8.

Lee, John D. 2014. “Dynamics of Driver Distraction: The Process of Engaging and Disengaging.” *Annals of Advances in Automotive Medicine / Annual Scientific Conference ... Association for the Advancement of Automotive Medicine. Association for the Advancement of Automotive Medicine. Scientific Conference* 58: 24–32. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4001670&tool=pmcentrez&rendertype=abstract.

Li, Wanjun, Konstantina Gkritza, and Chris Albrecht. 2014. “The Culture of Distracted Driving: Evidence from a Public Opinion Survey in Iowa.” *Transportation Research Part F: Traffic Psychology and Behaviour*. doi:10.1016/j.trf.2014.01.002.

Liang, Yulan. 2009. “Detecting Driver Distraction.” *ProQuest Dissertations and Theses* 3356220: 152. http://ezproxy.net.ucf.edu/login?url=http://search.proquest.com/docview/304900929?accountid=10003\nhttp://sfx.fcla.edu/ucf?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:dissertation&genre=dissertations+&+theses&sid=ProQ:ProQuest+Dissertations+&+Theses+Full+Text&atitle=&title=Detecting+driver+distraction&issn=&date=2009-01-01&volume=&issue=&spage=&au=Liang,+Yulan&isbn=9781109162257&jtitle=&btitle=&rft_id=info:eric/.

Liang, Yulan, and John D. Lee. 2014. “A Hybrid Bayesian Network Approach to Detect Driver Cognitive Distraction.” *Transportation Research Part C: Emerging Technologies* 38. Elsevier Ltd: 146–55. doi:10.1016/j.trc.2013.10.004.

National Highway Traffic Safety Administration. 2011. “Research Note Driver Electronic Device Use in 2011,” no. April 2013.

Ophir, Eyal, Clifford Nass, and Anthony D Wagner. 2009. “Cognitive Control in Media Multitaskers.” *Proceedings of the National Academy of Sciences of the United States of America* 106 (37): 15583–87. doi:10.1073/pnas.0903620106.

Petzoldt, Tibor, Schlema Gutachter, Josef F Krems, and Peter Sedlmeier. 2011. “Theoretical and Methodological Issues in Driver Distraction.”

Presenter, Michael A Regan, and Kristie L Young. 2001. “Driver Distraction : A Review of the Literature and Recommendations for Countermeasure Development” 1.

Ranney, Thomas, Elizabeth Mazzae, Riley Garrott, and Michael Goodman. 2000. “NHTSA Driver Distraction Research: Past, Present, and Future.” *USDOT, National Highway Traffic Safety Administration*, 1–11. http://www-nrd.nhtsa.dot.gov/departments/Human Factors/driver-distraction/PDF/233.PDF.

Report, Staff, and Pursuant To. 2001. “Driver Distractions,” no. 127.

Report, Status. 2014. “Eyes Road :” 49 (8).

Schweizer, Tom a, Karen Kan, Yuwen Hung, Fred Tam, Gary Naglie, and Simon J Graham. 2013. “Brain Activity during Driving with Distraction: An Immersive fMRI Study.” *Frontiers in Human Neuroscience* 7 (February): 53. doi:10.3389/fnhum.2013.00053.

Strayer, David L., Jason M. Watson, and Frank a. Drews. 2011. *Cognitive Distraction While Multitasking in the Automobile*. *Psychology of Learning and Motivation - Advances in Research and Theory*. Vol. 54. doi:10.1016/B978-0-12-385527-5.00002-4.

Strayer, Dl, Jm Cooper, and Jonna Turrill. 2013a. “Measuring Cognitive Distraction in the Automobile,” no. June: 52. http://trid.trb.org/view.aspx?id=1252566.

“Talking to Your Car is Often Distracting,” U News Center – University of Utah, accessed January 20, 2015, http://unews.utah.edu/news_releases/talking-to-your-car-is-often-distracting/

Threat, A Serious. 2009. “Distracted Driving – A Growing Problem.”

Tison, J., N. Chaudhary, and L. Cosgrove. 2011. “National Phone Survey on Distracted Driving Attitudes and Behaviors. (Report No. DOT HS 811 555).”

Victor, T., and ... n.d. “Analysis of Naturalistic Driving Study Data : Safer Glances , Driver Inattention , and Crash Risk.”

Voice, I S, and Activation Unsafe. 2015. “HEAR ME - SPEECH BLOG Technologies for a Secure and Superior UX .,” 1–2.

