ABSTRACT

ZAHABI, MARYAM. Analysis and Redesign of Police Vehicle Mobile Computer Terminal for Minimizing Officer Driving Distraction. (Under the direction of Dr. David B. Kaber and Dr. Manida Swangnetr).

Crash reports from various states in the U.S. have shown high numbers of emergency vehicle crashes, especially in law enforcement situations. Such crashes have not only been attributed to the need for officers to drive at high speeds in emergencies, but to make use of in-vehicle technologies while driving. Although the effect of in-vehicle distraction on driver performance and safety has been studied, few investigations have focused on distraction in emergency vehicles with fewer still examining police officer distraction. This research situation is ironic in that the New York Times labeled police cars as being, “the most wired vehicles on the road.”

The objectives of this study were to: (1) identify the perceived importance and frequency of police Mobile Computer Terminal (MCT) tasks; (2) quantify the visual and cognitive demands of high importance and high frequency MCT tasks; (3) formulate design recommendations for enhanced MCT interface design; and (4) conduct a driving simulator-based assessment of police officer visual behavior, performance and perceived workload in current and enhanced MCT interface use.

The research followed a three-phase approach. The first phase of this research required five officers to demonstrate performance of the range of MCT tasks (in a stationary vehicle). Officers were asked to “think aloud” and explain to a researcher why and how tasks are performed. At the end of this phase, officers were given a survey requesting subjective ratings of MCT task importance and frequency of performance in emergency situations. Results revealed that MCT was the most demanding in-vehicle technology in police vehicles.
In addition, the tasks of ‘access call notes’, ‘plate number check’, and ‘find location on map’ were found to be the most important and frequently performed MCT tasks for officers while driving. From these demanding tasks, ‘plate number check’ and ‘find location on map’ were the most time consuming in-vehicle tasks.

Results of the first phase of research were used as a basis for developing officer MCT task performance models identifying all perceptual, cognitive and motor operations as part of task methods. The models were used in the second phase of the research to identify those MCT tasks causing the highest degree of cognitive workload. Results revealed that “reading plate number information” requires substantially higher number of cognitive operations as compared to other tasks. In addition, this task leads to the highest number of consecutive cognitive sequence and highest number working memory chunks. Time estimation results from the models also showed that reading plate number information was the most time consuming task among other demanding MCT tasks. Results of these models were used a basis for formulating MCT design revisions, along with reference of existing human factors design guidelines, to reduce officer distraction from the roadway and to increase task performance accuracy.

The third phase of this research required 20 police officers to participate in a driving simulation study in order to make comparison of high workload MCT task performance with a current interface design and prototype enhanced interface. Officers were asked to drive a simulated urban environment while using the MCT interfaces for performing the plate number check task. Results revealed that use of MCTs while driving increased visual attention demand and driver workload, and decreased officer level of awareness regarding the driving environment. In addition, results revealed that even basic usability improvements
to the MCT interface can reduce off-road visual attention and secondary task completion time.

Results of this research is useful for understanding perceptual, motor and cognitive demands associated with police officer MCT tasks. This study also provides a basis for enhanced design of the MCT in order to reduce visual and cognitive distractions caused by the existing technology. Any design improvements are expected to ultimately increase officer and civilian safety during police emergency operations.
Analysis and Redesign of Police Vehicle Mobile Computer Terminal for Minimizing Officer Driving Distraction

by
Maryam Zahabi

A dissertation submitted to the Graduate Faculty of North Carolina State University In partial fulfillment of the requirements for the degree of Doctor of Philosophy

Industrial and Systems Engineering

Raleigh, North Carolina

2017

APPROVED BY:

_______________________________  ______________________________
David Kaber, PhD                 Manida Swangnetr, PhD
Co-Chair                           Co-Chair

_______________________________  ______________________________
Chang S. Nam, PhD                 Jonathan Stallings, PhD
                                          Minor Member

_______________________________
James Brunet, PhD
DEDICATION

To my parents, for their unconditional love and support.
BIOGRAPHY

Maryam Zahabi was born on May 24, 1989 in Gorgan, Iran to parents Gholamreza Zahabi and Tahereh Maleki. After graduating from the National Organization for Developing Exceptional Talents (Iran) in 2007, Maryam was awarded a scholarship to Sharif University of Technology (SUT) and graduated with a Bachelor of Science in Industrial and Systems Engineering in 2011. She also pursued her Master of Science degree in Industrial and System Engineering at SUT and graduated in 2013. Upon graduation, Maryam was offered an Edward P. Fitts Fellowship from the Industrial and Systems Engineering (ISE) Department at North Carolina State University (NCSU). She began work in the ISE Doctoral program in Fall 2013.
ACKNOWLEDGMENTS

This work could not have been completed without the support of several people. First, I want to thank my advisor Dr. David Kaber, for his guidance and support over the years and who was an example of excellence as a researcher, mentor, instructor, and role model for me. Second, I would like to thank my committee members, Dr. Manida Swangnetr, Dr. Jonathan Stallings, Dr. C.S. Nam, Dr. James Brunet, Chief Tony Godwin, and Dr. Jing Feng for their valuable inputs. I would also like to thank the Cary Police Department for their help and support regarding this study. In addition, this research would not have been possible without funding from NC Occupational Safety and Health Education and Research Center (NC OSHERC). Last but not least, I would like to thank my colleagues in Ergonomics Lab for their support, particularly Matthew Wadsworth, Yulin Deng, Wenjuan Zhang, David Feltner, James Shirley, Mei Lau, and Dr. Carl Pankok.
TABLE OF CONTENTS

LIST OF TABLES ................................................................................................................................. xi

LIST OF FIGURES ................................................................................................................................ xiii

LIST OF ABBREVIATIONS .................................................................................................................. xv

1 Introduction ....................................................................................................................................... 1

1.1 Background .................................................................................................................................... 1

1.1.1 Emergency vehicle crash rates ............................................................................................ 1

1.1.2 Emergency vehicle crash rates in North Carolina .............................................................. 3

1.1.3 NC State Laws regarding in-vehicle technology use ............................................................ 4

1.1.4 Emergency vehicle crash rates due to in-vehicle distraction ............................................ 5

1.1.5 Summary .................................................................................................................................. 7

1.2 Common in-vehicle technologies in emergency vehicles ....................................................... 8

1.2.1 MCT usage rate in emergency vehicles ................................................................................. 13

1.2.2 Description of various tasks in MCT ................................................................................... 14

1.2.3 Usability evaluation of MCTs ............................................................................................... 16

1.2.4 Summary .................................................................................................................................. 17

1.3 Review of literature on MCTs ..................................................................................................... 18

1.3.1 MCT effect on distraction and driver performance .......................................................... 18
1.8 Problem Statement ................................................................................................................. 50

1.8.1 Limitations of existing literature .................................................................................... 50

1.8.2 Objectives of the present research.................................................................................. 51

2 Determination of the most demanding MCT task................................................................. 53

2.1 Objective ............................................................................................................................. 53

2.2 Participants .......................................................................................................................... 53

2.3 Procedure ........................................................................................................................... 53

2.4 Decision tree analysis ......................................................................................................... 55

2.5 Hierarchical task analysis on MCT tasks .......................................................................... 59

2.6 Task Time Analysis ............................................................................................................ 62

2.7 Identification of the most visual and cognitive demanding task ........................................ 64

2.7.1 Procedure ......................................................................................................................... 64

2.7.2 Results .............................................................................................................................. 66

2.8 Conclusion .......................................................................................................................... 71

3 MCT interface design ............................................................................................................. 72

3.1 Objective ............................................................................................................................. 72

3.2 Participants .......................................................................................................................... 72

3.3 Procedure ........................................................................................................................... 72

3.4 Usability violations and recommendations for an enhanced design .............................. 74
3.5 MCT interface design ........................................................................................................ 80

3.5.1 Baseline MCT interface ................................................................................................. 81

3.5.2 Enhanced MCT interface .............................................................................................. 82

3.6 Comparison of current and enhanced MCT interfaces ...................................................... 85

3.6.1 Hierarchical task analysis .............................................................................................. 85

3.6.2 GOMSL modeling ........................................................................................................ 87

3.7 Conclusion ....................................................................................................................... 90

4 Driving simulation study ..................................................................................................... 91

4.1 Objective ......................................................................................................................... 91

4.2 Participants ...................................................................................................................... 91

4.3 Apparatus ........................................................................................................................ 93

4.4 Independent variables .................................................................................................... 96

4.5 Experiment design .......................................................................................................... 96

4.6 Dependent variables ....................................................................................................... 98

4.7 Task .................................................................................................................................. 101

4.8 Procedure ....................................................................................................................... 104

4.9 Hypotheses ..................................................................................................................... 106

4.10 Data analysis .................................................................................................................. 107

4.11 Results ........................................................................................................................... 110
4.11.1 Effect of using MCT while driving (Phase 1) ............................................. 110

4.11.2 Analysis on baseline driving conditions (Phase 2) ................................. 115

4.11.3 Analysis on driving conditions including secondary MCT task (Phase 3)
........................................................................................................................................ 116

4.11.4 Correlation analysis among driving simulation experiment responses ... 122

4.11.5 Comparison of GOMSL time estimates and secondary task completion
time.................................................................................................................................... 123

4.12 Discussion.................................................................................................................. 126

4.12.1 Driving performance ........................................................................................... 126

4.12.2 Attention allocation ......................................................................................... 127

4.12.3 Driver level of awareness ................................................................................ 129

4.12.4 Secondary task performance .......................................................................... 130

4.12.5 MCT usability score .......................................................................................... 131

4.12.6 Driver perceived workload .............................................................................. 131

4.12.7 Correlations among measures .......................................................................... 133

5 Conclusions.................................................................................................................... 134

5.1 Determination of the most demanding MCT task .............................................. 134

5.2 MCT interface design ............................................................................................ 135

5.3 Driving simulation study ........................................................................................ 135
5.4 Limitations ............................................................................................................. 137
5.5 Future work .......................................................................................................... 137

REFERENCES ............................................................................................................. 139

APPENDICES ............................................................................................................. 152

Appendix A: Driving Activity Load Index ................................................................. 153
Appendix B: Demographic questionnaire ................................................................. 157
Appendix C: Subjective rating survey of MCT tasks ............................................... 159
Appendix D: Virtual storyboards ............................................................................. 160
Appendix E: Situation Awareness Subjective Rating ............................................... 166
Appendix F: System Usability Scale ........................................................................ 167
Appendix G: Driving Scenarios ............................................................................... 168
Appendix H: Driving Experiment Demographic Questionnaire ............................ 170
Appendix I: Experiment Instructions ...................................................................... 171
Appendix J: Scatter Plots of Significant Correlations .............................................. 180
LIST OF TABLES

Table 1: Descriptive Statistics on Police In-vehicle Technology Use ........................................57
Table 2: Descriptive Statistics on MCT Tasks ........................................................................... 58
Table 3: MCT Goals, methods, along with associated maximum numbers of perceptual, motor, cognitive operators, and time estimations ......................................................... 67
Table 4: Maximum number of cognitive operations in sequence ............................................. 69
Table 5: Number of working memory chunks ......................................................................... 70
Table 6: Usability Violation Identification and Recommendations for Enhanced Design .......................................................... .............................................................................. 76
Table 7: Distribution of heuristic evaluation responses ............................................................ 80
Table 8: GOMSL Comparison of Baseline and Enhanced MCT Interfaces ............................. 89
Table 9: Number of participants recruited in previous studies ................................................. 92
Table 10: Driving Experiment Participant Demographics ....................................................... 93
Table 11: Queries and answers regarding the secondary task ............................................... 103
Table 12: Descriptive Statistics of Driving performance in Different Driving Conditions ........................................................................................................................................... 111
Table 13: Descriptive Statistics of Driving Performance for Different MCT Interface Types ........................................................................................................................................................................................................... 117
Table 14: Descriptive Statistics of Driver Level of Awareness for Different MCT Types .......................................................... ........................................................................................................................................................................................................... 120
Table 15: Descriptive Statistics of SUS Score for Different MCT Design Types........ 121
Table 16: Correlation among Responses ................................................................. 123
Table 17: GOMSL Model Time Estimates ............................................................... 124
Table 18: Descriptive Statistics for Multi-Tasking Times .................................. 124
LIST OF FIGURES

Figure 1: MCT inside a police car ............................................................. 9
Figure 2: A video camera inside a police car ........................................ 10
Figure 3: Radio systems and siren control panel inside a police car ....... 11
Figure 4: A radar system inside a police car ......................................... 12
Figure 5: Screen shot of a MCT display .................................................. 15
Figure 6: Decision tree structure ............................................................ 43
Figure 7: Decision Tree Analysis on Police In-Vehicle Technologies ....... 56
Figure 8: Decision Tree Analysis on MCT Tasks .................................... 58
Figure 9: HTA for Access to Call Notes Task ......................................... 60
Figure 10: HTA for Plate Number Check Task ...................................... 61
Figure 11: HTA for Finding Location on Map ......................................... 62
Figure 12: MCT Task Time Analysis ...................................................... 63
Figure 13: MCT Method Time Analysis .................................................. 64
Figure 14: Design guideline formulation process ..................................... 74
Figure 15: Current MCT Interface Design .............................................. 82
Figure 16: Enhanced MCT Interface Design: Summary Page ................. 83
Figure 17: Enhanced MCT Interface Design: Driver License Page ......... 84
Figure 18: HTA for Reading Plate Information in Baseline MCT Interface ... 86
Figure 19: HTA for Reading Plate Information in Enhanced MCT Interface ..... 87
Figure 20: Ergonomic Lab Driving Simulator Set up ............................... 94
Figure 21: FaceLAB System Hardware ................................................... 95
Figure 22: Overview of Data Analysis Phases.......................................................... 108
Figure 23: Effect of Driving Condition on Longest Off-Road Glance Duration........ 112
Figure 24: Effect of Driving Condition on Off-Road Fixation Frequency .................. 113
Figure 25: Effect of Driving Condition on Situation Awareness.................................. 114
Figure 26: Effect of Driving Condition on Workload.................................................. 115
Figure 27: Effect of MCT Interface Type on Longest Off-road Glance Duration .... 118
Figure 28: Hazard Exposure and MCT Interface Type Interaction................................. 118
Figure 29: Effect of MCT Interface Type on Fixation Frequency .................................. 119
Figure 30: Effect of MCT Interface Type on Secondary Task Completion Time .... 120
Figure 31: Effect of MCT Interface Type on Temporal Demand .................................. 122
Figure 32: Comparison of GOMSL Time Estimates with Multi-Tasking Times ........ 125
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>AOI</td>
<td>Area of Interest</td>
</tr>
<tr>
<td>CPM-GOMS</td>
<td>Critical Path Method GOMS</td>
</tr>
<tr>
<td>CRD</td>
<td>Completely Randomized Design</td>
</tr>
<tr>
<td>CW</td>
<td>Cognitive Walkthrough</td>
</tr>
<tr>
<td>DALI</td>
<td>Driving Activity Load Index</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
</tr>
<tr>
<td>EMS</td>
<td>Emergency Medical Services</td>
</tr>
<tr>
<td>EMV</td>
<td>Expected Monetary Value</td>
</tr>
<tr>
<td>FARS</td>
<td>Fatality Analysis Reporting System</td>
</tr>
<tr>
<td>GCBD</td>
<td>General Complete Block Design</td>
</tr>
<tr>
<td>GES</td>
<td>General Estimate System</td>
</tr>
<tr>
<td>GOMS</td>
<td>Goals, Operators, Methods, and Selection Rules</td>
</tr>
<tr>
<td>GOMSL</td>
<td>GOMS Language</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HCI</td>
<td>Human-Computer Interaction</td>
</tr>
<tr>
<td>HTA</td>
<td>Hierarchical Task Analysis</td>
</tr>
<tr>
<td>KLM</td>
<td>Keystroke Level Model</td>
</tr>
<tr>
<td>MCT</td>
<td>Mobile Computer Terminal</td>
</tr>
<tr>
<td>NASA-TLX</td>
<td>NASA Task Load Index</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>NGOMSL</td>
<td>Natural GOMS Language</td>
</tr>
<tr>
<td>NHTSA</td>
<td>National Highway Traffic Safety Admin</td>
</tr>
<tr>
<td>SA</td>
<td>Situation Awareness</td>
</tr>
<tr>
<td>SPD</td>
<td>Split Plot Design</td>
</tr>
<tr>
<td>SSQ</td>
<td>Simulator Sickness Questionnaire</td>
</tr>
<tr>
<td>SUS</td>
<td>System Usability Scale</td>
</tr>
<tr>
<td>WM</td>
<td>Working Memory</td>
</tr>
</tbody>
</table>
1 Introduction