Williams-Bergen, Eric, James Hedlund, Karen Sprattler, Susan Ferguson, Cheri Marti, Barbara Harsha, Johnathan Adkins, and Vicki Harper. 2011. “Distracted Driving.” *Communications* 76 (1): 1–50. doi:10.1037/e535772009-005.

Young, K. & Regan, M., K Young, M Regan, and M Hammer. 2007. “Driver Distraction : A Review of the Literature.” *Distracted Driving. Sydney, NSW: Australasian College of Road Safety*, 379–405. doi:10.1201/9781420007497.

APPENDIX A

CONSENT FORM

Title of Investigation: Modeling and Measuring Cognitive Load to Reduce Driver Distraction in Smart Cars

This document is to certify that I, ____, hereby freely agree to participate as a volunteer in a (research study, experiment, program, etc.) as an authorized part of the educational and research program of the Arizona State University under the supervision of Tanvi Jahagirdar

- The research project has been fully explained to me by Tanvi, and I understand this explanation, including what I will be asked to do. A copy of the procedures of this investigation and a description of any risks, discomforts and benefits associated with my participation has been provided and discussed in detail with me.

- I have been given an opportunity to ask questions, and all such questions and inquiries have been answered to my satisfaction.

- I understand that I am free to decline to answer any specific items or questions in interviews or questionnaires.

- I understand that all data will remain confidential with regard to my identity.

- I understand that participation in this research project is voluntary and not a requirement or a condition for being the recipient of benefits or services from the Arizona State University or any other organization sponsoring the research project.

- I understand that the approximate length of time required for participation in this research project is (15 minutes).

- I understand that if I have any questions concerning the purposes or the procedures associated with this research project, I may email to tjahagir@asu.edu

  I understand that it will not be necessary to reveal my name in order to obtain additional information about this research project from the principal investigator(s).

- I understand that if I have any questions or concerns about the treatment of human subjects in this study, I may email to tjahagir@asu.edu

  Although this person will ask my name, I understand that all inquiries will be kept in the strictest confidence.

- I UNDERSTAND THAT I AM FREE TO WITHDRAW MY CONSENT AND DISCONTINUE MY PARTICIPATION AT ANY TIME.

Date ______________

____

Signature of Subject

APPENDIX B

DRIVING SIMULATOR

The Driving Simulation Setup consists of 2 simulation systems. One is a small screen version, where a designer can build his simulation and test it before deploying it on the main, large screen version. The small version is a replica of the main simulator only to a lesser level. Its driving components are similar to that of videogame set.

The Main Simulator is an exact replica of a car with all basic functionalities and the features of the small version simulator. The design tools for the driving simulator are also easy to learn and implement.

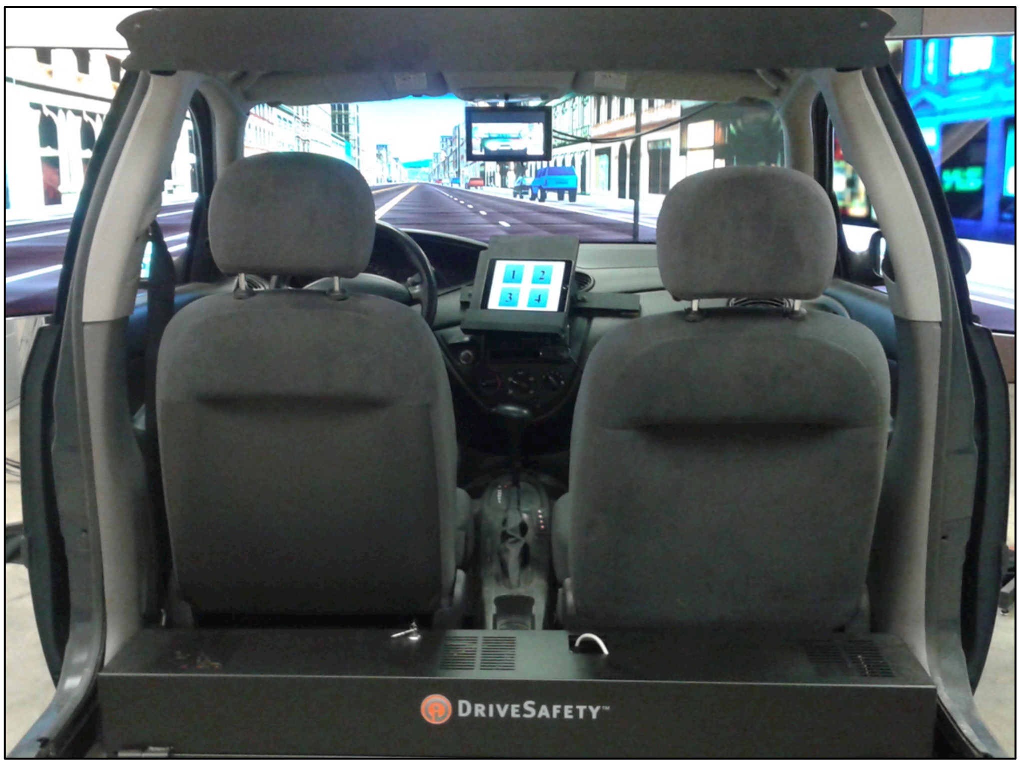


Figure 64. Driving Simulator Setup

To support 4 types of screens – 7" Portrait, 7" Landscape, 10" Portrait and 10" Landscape, built a screen holder (Figure 65).

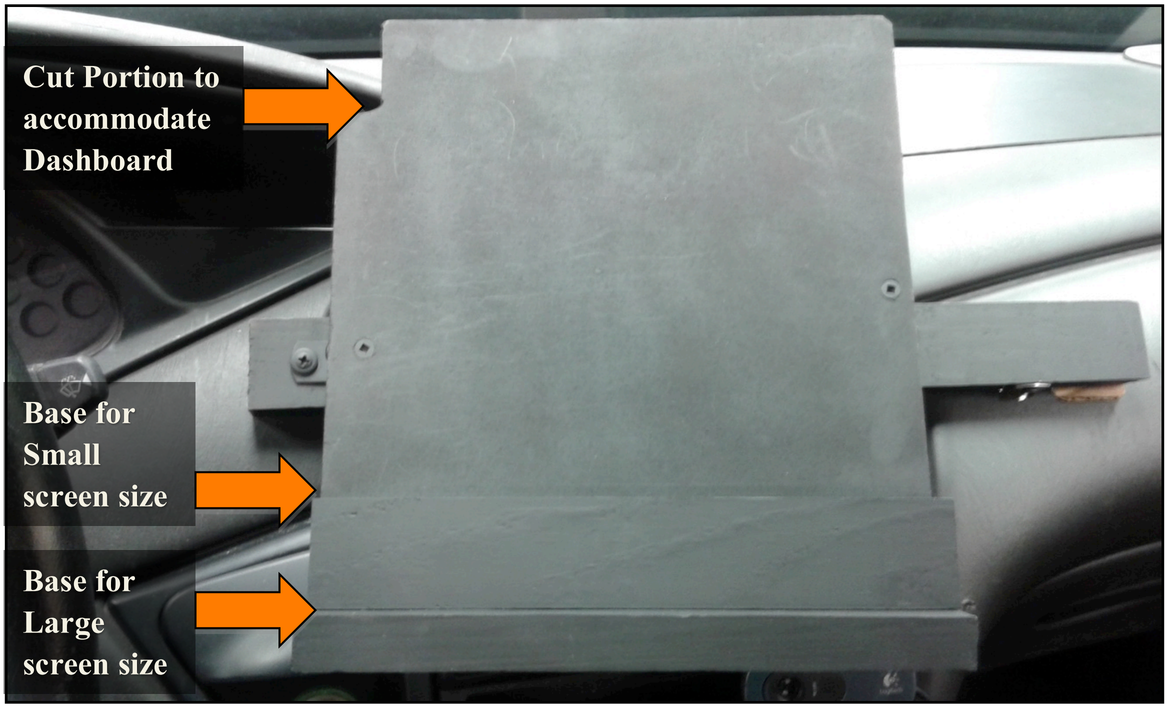


Figure 65. Screen Holder

Since, We wanted the screen to be slightly angled to the driver and at a height, which does not result in total visual distraction. Thus it was affixed at a height that could be seen from the corner of our eye, without losing visual on the road. To angle it towards the driver, the support between the back and front was cut of different lengths. And a base for the screens to rest on was fixed at the bottom. However, it was observed that at that height, the 10” would obstruct the road view slightly. Hence another beam was attached horizontally at the bottom to support the 10” portrait mode. Thus all screens were at similar lengths, despite their varying sizes. Nailing a toggle bolt to the rear support and a wire used to hold the car dashboard and screen holder together supported this entire structure.