1.1 Background

In the U.S., there are three main categories of emergency services including: firefighting, emergency medical services (EMS), and law enforcement. According to Karter and Stein (2012) and Reaves (2011), there are 30,100 fire departments and 17,985 state and local law enforcement agencies throughout the country that provide emergency services. A large number of firefighters, paramedics, and police officers at these agencies spend most of their work shift in emergency vehicles. For example, in a survey of 476 officers in the New South Wales police in Australia, 75% indicated that they spend at least half of their shift in police vehicles and about 70% of these officers mentioned spending at least 75% of shifts in vehicles (Mitsopoulos-Rubens et al. 2009). There are many different vehicle and onboard technologies that are used for providing emergency services. Although there are several studies that found in-vehicle technologies to increase driver distraction and compromise safety for normal drivers (e.g. Blanco et al. 2006; Salvucci et al. 2007; Kaber et al. 2012), there are few studies that have focused on distraction due to in-vehicle technologies in emergency vehicles.

1.1.1 Emergency vehicle crash rates

Based on the National Highway Traffic Safety Administration (NHTSA) report in 2010, the total number of persons killed in crashes involving emergency vehicles was 31 for ambulances, 14 for fire trucks, and 84 for police vehicles. The report in 2011 shows a slight
decrease in this trend but death rates remain high with 29 for ambulances, 6 for fire trucks, and 81 for police vehicles. Finally, in a 2012 report, there were 34 deaths as a result of ambulance crashes, 14 involving fire trucks, and 83 involving police vehicles. It is important to note that about half of the death rates documented in all the above reports occurred in emergency situations. A similar report from 2002-2012 indicates that in the last 10 years 49.3% of fatalities involving emergency vehicles in the United States occurred in emergency mode (NHTSA FARS and GES reports, 2002-2012).

Symmons et al. (2005) assessed the number and characteristics of emergency vehicle crashes in New South Wales, Australia from 1996-2000. The results revealed that the largest number of emergency vehicles in crashes by crash severity were police vehicles (785), followed by ambulances (156) and then fire brigade vehicles (70). NHTSA Fatality Analysis Reporting System (FARS) and General Estimate System (GES) reports from 2002 to 2012 also indicate that police vehicles are involved in significantly more fatalities in comparison to fire or emergency medical vehicles. The greater number of crashes and fatalities for police vehicles might be due to the larger number of police cruisers in comparison to other emergency vehicles and the fact that police vehicles are more likely to be single-crewed (Yager, 2015).

Noh (2011) reported the proportion of law enforcement officers killed in motor vehicle crashes to the total law enforcement officers killed from 1980 to 2008 in US. The report showed that law enforcement officers killed in motor vehicle crashes was 29 percent of the total law enforcement officers killed in the 1980s, but increased to 35 percent in the 1990s, increased to 48 percent in the 2000s, and finally increased to 53 percent in 2008. It is
important to note that Noh (2011) analyzed the characteristics of these fatalities in terms of regional distribution, crash level, vehicle level, and person level and did not investigate fatalities due to driver distraction.

1.1.2 Emergency vehicle crash rates in North Carolina

Based on North Carolina (NC) crash fact reports in 2012, there were 785 police vehicle crashes followed by 201 EMS vehicles, ambulances, and rescue squads crashes, and 101 crashes involving fire trucks. A similar report in 2013 indicates 843 police vehicle crashes, 198 EMS vehicles, ambulances, and rescue squads crashes, and 101 crashes involving fire trucks. It is important to note that the above rates include crashes involving emergency vehicles, which might also be caused by other vehicles hitting emergency vehicles. However, the trend is in line with other national reports (e.g. NHTSA), which identified police vehicles as being involved in significantly more crashes in comparison to other emergency vehicles.

Between 1921 and 2015, there have been 540 NC police officer deaths in the line of duty. Sixty-eight of these deaths occurred due to automobile accidents. Based on this report, vehicle accidents are the second major cause of law enforcement officers’ death after gunfire (310 deaths). Related to this, Noh (2011) mentioned that the number of law enforcement officer fatalities in motor vehicle crashes shows an increasing trend in NC. His review of crash reports revealed three officer fatalities from 1980 to 1989 followed by 13 fatalities from 1990 to 1999, and 13 deaths from 2000 to 2008.

It is important to note that although several reports identified the number of crashes and fatalities due to automobile accidents in NC, none of these reports provide the exact
number of crashes due to officer distraction, especially in-vehicle distraction. However, law enforcement crash analysis in other states, such as Kansas, Texas, South Carolina, etc., have identified officer in-vehicle distraction as a primary cause of crashes (e.g. Yager, 2015; Abdelwanis, 2013). Consequently, it is plausible that some law enforcement crashes in NC are also caused by driver in-vehicle distraction.

1.1.3 NC State Laws regarding in-vehicle technology use

Some states (e.g. Washington State) have recently banned the use of in-vehicle technologies, such as talking on a phone and texting while driving for law enforcement and other emergency vehicle drivers. However, the NC law regarding use of mobile telephones for text messaging or electronic email (20-137.4A), exceptions are provided for emergency operators. The law states that:

“It shall be unlawful for any person to operate a vehicle on a public street or highway or public vehicular area while using a mobile telephone. The provisions of this section shall not apply to any of the following while in the performance of their official duties: a law enforcement officer; a member of a fire department; or the operator of a public or private ambulance.”

In addition, in another NC law (20-136.1) regarding the location of in-vehicle television, computer, or video players, monitors, and screens, it is said that:

“No person shall drive any motor vehicle upon a public street or highway or public vehicular area while viewing any television, computer, or video player which is located in the motor vehicle at any point forward of the back of the driver’s seat, and
which is visible to the driver while operating the motor vehicle. This section does not apply to the use of global positioning systems; turn-by-turn navigation displays or similar navigation devices; factory-installed or aftermarket global positioning systems or wireless communications devices used to transmit or receive data as part of a digital dispatch system; equipment that displays audio system information, functions, or controls, or weather, traffic, and safety information; vehicle safety or equipment information; or image displays that enhance the driver's view in any direction, inside or outside of the vehicle. The provisions of this section shall not apply to law enforcement or emergency personnel while in the performance of their official duties, or to the operator of a vehicle that is lawfully parked or stopped.”

Based on the above laws, police officers are exempt, and are not only able to text, but can also make use of their computers while driving. For police officers, there are many reasons to constantly make use of dashboard computers. An officer may need to check the license plate of a car he/she is following by using a keyboard to retrieve a screen, type in the plate number, read more about the owner, etc. Therefore, on occasion, officers may need to use in-vehicle technologies, at high speeds.

1.1.4 Emergency vehicle crash rates due to in-vehicle distraction

Some prior research has observed that use of in-vehicle technologies in emergency vehicles might cause driver distraction and reduce attention to the driving task (e.g. Hampton and Langham, 2005). Callander and Zorman (2007) mentioned that vendors of patrol vehicle information systems state that such systems are not designed for use while driving. However,
after interviewing a large sample of officers, they found that all respondents confirmed computer use while driving. The main motivation for officers to use a Mobile Computer Terminal (MCT) while driving is that the technology can provide safety-critical information in timely manner and increase officer awareness of case circumstances while on route. The following are some examples of emergency vehicle crash reports from different states that identified distraction as a main cause of accidents. Yager (2015) collected most of the accident data through public information requests to police departments in different metropolitan areas across United States.

• The Kansas City (Missouri) Police Department reported a total of 181 crashes from 2009 to November 30, 2014 and an average of over 30 per year. They identified distraction as the main reason for these crashes (Yager, 2015).

• The State of Texas recorded 1021 crashes of emergency vehicles from 2010 to 2014 as a result of distraction/inattention (Yager, 2015).

• The Austin (Texas) Police Department reported 48 patrol car crashes from 2010 to October, 2014, which were caused by distracted driving. They mentioned that in 25 of these 48 instances, the police officer was interacting with the MCT while driving, and in 8 other cases, the officers were interacting with a cell phone or other on-board equipment (Yager, 2015).

• The Illinois Department of Transportation (DOT) recorded a total of 137 emergency vehicle crashes that were caused by in-vehicle distraction from 2010 to 2012 (Yager, 2015).
• The South Carolina Department of Public Safety recorded 803 emergency vehicle crashes between the year 2001 and 2010. Fatigue and distraction were mentioned as main causes of these accidents (Abdelwanis, 2013).

• In July, 2012, NBC 5 (Arlington City, Texas) reported an investigation of the number of police vehicle crashes in the past 3 years. They found 18 crashes involving officer interactions with a MCT. Although Arlington did not have any written policy against officers typing and driving at the same time, the city has the toughest laws in the area against texting and driving (Speeding Cops, 2012).

In general, these crash reports provide evidence that divided attention and driver distraction are growing problems for emergency vehicle drivers.

1.1.5 Summary

The above literature and crash reports reveal high emergency vehicle crash rates, especially for law enforcement. These crashes are not only attributable to the need for officers to drive at high speeds in emergency situations, but reports show that crashes are mainly due to interaction with in-vehicle technologies. Although it is suggested that officers not use computers while driving, there is no written law regarding this issue in NC. There are several in-vehicle technologies in police vehicles and most officers confirm using them while driving and identify such operations as part of their jobs.

Although the effect of in-vehicle distraction on driver performance and safety has been documented in many studies, few investigations have focused on distraction in emergency
vehicles. Ironically, the New York Times called police vehicles, “the most wired vehicles on the road”.

1.2 Common in-vehicle technologies in emergency vehicles

Each of type of emergency service has its own type of vehicle and in-vehicle technologies that are used by operators. Based on the crash reports mentioned earlier, law enforcement vehicles are involved in more crashes than other types of emergency vehicles. Therefore, this research is focused on police vehicles and the in-vehicle technologies that are available to officers while driving.

Common law enforcement vehicles include large sedans such as Ford Crown Victoria, Chevrolet Impala, Dodge Intrepid and Charger, and SUVs such as the Chevrolet Tahoe or Suburban (Yager, 2015). The following is a list of common in-vehicle information systems that are used in law enforcement vehicles:

- **Mobile Computer Terminal (MCT):** MCT, mobile data terminal (MDT) or mobile digital computer (MDC) includes a visual display with touch screen capabilities and a keyboard that can also be used for data entry (Filtness et al. 2013). Figure 1 shows a MCT and its location in a police vehicle. The general functionalities of MCTs include: providing information for the officer, serving as a portal for communication among responders, and providing auditory and verbal notifications. In more detail, MCT software includes a map/GPS system, access to call notes (information relevant to a case), current location, assignment of personnel, and a video recording module (Yager, 2015). (Detail on the various tasks that can be performed with MCTs is
provided later in this chapter.) However, MCTs do not provide access to all available law enforcement data mainly due to screen size and cost of information retrieval from wireless networks (Hampton and Langham, 2005).

Figure 1: MCT inside a police car (from http://progressivelawenforcement.com/vintage-policing.html)

- Video cameras: Many police vehicles have video cameras mounted inside the car cab, which can record video and audio. Cameras can tape in front of the police cruiser to provide evidence for capturing and potentially convicting criminals, recording inappropriate police behavior, or videotaping suspects while an officer remains inside the car. Figure 2 shows an example of a video camera in a police car.
Radio systems: Radios are one of the most important communication devices in police cars. Police officers use radio systems to communicate with dispatchers and other responders. Yager (2015) mentioned radio systems as the quickest way for police responders to communicate with dispatchers. In addition, dispatchers are able to communicate with police officers and provide them with information when other information systems, such as MCTs, cannot be used. Figure 3 shows a radio system and a siren control panel (described below) in a police car.
• Siren and light control panel: These systems are usually controlled by buttons or switches. They can also provide haptic feedback to the officer in order to reduce visual attention requirements while driving. These systems can be very complex as a result of several sirens and light combinations that might be used by the officer, dependent on the emergency situation (Yager, 2015). An example of a siren and a light control panel is shown in Figure 3.

• Radar system: These systems are mainly used to measure the traveling speed of nearby vehicles. Two types of radar are used which are stationary and moving. Stationary radar must be used from a static site, typically a patrol car or motorcycle parked alongside the road. However, with moving radar an officer can clock
approaching vehicles while driving on patrol. Figure 4 shows a radar system inside a police car.

![Radar System Inside Police Car](image)

**Figure 4: A radar system inside a police car**

In addition to the technologies discussed above, police officers may also use their personal cellphones while driving. The main benefits of a cell phone for police officers include providing a direct verbal communication link to people who do not have radios and use as a backup when radio signals are weak. In addition, the cell phone provides access to information that can be dispersed to the public or police officers in cases of catastrophic disasters or major community events.
Police in-vehicle technologies are a combination of products from different vendors that are adapted to a vehicle and that may expose the officer to a mixture of inconsistent user interfaces and communication methods (Kurkinen et al. 2010).