APPENDIX C

DATA COLLECTED

[Consult Attached Files]

APPENDIX D

STATISTICAL ANALYSIS

Statistics is the study of the collection, analysis, interpretation, presentation, and organization of data. Statistics deals with all aspects of data including the planning of data collection in terms of the design of surveys and experiments. Two main statistical methodologies are used in data analysis: descriptive statistics, which summarizes data from a sample using indexes such as the mean or standard deviation, and inferential statistics, which draws conclusions from data that are subject to random variation (e.g., observational errors, sampling variation). Standard statistical procedure involves the development of a null hypothesis, a general statement or default position that there is no relationship between two quantities. Rejecting or disproving the null hypothesis is a central task in the modern practice of science, and gives a precise sense in which a claim is capable of being proven false. What statisticians call an alternative hypothesis is simply a hypothesis that contradicts the null hypothesis.

Statistical analysis is a component of data analytics. In the context of business intelligence (BI), statistical analysis involves collecting and scrutinizing every single data sample in a set of items from which samples can be drawn. Statistical analysis is fundamental to all experiments that use statistics as a research methodology. Most experiments in social sciences and many important experiments in natural science and engineering need statistical analysis. Statistical analysis is also a very useful tool to get approximate solutions when the actual process is highly complex or unknown in its true form. Example: The study of turbulence relies heavily on statistical analysis derived from experiments. Turbulence is highly complex and almost impossible to study at a purely theoretical level. Scientists therefore need to rely on a statistical analysis of turbulence through experiments to confirm theories they propound. In social sciences, statistical analysis is at the heart of most experiments. It is very hard to obtain general theories in these areas that are universally valid. In addition, it is through experiments and surveys that a social scientist is able to confirm his theory.

Statistical analysis can be broken down into five discrete steps, as follows:

- Describe the nature of the data to be analyzed.
- Explore the relation of the data to the underlying population.
- Create a model to summarize understanding of how the data relates to the underlying population.
- Prove (or disprove) the validity of the model.
- Employ predictive analytics to run scenarios that will help guide future actions.

The goal of statistical analysis is to identify trends. A retail business, for example, might use statistical analysis to find patterns in unstructured and semi-structured customer data that can be used to create a more positive customer experience and increase sales.

Calculation of the test statistic requires four components:

- The average of the sample (observed average)
- The population average or other known value (expected average)
- The standard deviation (SD) of the sample average
- The number of observations.

With these four pieces of information, we calculate the following statistic, t:

$$t = \frac{\text{(observed-expected)}}{SD_{observed} \times \sqrt{\text{(number of observations in sample / number of observations-1)}}}$$

A single sample t-test (or one sample t-test) is used to compare the mean of a single sample of scores to a known or hypothetical population mean. So, for example, it could be used to determine whether the mean diastolic blood pressure of a particular group differs from 85, a value determined by a previous study.

Requirements

- The data is normally distributed
- Scale of measurement should be interval or ratio
- A randomized sample from a defined population
- Null Hypothesis

H0: M - μ = 0, where M is the sample mean and μ is the population or hypothesized mean. As above, the null hypothesis is that there is no difference between the sample mean and the known or hypothesized population mean.

Equation:

$$t = \frac{M - \mu}{\sqrt{\frac{\Sigma X^2 - \left(\left(\Sigma X^2 \right) / N \right)}{(N - 1)\,(N)}}}$$

Suppose that you've collected data from two samples of animals treated with different drugs. You've measured an enzyme in each animal's plasma, and the means are different. You want to know whether that difference is due to an effect of the drug – whether the two populations have different means. Observing different sample means is not enough to persuade you to conclude that the populations have different means. It is possible that the populations have the same mean (i.e., that the drugs have no effect on the enzyme you are measuring) and that the difference you observed between sample means occurred only by chance. There is no way you can ever be sure if the difference you observed reflects a true difference or if it simply occurred in the course of random sampling. All you can do is calculate probabilities. The P value is a probability, with a value ranging from zero to one, that answers this question (which you probably never thought to ask): In an experiment of this size, if the populations really have the same mean, what is the probability of observing at least as large a difference between sample means as was, in fact, observed?