1.2.1 MCT usage rate in emergency vehicles

Although MCTs were not originally designed to be used while driving, the interfaces can be used while driving and several police officers confirm using them frequently. Among all in-vehicle technologies in police cars, MCTs are most frequently used for officer performance of in-vehicle tasks (McKinnon, Callaghan, & Dickerson, 2011). In one study, Garrison et al. (2012) found officers spent approximately 7% of their time attending to the MCT display while a vehicle was in motion (i.e., while driving). Related to this, Girouard et al. (2013) found that officers use the MCT approximately 13% of their shift time during a typical workday.

After conducting an on-road study with users of two single-crewed and one double-crewed police car, Hampton and Langham (2005) found that double-crewed cars used MCTs almost twice as often as single crewed cars (41 times in 4-hr period vs. 27 and 21) while driving. They also mentioned distraction due to MCT use as a major concern for officers. In addition, as a part of their study, Yager (2015) conducted an online survey of emergency responders. The responses from Austin-Travis County EMS showed that the most frequently used in-vehicle technology was MCTs (about 10% of on-the-job time) followed by radio and cellphone use. Finally, Anderson et al. (2005) conducted a field study with 121 police officers from British Columbia and observed their activities. The results showed that 77% of
officers used MCTs while driving. In addition, they found that 55% of officers used MCTs while performing at least one other task, and 11% used MCTs while performing at least two other tasks simultaneously. In general, to reduce decrements as a result of multi-tasking, Anderson et al. recommended that both MCT use and driving should be first mastered separately through training and, once automated, tasks can be gradually conducted in combination.

1.2.2 Description of various tasks in MCT

The high frequency of MCT use in comparison to other in-vehicle technologies is attributable, in part, to the capability of these systems to perform several tasks critical to an officer’s duty. The most common task is checking license plate numbers that enable officers to determine if they have cause to stop a vehicle. In addition, plate number check helps officers to find out if the vehicle had been reported stolen or if the vehicle or its occupants match any characteristics of persons with warrants for arrest (Marcus and Gasperini, 2006). Several studies used this task as a basis for MCT usability analysis or driver distraction studies. For example, Filtness et al. (2013) asked participants to search for a license plate number in order to assess the effect of different modalities of MCT information presentation on glance pattern of police officers during driving. In another study, Callander and Zorman (2007) conducted a usability analysis on the plate check task that could be performed through a radio system or MCT. In addition, Mitsopoulos-Rubens et al. (2013) used plate number check as a secondary task during driving in order to assess the potential for voice-based input and output modalities to reduce subjective workload of police officers while driving.
In addition to plate number check, MCTs can be used for communication among patrols. It provides two-way messaging among police cars in order to access status updates on other police cars in the region. In addition, MCTs have a function called “incident list” that allows officers to look through recent incidents to see if any colleagues might need assistance (Hampton and Langham, 2005). The other important application of MCTs is accessibility to call notes. Call notes are information related to a present emergency case.

MCTs can also be used for navigation. They include maps and GPS systems in order to guide officers, who might be unfamiliar with an area. Finally, MCTs can be used to submit records once a situation has been resolved. For this reason, some MCTs also have access to email and limited internet (Yager, 2015). Figure 5 shows a screen shot of a sample MCT.

![Figure 5: Screen shot of a MCT display (from http://mobilenetworksworld.blogspot.com/)](http://mobilenetworksworld.blogspot.com/)
1.2.3 Usability evaluation of MCTs

Although MCTs have been developed extensively by integrating voice recognition systems and touchscreen capabilities, there are still concerns regarding the potential for these devices to contribute to officer distraction. Especially, high police car crash rates, attributed to officer distraction in use of MCTs, motivated several researchers to conduct usability analyses on these devices. Marcus and Gasperini (2006) conducted interviews with six police officers after receiving complaints from the San Jose police department about their new in-vehicle computer system. They found several usability issues with the system such as difficulty in completion of numerous important tasks while driving, reliance on indirect rather than direct controls, a user interface not optimized for touch screens, poor filtering of important information, information poorly laid out, problems with sending and receiving messages, and numerous issues with mapping and routing (e.g. symbols, colors, and text appeared in confusing formats). They recommended user-centered design and considering police officers, who are the users of these systems, in the design process as well as conducting task analyses for understanding what officers actually do in police cars. Related to this, Hampton and Langham (2005) conducted three studies to evaluate MCT use in police patrols. In their last study, which was aimed at quantifying system usability from a telematics point of view, they used a technique called “The safety checklist for the assessment of in-vehicle information systems”. Results of the checklist showed that MCT use is incompatible with driving.

Finally, Callander and Zorman (2007) conducted a usability study to assess police distraction as a result of in-vehicle technology. Combining a NHSTA workload assessment protocol and a cognitive modeling tool called Goals, Operators, Methods, and Selection
Rules (GOMS), they compared the task of plate number check via radio with the same task via computer. The result of GOMS modeling showed that checking the plate via radio dispatch required fewer steps with a minimum of zero and maximum of four off-road glances while the same task with a computer required a minimum of eight and maximum of 27 off-road glances. However, they mentioned that officers still use the MCT since it allows them to receive safety-critical information in timely manner and frees radio for emergency situations. After this assessment, they suggested use of a “project54” system, a speech recognition system, in patrol vehicles. There was only one reported accident after implementation of the new system and the reason was that the officer wanted to login to the system manually while driving and this task was not supported by the speech recognition system.

1.2.4 Summary

There are several technologies that are integrated in emergency vehicles. Based on the literature review, the most frequently used device is a MCT. It can help officers with tasks such as plate number checks, access to call notes, maps, instant messaging, etc. Usability evaluations on MCTs showed several problems with the current technology. Prior studies show that current MCTs do not represent user-centered design but are designed from the perspective of what is most feasible in terms of systems engineering for common function delivery. It was also found that these systems are incompatible with driving task demands. However, several police officers confirmed using MCTs while driving.
1.3 Review of literature on MCTs

1.3.1 MCT effect on distraction and driver performance

Driver distraction has been defined as “diversion of attention from activities critical to safe driving for performance of a secondary competing activity” (Lee, Regan, & Young, 2009). The effect of visual and cognitive distraction caused by in-vehicle technologies on civilian driver performance, and attention allocation has been examined through many studies documented in the literature. For example, Liang and Lee (2010) conducted an empirical study to investigate the combined effect of visual and cognitive distraction on driver performance caused by a secondary navigation task and compared it with only visual or only cognitive distraction effects. Results showed that visual distraction interferes with driving performance more than cognitive distraction, and visual distraction dominates performance decrements during combined distraction. In a more recent study, Kaber et al. (2012) also assessed the effect of visual, cognitive, and simultaneous distraction of an in-vehicle navigation aid on operational and tactical driver behavior. Their results showed that tactical behavior is more demanding in terms of cognitive distraction than operational behavior. In addition, they found that visual and cognitive distraction both increase driver workload but in different ways in terms of vehicle control and gaze behavior.

Liu and Donmez (2011) found that crashes that involved police officer distraction due to in-vehicle sources are more severe than crashes involving civilian driver distraction by in-vehicle sources. In addition, in-vehicle technologies used in emergency vehicles are more complex and demanding than normal cars. However, few studies have focused on visual and cognitive distraction caused by interacting with these devices.
In an on-road study of single and double-crewed police cars, Hampton and Langham (2005) found distraction due to interaction with MCTs as a main concern. On the basis of this research, other studies have focused on assessing the effect of different modalities of interaction on distraction and driver performance. For example, after designing a new integrated MCT with speech recognition capability, Kun et al. (2004) did a field test to compare it with an old system without speech capability. Results showed that officers found the speech user interface (SUI) most useful while driving and the graphical user interface (GUI) most useful when parked. Related to this, in Mitsopoulos-Rubens et al. (2013) simulation study of voice-based input and output modalities for reducing officer workload while driving, three different interface output-input modalities were tested, including: visual-manual, visual-voice, and audio-voice. Results showed that the visual-manual interface required more time and posed physical demand and it was reported as hardest to use in comparison to the other two interfaces. They also found that the visual-manual interface was associated with significantly more eyes-off-road time than either of the two voice-based interface types, and significantly more long, safety-critical glances. Performance on the license number task was also worst when participants used the visual-manual interface. Filtness et al. (2013) also found that visual-manual and visual-voice interfaces resulted in significantly more glances to the MCT display than an audio-voice interface. For longer duration glances, the visual-manual interface caused significantly more fixations than baseline or audio-voice interfaces.

Although all the studies above found benefits of using speech and voice based interaction styles with MCTs, Lee et al. (2001) assessed the effects of a speech-based email
system on driver performance and found that reaction-time increased when the speech-based system was used. In addition, they found that speech based interaction introduces a significant cognitive load for drivers. Although their study was not in the context of emergency vehicle operation, their task was similar to tasks that can be done with MCTs in emergency vehicles. Therefore, this study supported the observation that using speech-based interaction may not actually reduce driver distraction.

Finally, it is important to note that although several studies have found using MCTs to increase officer distraction, results of a study by Williams et al. (2013) supported the use of in-vehicle technology to help remember current situational data. They conducted a driving simulation study to assess both the communication format (ten codes vs. natural language) and presence of support technology (a text display repeating information from a call for service vs. no repetition of a call). Results showed that, in terms of lane variability and situation awareness responses, the most demanding condition was ten-codes with a static display. However, it should be noted that the MCT in this experiment was basically used for presenting detailed information about a received call and the officers did not have any other interaction (e.g., typing) with the device, which might not actually represent real situations. Therefore, Williams et al. (2013) did not see any negative effect of in-vehicle devices on driving performance and situation awareness.
1.3.2 MCTs and context of work

Besides the studies that focused on different modalities of information presentation in MCTs, there is some research that has focused on understanding the relationship between the context of work and the use of in-vehicle technologies for emergency vehicles.

Sørensen and Pica (2005) conducted a 7-month observational study of operational police work in a British constabulary in order to describe the relationship between work activities and use of mobile technologies by police officers. They defined five main operational policing activities as: standing-by in car before incident, driving to an incident, taking action at the incident, driving from the incident, and standing-by in car after an incident. For the categories of driving to an incident and driving from the incident, in both traffic and response vehicles, MCTs and radios have the highest levels of use by police officers.

Related to driving to an incident, the information needed for response vehicles and traffic officers are mostly destination, risk assessment, vicinity and status of other vehicles. Related to driving from the incident, the most information needed by response vehicles is status of custody and active incidents queue. The most needed information for traffic officers is hot spots, status of custody, and active incidents queue.

In another study, Streefkerk et al. (2006) designed a personal attentive user interfaces (PAUI) for which the content and style of information presentation was based on cognitive capacity, task, context and user aspects. Based on their review of literature, the authors came to a conceptual design in which modality of information presentation, amount of information presented and task switching is supported by the priority of information. They also
mentioned that context features such as location, time, and elements from the environment should be considered in the design of interfaces in the mobile public safety domain. Finally, the authors recommended that user aspects such as preferences, duties, expertise should also be considered in the design.

In a more recent study, Kurkinen et al. (2010) developed a prototype called SUMO (Situational Updates from Mobile Officers) that recognizes the cognitive/attentional demands of officers while driving and that the user interface itself could adapt such that required interactions are optimal for user expected states. The system worked based on gathering information from in-vehicle sensors to determine data such as location, speed, pursuit (light/siren activation), combined with a physical keypad and virtual symbolic keypad for entry of standard status information.

1.3.3 Summary

Despite the fact that in-vehicle technologies in emergency vehicles are more complex than the normal cars, and crashes due to distraction caused by these devices are more severe than civilian driver crashes, few studies have focused on this topic. Published studies have mainly concentrated on the effect of different modalities of driver performance. Some of these studies have advocated for using speech-based interaction between an officer and a MCT as a potential solution for reducing officer distraction. Some other potential solutions include using automated vehicles or automating important tasks for officers while driving (e.g., use of automated license plate recognition systems). Finally, the review of literature showed that MCTs should be designed based on the context of work and user requirements.
1.4 Knowledge elicitation

1.4.1 Definition

Knowledge elicitation is defined as “the process of explicating domain specific knowledge underlying human performance” and is considered part of a knowledge acquisition process (Cooke, 1999). It consists of techniques and methods that aim at eliciting knowledge of domain experts especially through some forms of direct interaction. Christou et al. (2009) said that knowledge required for performing a task can be obtained using knowledge elicitation methods and this can be used to conduct with various cognitive models.

Knowledge elicitation was introduced in the mid to late 1980's in the context of knowledge engineering for expert systems. Researchers began to develop different knowledge elicitation methods with many coming from cognitive methods and other fields such as education, anthropology, etc. (Cooke, 1994). However, it is important to know the advantages and limitations of each technique in order to understand which technique is best for a specific application. In addition, due to the limitations of individual methods, several studies have implemented a combination of elicitation techniques to better incorporate user and domain considerations in design process (e.g. Blandford and Rugg, 2002). Some of the most important knowledge elicitation techniques are described in more detail below.

1.4.2 Methods

Cooke (1999) identified four general categories of knowledge elicitation techniques including: observations, interviews, process tracing, and conceptual methods. The following subsections present examples of methods in each category.
1.4.2.1 Observations

Observations can provide general impressions of a task. Cooke (1994) identified observations as the most powerful tools of knowledge elicitation. Observations can occur in the field or be performed in a simulated context. Observations may be different in terms of what is being observed (e.g., specific events), the observer’s role (passive or participatory), and the method of recording (video, photos, audio, etc.; Cooke, 1999). The main advantage of observations is that they tend to interfere minimally with task performance. In addition, observations provide more details on how people interact with different systems as compared to other knowledge elicitation methods. For example, by observing different people using interactive tables, Ryall et al. (2006) could find several common usage patterns that help them to further improve the design. Although the main disadvantage of this method is that it takes a lot of time and effort and produces a huge amount of data, there are some observation methods (e.g., discount user observation) in which are aimed at making the process more efficient using a more detailed procedure (Wixon et al., 2002).

1.4.2.2 Interviews

Interviews usually occur in the early stages of elicitation. There are two general approaches to interviews, including: unstructured and structured interviews. Structured interviews follow a predetermined content while unstructured interviews are basically free-flowing (Cooke, 1999). Shadbolt and Smart (2015) said that although unstructured interviews allow elicitors and experts to discuss the domain without any constraint, such interviews can lead to collection of irrelevant data. The advantage of structured over unstructured interviews is that
they provide more complete coverage of a task. In addition, they provide structured data that is easier to analyze than unstructured conversations between an expert and analyzer. However, the disadvantage of this approach is that it requires substantial preparation to determine interview format. Agarwal and Tanniru (1990) conducted an experiment to extract knowledge in a managerial decision making domain and made comparison of unstructured and structured interview methods. Results revealed structured interviews to increase the efficiency of knowledge acquisition, and extract more subjective and qualitative knowledge than unstructured interviews. Interviews are easier to administer than other knowledge elicitation methods. However, there are some trade-offs in using this technique. For example, Cooke (1994) mentioned that verbal reports are usually unreliable and more information can be obtained by observation. In addition, Shadbolt and Smart (2015) said that interviews capture only verbalized aspects of the domain. However, if there are non-verbalized sections in a task, it is probable that interviews cannot capture them. Therefore, they recommend supplementing interviews with additional elicitation methods to get more valid data.

1.4.2.3 Process tracing

Process tracing is the collection of sequential behavioral events that leads to inferences regarding cognitive processes. Process tracing techniques can be categorized based on their timing with the task. They are either concurrent or retrospective reports. The think-aloud technique is a contemporary process tracing method and has been used in several studies to understand user interaction with interfaces. For example, Jaspers et al. (2004) found that think aloud technique in early stages of the design cycle is an efficient method to enhance the
1.4.2.4 Conceptual methods

Cooke (1999) defines conceptual methods as techniques that “represent conceptual structure in the form of domain-related concepts and their interrelations”. A technique for conducting this knowledge elicitation method is called “concept sorting”. In this technique, an expert is presented with some cards containing concept words. The expert is then asked to group the cards into piles that (s)he feels appropriate. This process is repeated many times. After this process, the analyst tries to extracts some decision rules based on the relationship of concepts that the user identified (Shadbolt and Smart, 2015). Concept sorting processes can be manual or automated. Rugg et al. (1992) compared three versions of concept sorting, including item sort, a card sort, and a computerized label sort. There was no significant difference in the knowledge elicited among different methods. The authors concluded that computerized sorting procedures elicited the same knowledge as manual sorts. Although the method is easy
and quick to conduct in comparison to other knowledge elicitation methods, Cooke (1999) mentioned concept sorting as an indirect method, which is focused on comparison and assessment using conceptual structures.

1.4.3 Knowledge elicitation in driving research

Knowledge elicitation methods have been used previously in driving research area for analysis and redesign of in-vehicle technologies. For example, Leshed et al. (2008) assessed in-vehicle navigation systems by conducting semi-structured interviews and direct observations with GPS users. Using knowledge elicitation methods, Leshed et al. found that navigation system use while driving changed driver interaction with their surrounding environments. Related to this, Jensen et al. (2010) used field observations to investigate how different modalities of navigation system outputs (i.e., auditory, visual and auditory-visual) affect driver behavior. Results revealed that visual outputs increased eye glances and impaired driver performance. In addition, drivers preferred auditory-visual output over other modalities. Finally, Karvonen et al. (2006) used interviews and think-aloud technique combined with quantitative data to assess the effect of using ubiquitous computing in vehicles. After analyzing drivers’ comments from the think-aloud process, the authors found that novice drivers considered the system to be more useful than the experienced users. In addition, the results of structured interviews showed that drivers had a positive opinion regarding the system.
1.4.4 Summary

In general, knowledge elicitation methods are useful for developing models of expert cognition in performing certain tasks. Observation and interview methods are usually conducted in initial phases of knowledge elicitation to better define the domain and characteristics of certain tasks. Process tracing methods assess cognitive structure related to task performance whereas conceptual methods focus on conceptual knowledge of a task. In addition, the review of literature revealed a number of studies which used knowledge elicitation techniques to understand drivers’ interaction with in-vehicle systems.

1.5 Usability evaluation

1.5.1 Usability definition and principles

Usability is a general term concerning the effectiveness, efficiency and satisfaction with which users achieve goals with an interface (International Organization for Standardization, 1998). There are many principles of usability identified in the literature (e.g. Dix et al. 2004), ranging from interface learnability, flexibility, robustness in functionality, capability for error recovery, etc. A more detailed list of usability principles was published by Molich and Nielsen (1990). These principles include: simple and natural dialogue, speak the user’s language, minimize the user’s memory load, be consistent, provide feedback, provide clearly marked exists, provide shortcuts, provide good error messages, and error prevention. It is important to note that all of these principles may not be applicable to a specific analysis. In order to design a usable system, the designer needs to identify the users, describe the context in which the system will be used, describe the task, critique the design in terms of identifying
usability violations, redesign the system based on consideration of usability principles, and finally evaluate the revised system using usability evaluation methods (Dix et al. 2004).

1.5.2 Usability evaluation methods

Usability analysis methods can be classified in two main categories: walkthrough and non-walkthrough methods. Walkthrough methods require predefined activity sequence and include Cognitive Walkthrough (CW) and Goals, Operators, Methods, and Selection Rules (GOMS). The CW is a method for evaluating user interfaces by analyzing the mental processes required by users (Lewis and Wharton, 1997). In this method, the system designer role plays a novice user to determine if the user’s mental model will allow for identification of correct action at each step in the cycle of interaction. However, the CW is not applicable to systems used by experts and the designer must have a clear concept of the user’s mental model to answer questions appropriately. On the other hand, GOMS focuses on trained user performance assessment. With respect to the present research, GOMS may be more applicable to emergency vehicle operators since they are usually highly trained in using in-vehicle technologies and they can be classified as expert users. More details on GOMS are presented below.

Non-walkthrough methods do not require a particular sequence of activities to be defined. Heuristic evaluation is an example of a non-walkthrough method. In this method, domain experts or usability professionals subjectively evaluate a system interface. However, the disadvantages of this method are that it focuses on problems and not potential solutions.
In addition, such analysis is not conducted within a particular context and different evaluators may identify different sets of problems using this method (Dumas, 2002).

Another category of usability evaluation method is user-based evaluation. Dumas (2002) defines user-based evaluation as “evaluations in which users directly participate.” One of the most important user-based evaluation methods is usability questionnaires. The advantages of questionnaires include the ability to reach a large population, such that a data set might be sufficient for statistical analysis. Dumas (2002) also identifies the main objectives of usability questionnaires to be a short user evaluation that should provide an absolute measure of the subjective usability of a product.

Since different evaluation methods might reveal different usability problems with an interface, these methods should be used in combination whenever possible. The following subsections describe usability evaluation methods in more detail.

1.5.2.1 Goals, Operators, Methods, and Selection rules (GOMS)

Engineering models must address a useful range of design issues. Activities performed by people interacting with computer systems are quite varied, ranging from simple perceptual-motor actions such as pointing with a mouse to extremely complex activities such as comprehending textual or pictorial material. Proposed by Card, Moran, and Newell (1983), GOMS analysis has become one of the most well-known theoretical modeling approaches in human-computer interaction (HCI) literature. The general motivation for GOMS and other cognitive modeling techniques is to provide a model of human performance such as learning time, execution time, errors, etc. The GOMS model family ranges from simple Keystroke-
Level Models (KLM) to more detailed models, such as Natural GOMS Language (NGOMSL), and Critical Path Method GOMS (CPM-GOMS). John and Kieras (1996) compared four variations of GOMS models, including KLM, CMN-GOMS, NGOMSL and CPM-GOMS. They found NGOMSL to be the most flexible form of GOMS models. GOMS analysis has a wide range of applications in different domains ranging from routine tasks such as text editing, and spreadsheet use (Lerch et al. 1989) to the analysis of touch screen interfaces (Rice and Lartigue, 2014).

1.5.2.1.1 Description of method

GOMS stands for Goals, Operators, Methods, and Selection Rules. A GOMS model consists of descriptions of the methods needed to accomplish specified goals. In general, methods include steps that consist of different operators that a system user would perform. Methods may include sub-goals and they may have a hierarchical structure. If there is more than one method to reach a goal, then selection rules are used to model user selection of the appropriate method depending on the context (Kieras, 1999). It is important to note that GOMS models do not replace task analysis but are based on task analysis. An analyst must conduct a task analysis to identify user goals and how they may want to accomplish goals using the target system.

Advantages of the GOMS modeling method include a breakdown a user interaction with a computer in terms of elementary actions. This breakdown allows for prediction of the time an expert user takes to perform the composite actions of retrieving information from memory, choosing from alternatives, keeping track of what needs to be done, and executing
motor movements. In addition, the most important benefit of GOMS models is the ability to provide designers with quantitative information about the system in early stages of the design cycle without the need to run costly trials (Dix et al. 2004).

In order to make performance predictions, GOMS assumes tasks as a serial sequence of cognitive operation and motor activities. Each of these tasks has an associated time estimate. These estimates generally come from empirical data on people performing several tasks such as text editing, etc. Numbers may also be generated from regression models. Several studies have proposed times for various computer-interaction tasks (e.g. Olson and Olson, 1990) based on data from previous similar tasks reported in the literature. These times are also used to predict performance on new tasks.

Using the GOMS method, task can be analyzed in high detail including classification of operators in three main categories: Perceptual (P), Motor (M) and Cognitive (C). Perceptual operators are basically divided into two categories: visual and auditory. Motor operators include: moving hands, using a mouse, keyboard entry, etc. Memory and cognitive processes mainly include memory retrieval, executing steps in a mental procedure and choosing among methods (Olson and Olson, 1990). In addition, GOMS operators can include multiple processing resources (e.g., perceptual and cognitive). For example, the ‘look for’ operator in GOMS model coding represents a combination of perceptual and cognitive channel/resource use. GOMS models also provide the capability to identify which, if any operators, during the performance of a task may occur in parallel with each other. For example, visual perceptual operations, such as viewing a screen, may occur simultaneously with manual motor operations, such as positioning a mouse pointer. Coding of serial and
Parallel operations as part of methods is critical to ensuring accurate model predictions of performance times.

1.5.2.1.2 GOMS in driving research

Salvucci (2001) claimed that application of GOMS models are focused on primary-task interfaces rather than secondary-task interfaces in the presence of a performance-critical primary task. However, the GOMS family of models has been used a lot in the driving literature in order to assess in-vehicle technology use as a secondary task. For example, Manes et al. (1998) used KLM and empirical study of drivers interacting with an in-vehicle navigation system. They found a strong correlation between observed and model predicted times. In a more recent study, Quaresma (2012) also used an extended KLM model to assess the visual demand of typical data entry tasks with two navigation systems. Related to this work, Pettitt et al. (2007) assessed the potential distraction of in-vehicle information systems by developing an extended KLM model to predict measures based on a visual occlusion protocol. Their results showed significant correlations between observed and predicted performance results. In another study, Manes and Green (1997) used a GOMS model to assess driver use of a menu system while driving. Results showed that GOMS could predict driver performance with hierarchical menu systems. Liang and Lee (2010) also defined the nature of their in-vehicle secondary task (whether visual, cognitive or a combination) by using GOMS models.

However, as mentioned earlier, the only study that used GOMS to analyze police distraction as a result of in-vehicle technology was Callander and Zorman (2007). As
previously mentioned, this study compared the task of plate number checking via radio with the same task via a computer.

1.5.2.1.3 Limitations of GOMS

Although GOMS is a well-defined method and has many advantages, such as providing good quantitative estimates of performance times for expert users, there are some limitations regarding the method and its assumptions. The most detailed accounting of GOMS limitations was identified in the original GOMS framework by Card et al. (1983). Some of these limitations include:

- The application of GOMS model is only for skilled users.
- The model does not account for errors that might occur even for expert users.
- Models assume that all tasks occur via in a serial sequence unless otherwise specified.
- Models do not account for individual differences among users.

Some of the above limitations have been addressed by extensions of the original form of GOMS modeling. For example, Kieras and Polson (1985) modified the KLM method to consider differences in performance from different levels of expertise. The new model could consider both the time to learn new procedures and the transfer of training between procedures.

One of the most critical limitations of GOMS is the assumption of serial tasks. This assumption simplifies the modeling process since total task time becomes the sum of the times of a number of operations in a method. In addition, some early works on cognitive modeling confirm that much cognitive activity is serial in nature (e.g. Newell and Simon,
However, in many tasks, the key components of performance may happen in parallel. For example, a police officer may read information on a MCT screen, translate the information to motor output, and type characters while (s)he continues to read the screen. In addition, in some tasks, there are dependencies among subcomponents. For example, a telephone operator helping a customer cannot hit the collect-call key until (s)he hears the customer request a collect call. Some of these issues have been solved by other variations on the GOMS modeling approach. The original GOMS methodology, referred to as CMN-GOMS, is the ancestor of a family of GOMS models that were elaborated later. Among them are Critical Path Method GOMS (CPM-GOMS) and GOMS Language (GOMSL), which will be described in more detail below.

1.5.2.1.4 Critical Path Method GOMS (CPM-GOMS)

The acronym CPM stands for both the Cognitive-Perceptual-Motor level analysis and Critical Path Method. Unlike the other GOMS methods, CPM-GOMS does not assume that human-system interaction is a serial process. Therefore, CPM-GOMS can be used to model multitasking behavior that can be exhibited by experienced users.

The idea of using CPM for representing non-serial cognitive processes was first proposed by Schweiickert (1978, 1980). John (1988) proposed using CPM in the HCI domain by analyzing a typing task. CPM is a tool from operations research that allows specification of component processes, their duration, and the dependencies among them. CPM-GOMS is a cognitive modeling method that can be used to predict times for processes that have parallel components. Related to this, in a review of cognitive modeling literature, Harvey et al.
(2011) identified CPM as a method that could be used for usability evaluation in the context of driving. However, John and Kieras (1996) found that quantitative predictions using CPM-GOMS are much shorter than KLM, CMN-GOMS, and NGOMSL. They said that the difference is attributable to the CPM-GOMS assumption of extremely experienced users. Consequently, the modeling approach might be most accurate for representing expert driver behavior. John and Kieras also identified CPM as a powerful but relatively unspecified multiple parallel processor and said CPM-GOMS models are too detailed for tasks that could otherwise be usefully approximated by serial operators.

CPM-GOMS models were first generated manually by creating PERT charts of complex system operator cognitive functions (e.g. Gray and Boehm-Davis, 2000; Gray et al. 1992). Later, some other studies proposed software tools to generate CPM-GOMS models and to automate the modeling process. For example, Patton et al. (2012) used a method to transform experimental data into CPM-GOMS models using the Stochastic Analytic Network Laboratory (SANLAB). This extension, which was labeled LogAnalyzer, could generate CPM-GOMS models from human performance data. Comparing the results of these automatically generated models with Gray and Bohem-Davis (2000), they found the overall critical path times to well match the previous predictions.