The confidence interval (CI) of a mean tells you how precisely you have determined the mean. In statistics, the number of degrees of freedom (df) is the number of values in the final calculation of a statistic that are free to vary. The standard deviation (SD) quantifies variability. It is expressed in the same units as the data. The Standard Error of the Mean (SEM) quantifies the precision of the mean. It is a measure of how far your sample mean is likely to be from the true population mean. It is expressed in the same units as the data. For example, you measure weight in a small sample (N=5), and compute the mean. That mean is very unlikely to equal the population mean. The size of the likely discrepancy depends on the size and variability of the sample. If your sample is small and variable, the sample mean is likely to be quite far from the population mean. If your sample is large and has little scatter, the sample mean will probably be very close to the population mean. Statistical calculations combine sample size and variability (standard deviation) to generate a CI for the population mean. As its name suggests, the CI is a range of values. To interpret the confidence interval of the mean, you must assume that all the values were independently and randomly sampled from a population whose values are distributed according to a Gaussian distribution. If you accept those assumptions, there is a 95% chance that the 95% CI contains the true population mean. In other words, if you generate many 95% CIs from many samples, you can expect the 95%

CI to include the true population mean in 95% of the cases, and not to include the population mean value in the other 5%. The unpaired t test compares the means of two unmatched groups, assuming that the values follow a Gaussian distribution. The unpaired t test assumes that the two populations have the same variances (and thus the same standard deviation). The paired t test compares the means of two matched groups, assuming that the distribution of the before-after differences follows a Gaussian distribution. The paired t test assumes that you have sampled your pairs of values from a population of pairs where the difference between pairs follows a Gaussian distribution. Note that the paired t test, unlike the unpaired t test, does not assume that the two sets of data (before and after, in the typical example) are sampled from populations with equal variances. The pairing should be part of the experimental design and not something you do after collecting data. Prism tests the effectiveness of pairing by calculating the Pearson correlation coefficient, r, and a corresponding P value. If the P value is small, the two groups are significantly correlated. This justifies the use of a paired test. If this P value is large (say larger than 0.05), you should question whether it made sense to use a paired test. Your choice of whether to use a paired test or not should not be based solely on this one P value, but also on the experimental design and the results of other similar experiments. The results of a paired t test only make sense when the pairs are independent – that whatever factor caused a difference (between paired values) to be too high or too low affects only that one pair. Prism cannot test this assumption. You must think about the experimental design. For example, the errors are not independent if you have six pairs of values, but these were obtained from three animals, with duplicate measurements in each animal. In this case, some factor may cause the after-before differences from one animal to be high or low. This factor would affect two of the pairs, so they are not independent. The values used for paired and upaired tests are absolute values. The results of the t-test for the lanepos metric are -

1. Without Distraction:

P Value And Statistical Significance:

- The two-tailed P value equals 0.5323
- By conventional criteria, this difference is considered to be not statistically significant.

Confidence interval:

- The hypothetical mean is 0.00000
- The actual mean is 0.01371
- The difference between these two values is 0.01371
- The 95% confidence interval of this difference:
- From -0.02947 to 0.05690

Intermediate values used in calculations:

- t = 0.6254
- df = 246
- standard error of difference = 0.022

Mean - 0.01371
SD - 0.34458
SEM - 0.02192
N - 247

2. Distraction With Smaller Screen:

P value and statistical significance:

- The two-tailed P value equals 0.0004
- By conventional criteria, this difference is considered to be extremely statistically significant.

Confidence interval:

- The hypothetical mean is 0.00000
- The actual mean is 0.07839
- The difference between these two values is 0.07839
- The 95% confidence interval of this difference:
- From 0.03533 to 0.12145

Intermediate values used in calculations:

- t = 3.5858
- df = 246
- standard error of difference = 0.022

Mean - 0.07839
SD - 0.34359
SEM - 0.02186
N - 247

3. Distraction With Larger Screen:

P value and statistical significance:

- The two-tailed P value equals 0.0005

- By conventional criteria, this difference is considered to be extremely statistically significant.

Confidence interval:

- The hypothetical mean is 0.00000
- The actual mean is -0.07749
- The difference between these two values is -0.07749
- The 95% confidence interval of this difference:
- From -0.12079 to -0.03419

Intermediate values used in calculations:

- t = 3.5277
- df = 214
- standard error of difference = 0.022

Mean - (-0.07749)
SD - 0.32208
SEM - 0.02197
N - 215

4. Unpaired T Test Results For Smaller Screen

P value and statistical significance:

- The two-tailed P value equals 0.7031
- By conventional criteria, this difference is considered to be not statistically significant.