In another study, Matessa et al. (2002) developed CPM-GOMS models using Apex, which was first introduced by Freed (1998). Apex is capable of manipulating serial and parallel tasks in CPM-GOMS format. Using Apex, they built reusable templates of common behaviors that could be used directly in other cognitive models and reduced the amount of effort that is usually needed for building complex models.
Although substantial effort has been committed to automating the models using templates and software, the most serious drawback of CPM-GOMS is the difficulty of constructing models at this level of detail.

1.5.2.1.5 GOMS Language (GOMSL)

GOMSL is an executable form of Natural GOMS Language (NGOMSL) and provides a structured language notation for developing cognitive task performance models (Kieras, 1999). Although the traditional GOMS models were written in natural language, GOMSL models are computer code that can be run to simulate human behavior. GOMSL provides a structured language that allows GOMS models to be executed with computer hardware and software, but at the same time supports analyst readability and use in human performance evaluations (Kieras, 2003). In addition, task analysis methods such as Hierarchical Task Analysis (HTA) do not provide a detailed structured language like GOMSL. Using GOMSL, it is possible to identify different perceptual, cognitive, and motor operations as a part of task performance.

Several studies have used GOMSL as a computational cognitive modeling tool. For example, Kaber et al. (2011) used GOMSL in order to compare the usability of two interface prototypes in life science domain. The GOMSL model showed improvement in terms of performance with the new interface as compared to the existing high-throughput screening interface. In addition, the cognitive outputs were correlated with actual performance data, which indicated that the cognitive modeling approach was useful for assessing the usability of interfaces in the life science automation domain. In another study, Kaber and Kim (2011) used a refined GOMSL model to assess the effect of auditory cuing in an adaptive
automation system on human performance. The refined model considered human parallel processing in dual-task performance. Results showed that the refined model could accurately describe human performance and the reaction time (RT) predicted by the model was close to the actual human RT. They concluded that the refined GOMSL model, which considered parallel processing, could represent actual human behavior in a dual-task piloting simulation.

Finally, in a more recent study, Swangnetr et al. (2014) also used GOMSL to model manual and automated procedures in life science processes. By conducting a field study with three lab technicians and using a GOMSL model, they found positive correlations between GOMS operation counts and timings and NASA-TLX ratings. The most demanding tasks revealed by GOMSL and the NASA-TLX were considered as focal points for process automation.

Finally, Morgan et al. (2005) identified GOMSL as a modeling method that is much simpler than other cognitive modeling languages, such as ACT-R (Anderson and Lebiere, 1998).

1.5.2.2 Questionnaires

Questionnaires are user-based evaluation methods that can be used as stand-alone measures of usability or they can be used with other methods. There are two types of questionnaires including: short and long forms. Short questionnaires are developed to obtain a quick measure of usability from users. On the other hand, longer questionnaires can be broken-down into more specific subscales (Dumas, 2002). Short questionnaires include a three-scale questionnaire that was developed by Lewis (1991), and the software usability scale (SUS) first developed by Brooke (1996). An example of longer questionnaires is the computer user satisfaction inventory (CUSI), which was developed by Kirakowski and Corbett (1988).
Questionnaires are desirable usability evaluation methods because they provide cost-effective, easy, and practical subjective measures of system usability. Among all these methods, SUS has been identified as a simple usability scale and has been used widely in the HCI literature (e.g. Kortum and Bangor, 2013). In addition, Harvey et al. (2011) included the SUS in a usability evaluation toolkit for in-vehicle information systems. The scale has also been used in assessing in-vehicle technology displays (e.g. Cuřín et al., 2011). This method is discussed in more details below.

1.5.2.2.1 System usability scale (SUS)

The system usability scale (SUS) was first developed by Brooke (1996) as a “quick and dirty” rating scale to allow an analyst to quickly and easily assess the usability of a product. The SUS has several advantages that make it a good choice for general usability evaluation of an interface. Bangor et al. (2008) mentioned some of these advantages, including:

- The survey is flexible for assessing a wide range of interface technologies.
- The survey is easy and quick to use both by users and administrators.
- The survey provides a single score that can be easily understood by most people.
- It is non-proprietary, which makes it a cost effective tool for usability evaluation.

The SUS is based on a Likert Scale. It consists of 10 questions which users are asked to rate on a scale from strongly disagree to strongly agree. This method can be used as a stand-alone evaluation method or in combination with other usability evaluation methods (Dumas, 2002). The form for the SUS is shown in Appendix F.
Scoring the SUS is easy. It provides a single number that represents a composite measure of overall usability of a system. To calculate the SUS score, there is a need to calculate the sum of score contributions from each item. Each item score ranges from 0 to 4. SUS scores have a range of 0 to 100 where higher scores indicate better usability. Brooke (1996) describes the scoring process of SUS in more detail.

1.5.3 Summary

The GOMS family of cognitive task performance models has been used extensively as a usability evaluation tool in the HCI domain. Some variations of GOMS have also been used in driving research to analyze driver interactions with in-vehicle technologies, as secondary tasks. However, one of the limitations of traditional GOMS models is the assumption of serial tasks. In many tasks, the key components of performance may occur in parallel. CPM-GOMS models can be used for non-serial processes; however, these models are difficult to construct. Instead, GOMSL which is a computational version of NGOMSL, is considered to be a flexible and simple method. Several studies have validated GOMSL models with actual user performance data and found the models to have high accuracy. In addition, some studies have extended GOMSL to consider parallel task performance in order to be able to predict dual-task time more accurately.

Questionnaires are also useful and easy to use usability evaluation methods. The SUS is a usability survey that has been applied in many studies. It is a simple questionnaire for both users and analysts. Since different evaluation methods might reveal different usability
problems with interfaces, questionnaires and cognitive task performance models can be used in combination whenever possible.

1.6 Decision analysis

Decision analysis is basically a management technique in which statistical tools such as decision trees are applied to the mathematical models of real-world problems. The objective of a decision analysis is to discover the most advantageous alternative under a given set of circumstances. Howard (1988) defines decision analysis as a process in which a decision maker is faced with a real opaque decision problem and the decision analysis applies sequences of transparent steps to provide clarity on the problem and to help the decision maker to undertake the recommended action. Decision analysis is explicit as it requires a decision maker to break-down a problem into components while maintaining awareness of the broader operating context. In addition, it is a quantitative method as it uses probabilities of occurrence to reach the best decision. Finally, decision analysis is a prescriptive rather than a descriptive method, which identifies for a decision maker what action should be taken given specific conditions.

There are many useful frameworks by which to structure a decision making process but decision trees and matrices are among the most convenient tools for comparing decision alternatives on the basis of utility functions or expected values (Salvendy, 2012).
1.6.1 Decision tree analysis method

A decision tree is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. Decision trees are commonly used in operations research to help identify a strategy most likely to reach a goal. A decision tree consists of nodes and branches (Figure 6). A decision node is a point where a choice must be made. The branches extending from a decision node are decision branches with each branch representing one of the possible alternatives or courses of action available at that point. The set of alternatives must be mutually exclusive and collectively exhaustive. Each branch has a probability associated with it, which is the probability of reaching that outcome. Probabilities can be obtained directly from data or can be calculated using probability theories such as Bayes’ theorem. In addition, each node has a value associated with it, which indicates the expected outcome of that particular node.

One strategy that can be used in making decisions under risk is the expected monetary value (EMV) approach. Many persons are willing to act on the basis of EMVs. The expected monetary value of each decision alternative is calculated by multiplying the probability of each outcome by the outcome’s associated payoff and summing these products for each decision alternative, producing an EMV for each decision alternative. The decision maker compares the EMVs for the decision alternatives and selects the alternative with the highest EMV. Thus, decision trees can be classified as normative models of decision and represent humans as rational decision makers. They do not account for human biases and heuristics in decision making (Wickens, 1992).
1.6.2 Application

Decision trees are used in many disciplines, including medical diagnosis, artificial intelligence, game theory, engineering, and data mining. Beside these applications, decision trees have also been used in driving research. For example, Harb et al. (2009) assessed driver, vehicle and environmental characteristics associated with crash avoidance maneuvers. Using decision trees and a random forest method to rank the importance of these characteristics, they found that drivers’ visibility obstruction, drivers’ physical impairment, drivers’ distraction were associated with crash avoidance maneuvers. In another study, Zhang et al. (2004) used a machine-learning-based design process using decision trees for driver cognitive workload estimation. Using this method, they were able to predict the cognitive workload of drivers with an accuracy of more than 81%.
Although decision analysis methods have been used extensively in the operations research literature, there are few studies in the human factors and usability evaluation domain that used these techniques. In addition, there has been no application of decision analysis tools to emergency vehicle driver distraction and in-vehicle technologies use.

Kieras (1994) mentioned that the range of real-world tasks that can be analyzed using cognitive modeling methods is very large and there is a need to limit consideration to a subset of possibilities. He recommended choosing a set of tasks that: (1) include major methods of the target system, (2) are performed with high frequency, and (3) are important to perform quickly and accurately. Decision analysis techniques and especially decision trees can be very helpful in order to identify the most important and frequently used tasks for further analysis with cognitive models such as GOMS.

1.6.3 Summary

Decision analysis methods especially decision trees are widely used techniques in the operations research area for identifying the most beneficial outcome among all potential options. These methods can also be used in the human factors area, especially in studies related to driver distraction and safety, in order to identify the most important contributors to accidents and driver safety.

1.7 Workload assessment techniques

The study of workload is not a new topic with contemporary measures having been developed in the 1980s (e.g., Hart & Staveland, 1988). Workload is an important concept in
most industries in which management attempts to balance productivity and profit objectives with the need to minimize workload and ensure safety for workers. The solution to this problem is to determine a way to accurately measure workload, determine what levels of workload are excessive, and to associate appropriate controls with such levels.

At first, the concerns regarding workload were mainly focused on physical workload (Miller, 2001). However, nowadays, most physical work such as heavy lifting and moving is done with machines. In current human-machine system design, there is a focus on cognitive workload of operators (Gil et al., 2012; Kaber et al., 2007). Even though the topic of cognitive workload is well-known, there is no single definition of workload. This situation is primarily due to the growing number of causes, consequences and symptoms of workload that have been identified. In addition, defining the concept of workload is not a sufficient basis for control. There should be ways to measure cognitive workload. Since there is no one accepted definition of workload, there is no single accepted approach to measurement. For this reason, workload measures are usually a combination of different dimensions. It is assumed that some combination of these dimensions is likely to represent the “workload” experienced by most people performing most tasks.

There are three main classifications for measurement of workload, which include physiological, subjective and performance-based measures. Physiological workload measures are related to continuous measurement of physical responses of the body. Subjective measurement of levels of workload is based on the use of rankings or scales to measure the amount of workload a person is feeling. Finally, performance measurement of workload relies on examining the capacity of an individual by means of a primary or secondary task.
However, research has not revealed high correlations among subjective, physiological, and performance measures. For example, Hicks and Wierwille (1979) compared five methods of measuring mental load, including heart rate, primary and secondary task performance, and subjective ratings. They found that primary task performance and subjective scales were better in terms of measuring workload. However, the correlation among these measures was small.

The following subsections are mainly focused on subjective measures of workload. Although physiological measures might be more precise, subjective workload measures are more practical. In addition, since human–machine systems have become more complex and automated, evaluations based on operator performance have become difficult and there is a need to assess workload subjectively. Yeh and Wickens (1988) identified subjective workload measures as the easiest, most flexible and least expensive methods for assessing workload. However, they also said that a drawback of these measures is that they do not provide continuous measures. Subjective workload measures are often administered at the end of task performance. It is possible that people may forget the amount of workload they were feeling during a particular segment of a task if the delay between performance and measurement is substantial.

Several subjective measures have been identified to measure workload. One of the most common techniques called the subjective workload assessment technique (SWAT) was introduced by Reid and Nygren (1988). It is a multidimensional scaling method that is designed for measuring loads as a result of time, mental effort and stress. However, it has some disadvantages such as not being sensitive to low workload conditions and it requires a
time consuming pre-task card sorting procedure. Another subjective workload measure is Modified Cooper-Harper (MCH) scale. It is a 10-point unidimensional rating scale that gives a global rating of workload (Hill et al. 1992). However, there have been contradictory results regarding its validity and sensitivity. Although some studies found the method to be a good estimator of mental workload (e.g. Casali et al., 1983), some others found that the scale is hard to complete and it was not sensitive to task difficulty manipulations (e.g. Hill et al. 1992).

Hill et al. (1992) compared four subjective workload measures including the MCH, NASA Task Load index (NASA-TLX), SWAT, and Overall Workload (OW; i.e., a subject’s rating of overall workload on a unidimensional scale from 0 to 100). Their results showed that the NASA-TLX had the highest factor validity, which indicated the greatest correlation with actual operator workload and the TLX was also rated as the best method for representing workload. More details about this method are discussed below.

1.7.1 NASA Task Load Index (NASA-TLX)

The NASA-TLX was developed by Hart & Staveland (1988). The method measures workload in terms of six dimensions, including mental demand, physical demand, temporal demand, performance, effort, and frustration. The method originally consisted of two parts. The first part consists of a description for each of the subscales, which subjects are asked to read. They are subsequently asked to make 15 pair-wise comparisons of demands. In the second part of the measurement, each of these six dimensions are rated for each task on a
100-point range with 5-point steps. There are paper-based and computerized versions of this technique.

Although The NASA-T LX was originally designed to assess pilot workload in the aviation domain, a review of literature by Hart (2006) showed that the method was also used in studies related to the medical profession, automobile drivers, and users of computers and cell phones. Since workload is multidimensional construct (e.g., physical and cognitive demands), workload responses depend upon the type of task being performed. Therefore, several of these previous studies focused on modifying the NASA-T LX for application to specific domains. One of the revised versions of the NASA-T LX is called the Driving Activity Load Index (DALI) and it is adapted to the task of driving. The objective of applying this method instead of the NASA-T LX was to develop a test that is better able to assess driving workload. This method is discussed more below.

1.7.2 Driving Activity Load Index (DALI)

DALI is a method to measure subjective workload, specifically in a driving context. It was first developed by Pauzié and Pachiaudi (1997). The basic concept of DALI is the same as the NASA-T LX. In both of these methods, a scale rating procedure is defined for six pre-defined factors and it is followed by a weighting procedure to come to a global score (Pauzié, 2008). The most important difference among the methods is the unique set of DALI demand components to promote applicability to the driving domain. For example, the ‘physical demand’ component of the NASA-T LX are not very relevant to the driving activity where maneuvers are not physically demanding especially in modern cars. In addition, the
‘cognitive demand’ component of the NASA-TLX refers to both perceptual and cognitive aspects of workload but DALI identifies these various modalities in the context of driving. DALI has six workload dimensions including effort of attention, visual demand, auditory demand, temporal demand, interference, and situational stress. The description of factors and the questionnaire for this method are shown in Appendix A. It is important to note that DALI can be used to measure driving workload while performing a secondary task. Specifically, the ‘interference’ demand component can be used to parse-out workload due to possible disturbances in officer driving task performance as a result of interacting with in-vehicle technologies. For all the workload demands (except ‘interference’), participants are asked to subjectively rate their workload level for the entire driving scenario (i.e., driving and any secondary task performance).

1.7.3 Summary

There is no single agreed-upon definition of workload. Therefore, workload measures are usually a combination of different capacity and demand observations and/or ratings. Among all the measurement techniques, subjective measures of workload are the most practical method. DALI, which is an extension of the NASA-TLX, can be used in determining workload specifically in the driving domain.
1.8 Problem Statement

1.8.1 Limitations of existing literature

The review of literature on emergency vehicles revealed a large number of crashes in different states of the U.S. Moreover, it was found that police vehicles are involved in more crashes than EMS vehicles and fire trucks. This is surprising since police officers are required to pass a skill-based police driving course and they have more driving experience and training. On the other hand, police vehicles are more frequently involved in very high speed and potentially dangerous maneuvers. Based on the reviewed reports, more concerning, was also found that most of these accidents occurred due to officer distraction (Yager, 2015).

Police vehicles are equipped with different in-vehicle technologies that are designed to improve officer performance. The most frequently used technology in these vehicles is MCT (McKinnon, Callaghan, & Dickerson, 2011). Previous studies found that MCTs are not designed for use while a vehicle is in motion. However, many officers confirm that they use these technologies while driving (Callander and Zorman, 2007). Although NC State law banned the use of cellphones and computers while driving for civilian drivers, emergency vehicle drivers are exempt from this law.

Although the effect of in-vehicle distraction on driver performance and safety has been investigated in numerous studies, few investigations have focused on distractions in emergency vehicles with fewer still examining police distraction. Rossen and Davis (2015) said that there are currently three general solutions to reduce in-vehicle distraction for police officers, including:
1. Change the position of in-vehicle technology so that officers do not have to look down to see the display.

2. Automatically turn off those technologies that are most dangerous to use while driving, once an officer reaches a certain speed (e.g. 60 mph).

3. Put two officers in the car; one to work with the equipment and the other to focus on driving.

However, these solutions may be costly and/or not possible due to the need for officers to acquire information about a certain case while driving.

In addition, there are very few studies that have focused on usability evaluation of technologies in police vehicles. Callander and Zorman (2007) was the only study that used a cognitive modeling tool to understand the distraction caused by a specific MCT task. There has been no study focused on understanding cognitive and visual demands of MCT tasks. In addition, no previous work has focused on understanding the most frequently performed MCT tasks, which may be critical to understanding the source of distraction for police officers (i.e., identifying the nature of tasks, as related to distraction).

1.8.2 Objectives of the present research

Given high crash rates for police vehicles attributed to in-vehicle distraction, and the fact that the most frequently used technology in these vehicles is the MCT, there is a need to understand perceptual, motor and cognitive demands associated with police officer MCT use. Such understanding may support design and development of additional interventions to
reduce distraction and increase officer and civilian safety during police emergency operations.

The first objective of this study was to identify the perceived importance and frequency of different police in-vehicle technologies and different MCT tasks. The second objective was to quantify the visual and cognitive demands of high importance and high frequency MCT tasks. Identifying the most important and frequently performed MCT tasks, which pose high visual and cognitive demands, would help in terms of selecting tasks for which the MCT could be redesigned. The third objective of this research was to formulate design recommendations for enhanced MCT interface design in order to reduce driver distraction. Finally, the last goal of this study was to conduct a driving simulator-based assessment of police officer visual behavior, performance and perceived workload with current and enhanced MCT interface designs.
2  Determination of the most demanding MCT task

2.1 Objective

The objectives in this phase were to:

1) identify the perceived importance and frequency of use of police in-vehicle technologies as well as different MCT tasks;

2) analyze MCT tasks with the highest expected outcomes in order to identify goals, plans, and methods for goals;

3) identify tasks with significantly longer durations than others; and

4) identify perceptual, cognitive, and motor demands of the selected tasks and quantify the amount of cognitive and visual demands for drivers during performance.

2.2 Participants

Initially, one police officer was interviewed to identify different modules of MCT and their functionalities. Subsequently, structured field interviews, regarding MCT use, were conducted with five police (4 males, one female) officers with all having prior experience as a primary patrol officer (mean= 11.4 yrs., SD= 8.35 yrs.). All officers also demonstrated performance of the range of MCT tasks (in a stationary vehicle).

2.3 Procedure

One officer was initially interviewed in order to identify different modules of the MCT interface. As mentioned in the literature review, interviews are an easily applied knowledge
elicitation method and they can be used early in the system development lifecycle. Results of the interview were used to prepare a subjective rating survey of MCT tasks (see Appendix C). Upon completion of the development of the survey, five officers demonstrated performance of the range of MCT tasks while occupying a parked police vehicle. Although observation of officer performance of MCT tasks during vehicle operation might be more realistic, this approach was followed to ensure officer and researcher safety. In addition, Green (2008) said that there is a high correlation between static and dynamic task performance times. He also mentioned that depending on the driving situation, on-road task times are approximately 1.3 to 1.5 times the static times. For the static method, the maximum acceptable distraction time is less than 15 seconds, which is called the 15-second rule. However, the author recommended a 10-second distraction criterion, which is expected to compromise vehicle control. Although Green (2008) proposed this rule for navigation devices, he said that the rule should apply to any system with visual-manual tasks.

Prior to performing the MCT tasks, officers were asked to complete a demographic questionnaire. This questionnaire is presented in Appendix B. During the field test, officers were asked to “think aloud” during MCT task performance to explain why and how tasks are performed. As mentioned earlier, the “think aloud” method is an operator process tracing technique that yields a collection of sequential behavioral events supporting inferences on cognitive processes. In this step, officers were asked to perform each task with two replications (without verbal protocols). This in-car interaction was recorded with a video camera to identify the steps and timing of each task in detail for task time analysis and cognitive modeling purposes. At the end of this process, officers were given the survey
requesting subjective ratings of MCT task importance and frequency of performance in emergency situations (developed in the previous step). (See Appendix C for the subjective rating survey.)

2.4 Decision tree analysis

Initially, officers were asked to identify the frequency (from 0% to 100%) and benefit or cost (from -10 to 10) of using different in-vehicle technologies including: MCT, video cameras, radio, siren and control panel, radar system, cell phone, LoJack (stolen vehicle recovery system), and printer while driving. Although prior studies found that the MCT is the most frequently used in-vehicle technology in emergency vehicles (e.g. McKinnon, Callaghan, & Dickerson, 2011), the decision tree analysis of other technologies along with the MCT was conducted in order to further justify MCT importance and frequency of use as a basis for performing further analyses.

Referring to the decision tree diagram, it is important to note that decisions are made at decision nodes, which are represented by squares. Chance or probability nodes are presented with circles. In addition, the decision problem was analyzed from the point of view of the participants. An “averaging out and folding back” procedure was used in order to find the optimal decision (Raiffa, 1968). In general, this procedure involves starting at the terminal nodes of the tree and works backward to the initial decision node, determining expected values for each node.

As shown in Figure 7, MCT was the decision path with substantially higher EMV as compared to the other paths. Therefore, results revealed that the MCT is the most important
and frequently used in-vehicle technology for officers while driving. It is important to note that the EMV values in Figure 7 are based on the aggregated frequency and importance ratings from 5 police officers. The mean and standard deviations of responses regarding each in-vehicle technology are presented in Table 1.

![Decision Tree Analysis on Police In-Vehicle Technologies](image)

**Figure 7: Decision Tree Analysis on Police In-Vehicle Technologies**
Table 1: Descriptive Statistics on Police In-vehicle Technology Use

<table>
<thead>
<tr>
<th>Police In-vehicle Technology</th>
<th>EMV (Mean ±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Computer Terminal</td>
<td>8.28 ± 1.08</td>
</tr>
<tr>
<td>Video System</td>
<td>-1.23 ± 6.31</td>
</tr>
<tr>
<td>Radio System</td>
<td>4.16 ± 6.72</td>
</tr>
<tr>
<td>Siren and Control Panel</td>
<td>-3.82 ± 4.72</td>
</tr>
<tr>
<td>Radar System</td>
<td>-0.51 ± 1.51</td>
</tr>
<tr>
<td>Cell Phone</td>
<td>-2.01 ± 2.35</td>
</tr>
<tr>
<td>Lo Jack</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>Printer</td>
<td>0.55 ± 3.32</td>
</tr>
</tbody>
</table>

Secondly, officers were asked to identify the frequency (from 0% to 100%) and benefit or cost (from -10 to 10) of performing different MCT tasks while driving including: finding locations on a map, accessing call notes, communication among patrols (messaging), status checks, plate number checks, and mobile field reporting. As shown in Figure 8, access to call notes (EMV=7.1), plate number check (EMV=6.8), and find location on map (EMV=4.9) were found to be the decision paths with substantially higher EMVs as compared to the other paths. These tasks were further analyzed using HTAs (discussed below). In addition, the EMV values in Figure 8 are based on the aggregated frequency and importance ratings from 5 police officers. The mean and standard deviations of responses regarding each MCT task are presented in Table 2.
Figure 8: Decision Tree Analysis on MCT Tasks

Table 2: Descriptive Statistics on MCT Tasks

<table>
<thead>
<tr>
<th>Police In-vehicle Technology</th>
<th>EMV (Mean ±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Find Location on Map</td>
<td>5.10 ± 3.68</td>
</tr>
<tr>
<td>Access Call Notes</td>
<td>7.75 ± 0.50</td>
</tr>
<tr>
<td>Communications Among Patrols</td>
<td>1.80 ± 4.18</td>
</tr>
<tr>
<td>Status Check</td>
<td>-0.05 ± 6.99</td>
</tr>
<tr>
<td>Plate Number Check</td>
<td>6.90 ± 1.52</td>
</tr>
<tr>
<td>Mobile Field Reporting</td>
<td>-4.40 ± 5.17</td>
</tr>
</tbody>
</table>
2.5 Hierarchical task analysis on MCT tasks

The tasks of ‘find location on map’, ‘access call notes’, and ‘plate number check’ were analyzed using HTAs to understand the goals, plans, and methods for goals. The HTAs were developed based on retrospective think-aloud protocols with police officers (while viewing videos of them performing several tasks), and field interviews with them regarding task objectives and steps. In addition, all HTAs were verified by a police officer after completion. The results of the HTAs were useful in task time analysis and cognitive modeling steps (discussed below). Figure 9 shows the HTA for the ‘access call notes’ task. It is important to note that for most of the system functionalities, officers could use either a mouse controller or keyboard.
Figure 9: HTA for Access to Call Notes Task

Figure 10 shows the HTA for the ‘plate number check’ task. This task was found to be more complex than the task of ‘access call notes’ as its HTA diagram included more steps.
Figure 10: HTA for Plate Number Check Task
Figure 11 shows the HTA for the task of ‘find location on map’. Although the number of steps for this task is fewer than the tasks of ‘access call notes’ and ‘plate number check’, the steps for orientation on map might be performed several times by officers in a single call.

Figure 11: HTA for Finding Location on Map

2.6 Task Time Analysis

An analysis of variance (ANOVA) model was structured to identify the most time consuming tasks for officers while driving by considering those MCT tasks with the highest EMVs (i.e. access call notes, plate number check, and find location on map). Results revealed significant differences in time among those MCT tasks (F(2,15.91)=10.48, p=0.0012). Tukey’s Honesty Significant Difference (HSD) post-hoc test revealed plate number check, and find location on map to be significantly more time consuming as compared to access call notes (Figure 12).
The HTA was applied to tasks with longest duration (i.e. plate number check, and find location) in order to make clear specific methods for goals. An ANOVA model was subsequently structured to identify those methods with significantly longer durations than others, based on the video analysis data. It is important to note that the methods for goal for the task of ‘access call notes’ were not considered here since the task had significantly lower completion time as compared to ‘find location on map’ and ‘plate number check’.

Results revealed significant differences in method completion times (F(4,31.51)=16.34, p<0.0001). Tukey’s HSD post-hoc result (Figure 13) indicated that ‘orientation on map’, ‘read plate number information’, and ‘plate number entry’ methods require significantly longer time to complete as compared to the time for ‘initiating the plate

![Figure 12: MCT Task Time Analysis](image-url)
check’. Therefore, these methods for goals with the longest durations were considered to be targets for cognitive performance modeling.

![Figure 13: MCT Method Time Analysis](image)

2.7 Identification of the most visual and cognitive demanding task

2.7.1 Procedure
In this stage of the research, those MCT tasks previously ranked highly in terms of importance and frequency of use in police operations were further analyzed using the GOMS methodology. Each method was further broken into sequences of operations. Operations were classified as demanding a Cognitive (C) Processor, Perceptual (P) processor, or Motor (M) processor. According to the human information processing model underlying the GOMSL methodology, these processors work sequentially within themselves and can be
operate in parallel with each other, depending on the nature of each task. After identification of different operations, an expert officer was asked to review the models of MCT task performance (identifying physical and cognitive demands) in order to further validate the models.

For each method coded in a GOMSL model, the number of perceptual, motor and cognitive operations was obtained. In addition, the maximum number of consecutive cognitive operations occurring in each method (maximum number of steps among different pathways for accomplishing a method for goal) was used as a measure for understanding the cognitive load. It is important to note that the pathway selected for analysis was also a common task sequence for police officers based on the field observations. Working memory (WM) chunk counts was also used for estimating the cognitive demand of the MCT tasks. A WM chunk is defined as a single meaningful unit of information (Wickens, 1992). For example, for most American sports fans, the letters “NFL” have the meaning of football vs. indicating the letter “N” followed by the letter “F”, etc. The acronym is recalled as a single piece of information in memory. Previous studies have shown that cognitive overload may occur when more than five chunks of information must be maintained in WM at any given time (Kieras et. al, 1999).

In order to assess the potential for officer visual distraction, the number of visual perception operations in the model (Liang and Lee, 2010) were also determined. Finally, the time for each individual operation and the total task time was determined. These time estimates were made based on the videotapes of the field study. The average time for each
operation was used in all GOMSL models (Swangnetr et al. 2014). Otherwise, normative operation time estimates obtained from literature was used.