Confidence interval:

- The mean of Distractive minus Non-Distractive equals 0.00795

- 95% confidence interval of this difference: From -0.03302 to 0.04892

Intermediate values used in calculations:

- t = 0.3813
- df = 492
- standard error of difference = 0.021

	Distractive	Non-Distractive
Mean	0.26394	0.25599
SD	0.23297	0.23049
SEM	0.01482	0.01467
N	247	247

5. Unpaired T-Test Results For Larger Screen

P value and statistical significance:

- The two-tailed P value equals 0.8395
- By conventional criteria, this difference is considered to be not statistically significant.

Confidence interval:

- The mean of Distractive minus Non-Distractive equals -0.00422
- 95% confidence interval of this difference: From -0.04515 to 0.03670

Intermediate values used in calculations:

- t = 0.2027
- df = 460
- standard error of difference = 0.021

	Distractive	Non-Distractive
Mean	0.25177	0.25599
SD	0.21468	0.23049
SEM	0.01464	0.01467
N	215	247

6. Paired T-Test Results For Smaller Screen Vs. Larger Screen

P value and statistical significance:

- The two-tailed P value equals 0.3290
- By conventional criteria, this difference is considered to be not statistically significant.

Confidence interval:

- The mean of Small minus Large equals 0.02065
- 95% confidence interval of this difference: From -0.02096 to 0.06226

Intermediate values used in calculations:

- t = 0.9783
- df = 214
- standard error of difference = 0.021

	Small	Large
Mean	0.26394	0.25177
SD	0.23297	0.21468
SEM	0.01482	0.01464
N	247	215

The Figure 66 below shows the graphical representation of the 3 sets of data analyzed above. The green curve is for Non-Distractive drive, blue and red curves for smaller screen and larger screen Distractive drives. From the graph below we can conclude that there is slight change but the deviation is small and the 3 curves trace a similar trendline.

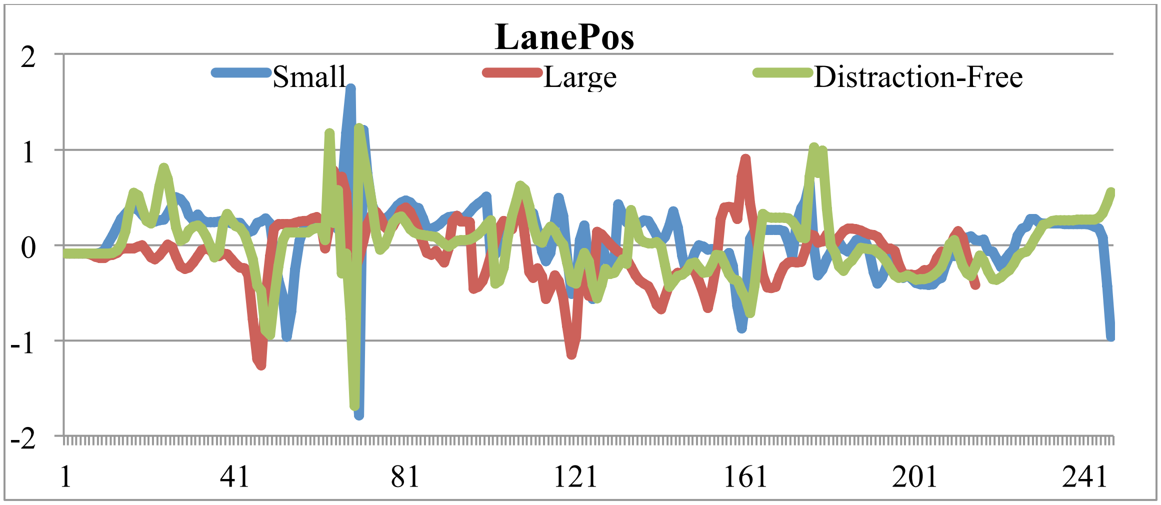


Figure 66. Statistical analysis

Conclusion:

Thus the above analysis shows that our distractive task causes minimum driver distraction and the variation between the constraints like small and large screen size, landscape and portrait orientation and 4 or 8 icons is insignificantly small (since p value is considerably small with CI = 95%).