Although some studies found visual-manual distraction to increase off-road glances and degrade lane maintenance (e.g. Wierwille, 1993), the selection criteria for this analysis started with the most time-consuming task and then focused on the most visually and cognitively demanding task. In other words, the task with maximum required time, the greatest number of consecutive cognitive operators, maximum number of visual operators, and maximum number of WM chunks was chosen as the most demanding task. This task was the focus of the MCT interface re-design phase.

2.7.2 Results

Table 3 presents the goals, and methods, obtained from the HTA for MCT tasks with longest durations. It is important to note that within the task methods there were often sequences of (GOMS) operations repeated by officers in order to accomplish goals under different circumstances. Therefore, the table includes the maximum number of perceptual, motor and cognitive operations executed as a part of each method given different approaches to completing a method. The number of operations identified for performance was based on observations of officers. During the officer interviews, it was found that some officers preferred to use a mouse controller while others prefer to use a keyboard for doing the same task. Therefore, GOMS model selection rules were used to account for differences in method performance for accomplishing goals.
<table>
<thead>
<tr>
<th>Goal</th>
<th>Method</th>
<th># Perceptual Operators</th>
<th># Motor Operators</th>
<th># Cognitive Operators</th>
<th>Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate number entry</td>
<td>1.1. Enter the vehicle data (keyboard)</td>
<td>3</td>
<td>9</td>
<td>15</td>
<td>6970</td>
</tr>
<tr>
<td></td>
<td>1.2. Enter the vehicle data (mouse)</td>
<td>3</td>
<td>10</td>
<td>13</td>
<td>7790</td>
</tr>
<tr>
<td></td>
<td>1.3. Submit the form (keyboard)</td>
<td>2</td>
<td>3</td>
<td>18</td>
<td>7340</td>
</tr>
<tr>
<td></td>
<td>1.4. Submit the form (mouse)</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2950</td>
</tr>
<tr>
<td>Read plate number information</td>
<td>2.1. Wait for response</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td><strong>2.2. Read the message (keyboard)</strong></td>
<td><strong>4</strong></td>
<td><strong>3</strong></td>
<td><strong>43</strong></td>
<td><strong>17810</strong></td>
</tr>
<tr>
<td></td>
<td><strong>2.3. Read the message (mouse)</strong></td>
<td><strong>6</strong></td>
<td><strong>5</strong></td>
<td><strong>35</strong></td>
<td><strong>17450</strong></td>
</tr>
<tr>
<td></td>
<td>2.4. Go to the other message (keyboard)</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>3130</td>
</tr>
<tr>
<td></td>
<td>2.5. Go to the other message (mouse)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3100</td>
</tr>
<tr>
<td>Orient on map</td>
<td>3.1. Find the current location (keyboard)</td>
<td>2</td>
<td>1</td>
<td>9</td>
<td>4530</td>
</tr>
<tr>
<td></td>
<td>3.2. Find the current location (mouse)</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>4500</td>
</tr>
<tr>
<td></td>
<td>3.3. Move the map (keyboard)</td>
<td>2</td>
<td>5</td>
<td>11</td>
<td>8480</td>
</tr>
<tr>
<td></td>
<td>3.4. Move the map (mouse)</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>8450</td>
</tr>
<tr>
<td></td>
<td>3.5. Zoom out the map (keyboard)</td>
<td>3</td>
<td>4</td>
<td>11</td>
<td>6580</td>
</tr>
<tr>
<td></td>
<td>3.6. Zoom out the map (mouse)</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>6550</td>
</tr>
<tr>
<td></td>
<td>3.7. Zoom in the map (keyboard)</td>
<td>3</td>
<td>4</td>
<td>11</td>
<td>6580</td>
</tr>
<tr>
<td></td>
<td>3.8. Zoom in the map (mouse)</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>6550</td>
</tr>
</tbody>
</table>

As shown in Table 3, ‘reading the message’ method was found to pose a substantially higher number of cognitive operations as compared to other methods. This was mainly due to the need to recall several pieces of information from memory (e.g. short keys, required information), make decisions, store new information to WM, etc. In addition, this method includes the highest number of perceptual operations. The perceptual operations in this
method were mostly visual due to the need for officers to look at the “next” or “previous” buttons on displays and to click to advance to other pages of information, look for specific information within a page, and read information. Beyond this, the time estimate for different sub-tasks using GOMS modeling revealed that ‘reading the message’ was the most time consuming sub-task for officers. The time estimation for this sub-task was also longer than the 10-second distraction criterion identified by Green (2008), which is expected to compromise vehicle control. It was found that the GOMS model time estimates for each goal were close to the method time analysis as shown Figure 13 (e.g. GOMSL model estimate for “orientation on map using mouse” = 4.50 + 8.45 + 6.55 + 6.55 = 26.05 sec; video analysis time for “orientation on map” = 26.4 sec) which further validate the cognitive models. It is also important to note that GOMSL models represent conservative time estimates, since they are based on a user population and may not be representative of specific individual performance.

Table 4 indicates the maximum number of consecutive cognitive operations occurring in each MCT task method. As can be seen, ‘read the message’ method for goal contained the highest number of consecutive cognitive operations as compared with all other methods. Based on the field observations, this method requires officers to first verify that they are on the correct MCT screen for reading vehicle plate information and whether the new message has been presented on screen. Secondly, they must recall from long-term memory the information that they need to check for an active case. Officers then need to look for this information within several screens/pages of new messages (usually 4-8 pages of information). They also need to store some information when scrolling from one page to
another in order to determine whether to stop a suspect vehicle. Once they decide on a law enforcement action, they delete the previous information from working memory (WM) and return with the goal accomplished.

The task of reading the message also requires the highest number of chunks (9 coherent pieces) of information to be maintained in WM at a given time. As shown in Table 5, “reading the message” is a difficult task for officers to perform, as it requires storing: (1) the status of current screen (whether it is presenting the correct message or not), (2) information to be gathered on a case, and (3) the combined vehicle/driver information they see across different MCT pages. Prior studies have shown that cognitive overload and errors are likely to occur if more than 5 chunks of information must be maintained in WM (e.g. Kieras et. al, 1999).

<table>
<thead>
<tr>
<th>Method</th>
<th>Max no. of serial cognitive operations</th>
<th>Sequence description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1. Enter the vehicle data (keyboard)</td>
<td>6</td>
<td>Store, recall, decide, delete, return</td>
</tr>
<tr>
<td>1.2. Enter the vehicle data (mouse)</td>
<td>5</td>
<td>Store, decide, delete, return</td>
</tr>
<tr>
<td>1.3. Submit the form (keyboard)</td>
<td>5</td>
<td>Recall, store, decide, return</td>
</tr>
<tr>
<td>1.4. Submit the form (mouse)</td>
<td>2</td>
<td>Verify, return</td>
</tr>
<tr>
<td>2.1. Wait for response</td>
<td>4</td>
<td>Store, decide, delete, return</td>
</tr>
<tr>
<td><strong>2.2. Read the message (keyboard)</strong></td>
<td><strong>12</strong></td>
<td><strong>Verify, delete, return, store, decide, do user defined</strong></td>
</tr>
<tr>
<td><strong>2.3. Read the message (mouse)</strong></td>
<td><strong>11</strong></td>
<td><strong>Verify, delete, return, store, decide, do user defined</strong></td>
</tr>
<tr>
<td>2.4. Go to the other message (keyboard)</td>
<td>4</td>
<td>Verify, delete, return</td>
</tr>
<tr>
<td>2.5. Go to the other message (mouse)</td>
<td>3</td>
<td>Verify, return</td>
</tr>
<tr>
<td>3.1. Find my current location (keyboard)</td>
<td>5</td>
<td>Delete, return, store, decide</td>
</tr>
<tr>
<td>3.2. Find my current location (mouse)</td>
<td>4</td>
<td>Look for, decide, return</td>
</tr>
</tbody>
</table>

Table 4: Maximum number of cognitive operations in sequence
<table>
<thead>
<tr>
<th>Method</th>
<th>Number of WM Chunks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3. Move the map (keyboard)</td>
<td>4</td>
<td>Decide, delete, return</td>
</tr>
<tr>
<td>3.4. Move the map (mouse)</td>
<td>4</td>
<td>Decide, delete, return</td>
</tr>
<tr>
<td>3.5. Zoom out the map (keyboard)</td>
<td>6</td>
<td>Decide, recall, store</td>
</tr>
<tr>
<td>3.6. Zoom out the map (mouse)</td>
<td>4</td>
<td>Store, decide</td>
</tr>
<tr>
<td>3.7. Zoom in the map (keyboard)</td>
<td>6</td>
<td>Decide, recall, store</td>
</tr>
<tr>
<td>3.8. Zoom in the map (mouse)</td>
<td>4</td>
<td>Store, decide</td>
</tr>
</tbody>
</table>

Table 5: Number of working memory chunks

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of WM Chunks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1. Enter the vehicle data (keyboard)</td>
<td>2</td>
<td>Selected field, plate number</td>
</tr>
<tr>
<td>1.2. Enter the vehicle data (mouse)</td>
<td>2</td>
<td>Selected field, plate number</td>
</tr>
<tr>
<td>1.3. Submit the form (keyboard)</td>
<td>2</td>
<td>Selected icon, short key</td>
</tr>
<tr>
<td>1.4. Submit the form (mouse)</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>2.1. Wait for response</td>
<td>1</td>
<td>New NCIC message cue</td>
</tr>
<tr>
<td>2.2. Read the message (keyboard)</td>
<td>9</td>
<td>Current screen, vehicle information, required information</td>
</tr>
<tr>
<td>2.3. Read the message (mouse)</td>
<td>9</td>
<td>Current screen, vehicle information, required information</td>
</tr>
<tr>
<td>2.4. Go to the other message (keyboard)</td>
<td>1</td>
<td>Short key</td>
</tr>
<tr>
<td>2.5. Go to the other message (mouse)</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>3.1. Find my current location (keyboard)</td>
<td>2</td>
<td>Current location, short key</td>
</tr>
<tr>
<td>3.2. Find my current location (mouse)</td>
<td>1</td>
<td>Current location</td>
</tr>
<tr>
<td>3.3. Move the map (keyboard)</td>
<td>2</td>
<td>Start point, end point</td>
</tr>
<tr>
<td>3.4. Move the map (mouse)</td>
<td>2</td>
<td>Start point, end point</td>
</tr>
<tr>
<td>3.5. Zoom out the map (keyboard)</td>
<td>3</td>
<td>Current location, dispatched location, short key</td>
</tr>
<tr>
<td>3.6. Zoom out the map (mouse)</td>
<td>2</td>
<td>Current location, dispatched location</td>
</tr>
<tr>
<td>3.7. Zoom in the map (keyboard)</td>
<td>3</td>
<td>Current location, dispatched location, short key</td>
</tr>
<tr>
<td>3.8. Zoom in the map (mouse)</td>
<td>2</td>
<td>Current location, dispatched location</td>
</tr>
</tbody>
</table>
Based on the GOMS model analyses, reading plate related information was found to be the most visually and cognitively demanding and the most time-consuming MCT task. On these bases, the MCT screen for reading a message was identified as a target for usability violation identification and recommendations for an enhanced MCT interface design.

2.8 Conclusion

The objectives of this phase were to: (1) identify the perceived importance and frequency of use of police in-vehicle technologies and different MCT tasks; (2) analyze the MCT tasks with the highest expected outcomes to identify goals, plans, and methods for goals; (3) identify the tasks with significantly longer durations than others; and (4) identify the perceptual, cognitive, and motor demands/requirements of the selected task and quantify the amount of cognitive and visual demands for drivers during performance. Results revealed that the MCT is the most demanding in-vehicle technology for police officers. In addition, “access call notes”, “plate number check” and “find location on map” are the most important and frequently performed MCT tasks for officers while driving. It was found that “reading plate information” is the most visually and cognitively demanding task, as well as the most time consuming task for officers. In general, by using decision tree analysis and GOMS-L cognitive task performance models, the most demanding MCT task was identified for design interventions and experimental testing. This modeling step of the research was used as a basis for MCT interface design recommendations and enhancements in the follow-on phase.
3 MCT interface design

3.1 Objective

The first objective of this stage of the research was to identify usability violations of the current MCT interface and to formulate design recommendations for an enhanced MCT interface design. The second goal was to apply those recommendations and guidelines in order to prototype an enhanced design, which might improve officer performance and visual attention. The third goal was to objectively demonstrate potential benefits of the enhanced design in terms of minimizing the task complexity, task completion time and visual and cognitive demands.

3.2 Participants

Five police officers with prior experience as a primary patrol officer (mean= 11.4 yrs., SD= 8.35 yrs.) were given a list of usability principles based on Molich and Nielsen (1990) and were asked to identify usability violations regarding the MCT interface and provided their suggestions to resolve the issues. They were also asked to provide a rating (0-100%) of the extent to which a usability principle was upheld by the current interface design.

3.3 Procedure

The most demanding task identified by the decision tree analysis and GOMSL modeling method was further analyzed in this phase. The analysis identified any usability violations associated with the MCT interface design supporting the task. Usability violations were
categorized in terms on Molich and Nielson’s (1990) usability principles by using a heuristic evaluation process, including the following steps:

- Identification of critical usability principles;
- Subjective evaluation of system interface features by two usability professionals;
- Subjective evaluation of system interface features by five domain experts (active duty police officers);
- Review of identified problems by another usability professional and a domain expert.

This approach was taken as prior research has shown a team of four analysts can produce a comprehensive list of problems (Virzi, 1997). MCT usability principle violations were converted into usability goals for the enhanced prototype design. A set of design recommendations and guidelines were developed to address the violations. The process of formulating design guidelines from usability violations is shown in Figure 14.
3.4 Usability violations and recommendations for an enhanced design

Although redesigning interfaces based on consideration of a set of usability principles is one of the requirements for usable design (Dix et al. 2004), there has been no prior study of emergency in-vehicle technology usability or identification of MCT interface usability issues.
In this Phase, results of the surveys distributed among five police officers were combined with those of two human factors professionals in order to identify potential usability violations related to the most demanding task identified by decision tree analysis and GOMSL modeling (i.e. reading plate number information). Table 6 presents the specific usability violations with reference to Molich and Nielsen’s principles, the average ratings indicating the extent to which the usability principles were upheld by the current MCT interface design (lower numbers indicate more severe usability violations) and recommendations to resolve the issues based on human factors paradigms. In addition, Table 7 presents the number of responders who identified each heuristic to have low (<33.33%), medium (>33.33% and <66.67%), or high (>66.67%) usability score based on the current MCT interface design.

It was found that the principle of “simple and natural dialog” was substantially violated followed by “minimize users’ memory load”. The main concern for officers was the need to scan several pages of information with interest in identifying specific case facts. In current MCT interface design, there are many unnecessary pages of data, which officers usually have to review and delete, in order to get the case information they need. In addition, poor organization of information among different pages makes the task of reading even more challenging for officers. On this basis, officers suggested providing critical information in a summary page and allowing officers to select preferred information for more details. The human factors professionals also recommended ranking information and only presenting highly ranked information to users, which was in-line with officer recommendations.
<table>
<thead>
<tr>
<th>Usability Principle</th>
<th>Violation Description</th>
<th>Rating (0-100%)</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simple and natural dialogue:</strong></td>
<td>Information provided is usually several pages (6-7) including some information that officers rarely need for a normal plate check task (e.g., sex offender, stolen vehicle).</td>
<td>40.71</td>
<td>1. Rank the information based on its importance and frequency of use 2. Provide a summary page showing the status of highly ranked information (e.g., in a tabular format)</td>
</tr>
<tr>
<td><strong>Speak the user’s Language:</strong></td>
<td>There are many abbreviations in each page.</td>
<td>78.57</td>
<td>1. Reduce the number of abbreviations to common phrases that are clear to all users. 2. Have uniform abbreviation across different system states.</td>
</tr>
<tr>
<td><strong>Minimize the user’s memory load:</strong></td>
<td>Information is presented across several pages and the officer needs to combine all information to make law enforcement action decisions. Usually, there are between 6-7 pages of information for</td>
<td>45.71</td>
<td>1. Rank the information based on its importance and frequency of use 2. Provide a summary page that shows the status of highly ranked information (e.g. in a tabular format)</td>
</tr>
</tbody>
</table>

Table 6: Usability Violation Identification and Recommendations for Enhanced Design
| **remember** information from one part of the dialog to another. | each case. | **3.** Use color coding to differentiate between active and violated information.  
**4.** Provide a summary table with links to detailed pages in order to give the user an overall picture of violations. |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Be consistent:</strong> Users should not have to wonder whether different words, situations or actions mean the same thing.</td>
<td>Some abbreviations are not consistent among different system states.</td>
<td>89.29</td>
</tr>
</tbody>
</table>
| **Provide feedback:** The system should always keep the user informed about what is going on by providing feedback in real time. | 1. Due to internet connection issues or the amount of information requested, there is delay in receiving feedback.  
2. If the officer enters a vehicle plate number incorrectly or makes entry in the wrong field, the system accepts the false input. There is no direct feedback that informs the officer about validity of input data.  
3. Excessive audio feedback; the system presents an audible notification of a message until the officer has tabbed through all | 67.14 |
| | 1. Provide real time feedback messages for the officer. Although the main solution might be to improve the internet connection, reducing the amount of unnecessary or irrelevant information might speed up the process.  
2. Provide a dialog that informs the user about any mistake in data entry; provide a visual reference (check mark if the entered data has a valid format).  
3. Provide an audible notification only for the initial check or |
of the MCT pages, even if the information is irrelevant or not necessary for the current to duty.

<table>
<thead>
<tr>
<th><strong>Provide shortcuts:</strong> Clever shortcuts may be included in a system such that the system caters to both inexperienced and experienced users.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Although there are short keys for going to the next (“N” key) or previous (“P” key) messages, the location of these keys on the keyboard makes them difficult to use. Therefore, officers mostly prefer to use a mouse to navigate to the next or previous message.</td>
</tr>
<tr>
<td>2. Shortcuts are not configurable and are restricted.</td>
</tr>
<tr>
<td><strong>Error prevention:</strong> The interface design should prevent errors from occurring.</td>
</tr>
<tr>
<td>1. Information is shown in text-based format with small font size. It is possible that the officer makes a mistake in reading the appropriate line of information especially for less experienced drivers.</td>
</tr>
<tr>
<td>2. The location of critical pieces of information varies from case to case. In addition, the format of presentation of information is similar to non-critical information. Therefore, it is possible that officers miss critical information.</td>
</tr>
<tr>
<td>3. Some information is not updated.</td>
</tr>
<tr>
<td>84.29</td>
</tr>
<tr>
<td>58.29</td>
</tr>
<tr>
<td>1. Make the short keys more natural for the user. For example, use right/left arrow keys to go to the next/previous message.</td>
</tr>
<tr>
<td>2. Allow the user to configure their own shortcuts and preferences.</td>
</tr>
<tr>
<td>1. Change the text-based format to tabular format. Use different font size and type or color coding, and bold or print the important words or sentences.</td>
</tr>
<tr>
<td>2. Use the proximity-compatibility principle to group relevant information together. Use different font size or color coding, and bold or print the important words or sentences. Show important messages in dominant and consistent locations on the screen.</td>
</tr>
<tr>
<td>3. Provide updated and valid information.</td>
</tr>
<tr>
<td>4. Provide accurate information.</td>
</tr>
<tr>
<td>4.</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>5.</td>
</tr>
<tr>
<td>5.</td>
</tr>
<tr>
<td>Usability Principle</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Simple and natural dialogue</td>
</tr>
<tr>
<td>Speak the user’s Language</td>
</tr>
<tr>
<td>Minimize the user’s memory load</td>
</tr>
<tr>
<td>Be consistent</td>
</tr>
<tr>
<td>Provide feedback</td>
</tr>
<tr>
<td>Provide shortcuts</td>
</tr>
<tr>
<td>Error prevention</td>
</tr>
</tbody>
</table>

### 3.5 MCT interface design

The enhanced MCT interface was designed based on the usability guidelines identified through the prior phase of research and the design was focused on interface features that support specific MCT tasks. Four device use scenarios were developed for the high importance and high demand MCT tasks selected through the decision tree analysis and GOMSL modeling work (i.e., reading plate information). The scenarios were developed based on the interviews with the police officers and were found to be representative of the most common violations committed by drivers. The scenarios included: find the status of a driver’s license, find the status of a vehicle tag, find the vehicle insurance status, and determine whether the vehicle is stolen.

Initially, virtual storyboards were developed to present the conceptual interface redesign. An example of a storyboard for the plate number check task is shown in Appendix D. Secondly, a semi-functional prototype was developed using the “Justinmind” prototyping
tool (version 7.3.0). In order to compare the performance of drivers interacting with the MCT while driving, a baseline prototype was also developed using Justinmind. This prototype was based on the current version of the MCT used by the officers participating in the present study.

3.5.1 Baseline MCT interface

Most current MCT designs present information in text-based format because the Division of Motor Vehicles (DMV) typically provides data in this format. Furthermore, the information transmitted by the DMV is typically several pages in length. Based on field study observations, usually, the first page of the report does not provide important content for the officer. Therefore, officers usually scan all the pages initially and delete the pages that they do not need. Information is not organized in a way that officers can quickly identify law violations. For example, there are no color differences or font size/format changes to distinguish active vs. expired plate status. Figure 15 presents an example of a current MCT interface for performing the task of reading a message.
3.5.2 Enhanced MCT interface

Based on the identified usability violations and recommendations, an enhanced MCT interface design was proposed for reading plate information task. The simplified display is shown in Figure 16. Once an officer entered the plate number, the software searches the DMV text file for critical information (i.e., driver license, tag, insurance, and vehicle status) and presents a summary page providing the overall case status required by the officer. The computer algorithm is very simple and easy to apply to an incoming text file. The formatting of the summary page is also intended to be simple and easy to read. Violations were identified in red text in order to further promote ease of recognition by officers. During the
field interviews, most officers mentioned that they only need to know high level information while they are driving in order to determine whether they needed to take law enforcement action. Therefore, providing a simple summary page will substantially reduce the visual and cognitive demand of gathering necessary information for officers while operation a vehicle.

![Figure 16: Enhanced MCT Interface Design: Summary Page](image)

If an officer wants to see detailed information regarding specific violations, (s)he can select the desired page identifier from the summary table (e.g. “1. Driver License”; “2. Tag Status”). Figure 17 shows a “driver license” page with additional information about the owner of the vehicle. In both summary and the detailed pages, the information is organized in a tabular format as tables are conductive to representing discrete sets of information (cf. Sanders & McCormack, 1993). In addition, navigation tool is presented in all detailed pages
to provide users with awareness of location in the system and information options. This graphic representation of the system structure was also helpful in improving users’ mental map of the system. Foss (1989) said that failure to develop an adequate mental map of the system would result in forgetting the information from one section to the other and difficulty in summarizing the information which also were the main issues identified in the field interviews with the officers. The officer can directly navigate through different pages of information by pressing the numbers associated with each page (i.e., 1-4) or by clicking on the desired tab at the top of the interface display.

- Information presentation in a table format
- Rank the information based on their importance in each page

Figure 17: Enhanced MCT Interface Design: Driver License Page
3.6 Comparison of current and enhanced MCT interfaces

As shown in Figure 14, HTAs and cognitive task performance models for the baseline and enhanced MCT designs were compared in order to objectively demonstrate potential benefits of the enhanced design in terms of reduced complexity, and reduced visual and cognitive demands. Since all of the four use scenarios were similar in nature, only one of them (i.e., vehicle insurance status check) is shown here as a basis for the interface complexity and demand comparisons. Although the baseline MCT interface might be more competitive relative to the enhanced version for certain scenarios (e.g., a message appears on an earlier pages), the focus of this comparison was on more demanding scenarios since the most important information for police officers typically starts from Page 2 or 3 of the DMV report, based on the field observations. In addition, it is important to note that since the recommendations and the enhanced design were focused on ‘reading plate information’ as part of the plate number check task, only this portion of the task was considered as a basis for comparison of the two interfaces.

3.6.1 Hierarchical task analysis

HTAs for reading information as part of the plate number check task for the baseline and enhanced MCT interfaces are shown in Figures 18 and 19. Results revealed that the enhanced design reduced the complexity of task performance by reducing the number of steps that needed to be performed (Baseline MCT: 8 steps, Enhanced MCT: 5 steps).
Figure 18: HTA for Reading Plate Information with the Baseline MCT Interface
3.6.2 GOMSL modeling

Table 8 shows the comparison between the baseline and the enhanced MCT interfaces for the defined scenario. Similar to previous GOMSL models, this table presents the maximum number of perceptual, motor and cognitive operations for each method (maximum number of steps among different pathways for accomplishing a method for goal). Results revealed that the enhanced design substantially reduced the number and maximum sequence of cognitive operations as compared to the baseline interface. The difference was mainly due to the need for going through several pages of information in the baseline MCT interface whereas in the enhanced design, the user could find the information using maximum of two pagers (i.e. summary and detailed information pages).

In addition, task completion time estimates were substantially lower for the enhanced design. The time estimate for performing the task using the enhanced design was around 6.6
seconds whereas in the baseline design, the time is near 11 seconds which is above the 10-sec rule identified by Green (2008). Although reducing the number of information pages was a key to decreasing task completion time, ranking information, improving information presentation (using a tabular format and color coding), and enhancing navigation between pages also had an influence.

The enhanced interface design also reduced perceptual and motor operation counts, which was mainly due to easier navigation among pages, reduction in the number of pages and better organization of information on each page. These findings objectively demonstrate the potential benefits of the enhanced MCT design for the task of reading plate information.
### Table 8: GOMSL Comparison of Baseline and Enhanced MCT Interfaces

<table>
<thead>
<tr>
<th>Interface Design</th>
<th>Goal</th>
<th># Perceptual Operators</th>
<th># Motor Operators</th>
<th># Cognitive Operators</th>
<th>Max No. of Cognitive Sequence</th>
<th>Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>Read plate information using keyboard</td>
<td>3</td>
<td>3</td>
<td>20</td>
<td>8</td>
<td>11110</td>
</tr>
<tr>
<td></td>
<td>Read plate information using mouse</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>5</td>
<td>10050</td>
</tr>
<tr>
<td><strong>Enhanced</strong></td>
<td>Read plate information using keyboard</td>
<td>3</td>
<td>2</td>
<td>10</td>
<td>4</td>
<td>6630</td>
</tr>
<tr>
<td></td>
<td>Read plate information using mouse</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td>3</td>
<td>6600</td>
</tr>
</tbody>
</table>
3.7 Conclusion

The objectives of this phase were to: (1) identify usability violations of the current MCT interface design and to formulate design recommendations for an enhanced MCT interface; (2) apply the usability recommendations and guidelines in order to prototype an enhanced design; and (3) objectively identify any potential benefits of the enhanced design in terms of minimizing task complexity and visual and cognitive demands. Results revealed that the usability principles of “simple and natural dialog” followed by “minimize user’s cognitive load” were strongly violated by the current MCT interface design. Recommendations to resolve these issues included providing a summary page, ranking display information, improving information presentation format, and enhancing navigation between different pages of information. Results of HTA and cognitive modeling comparisons revealed the enhanced MCT interface reduced task complexity and that there was a substantially decrease in the number of cognitive operations, cognitive overload potential, and task completion time.
4 Driving simulation study

4.1 Objective

The main objective of this phase of the research was to compare the performance of officers using the enhanced and baseline MCT interfaces while driving on a simulated urban environment. This comparison was made in terms of primary driving task performance, secondary task performance, perceived workload, level of officer awareness, and usability of the MCT interface prototypes.

4.2 Participants

Twenty police officers (18 males, 2 females) were recruited for the experiment. The study sample inclusion criteria included expert drivers with regular police vehicle use (Filtness et al. 2013). All participants were randomly sampled from a mid-sized suburban southern Police Department under a prior agreement between the Chief of Police and NC State University faculty in order to potentially achieve a sample that is representative of the cooperating department in terms of officer gender distribution (88.5% Male, 11.5% Female based on actual department demographics information). The sample Police Department is one of the major police departments in NC which uses MCTs, as provided by commercial vendors also supplying other departments in the state. Participating officers were between 24 and 54 years of age and had 20/20 or corrected vision. Participants were compensated $35 per hour for participation.
Only a limited number of studies have been conducted on the human performance implications of emergency in-vehicle technologies, which served as a basis for estimating an appropriate experiment sample size for this study. Table 9 presents the sample sizes for the prior studies. A conservative approach was taken to determine the number of participants in the current experiment, specifically the maximum number of participants in Table 9 with rounding to the nearest even number (due to experiment design conditions). Table 10 presents the demographic information of participants, which was collected using the questionnaire presented in Appendix H. The majority of participants were patrol officers with regular police vehicle use. However, a few participants were previous patrol officers but had recently been promoted to detective positions. This situation might explain the comparatively low in-vehicle time per week. In addition, officer level of experience using MCTs while driving was measured using a visual-analog rating scale (0-100%) for which 0% indicated “no experience” and 100% indicated “high experience” level.

**Table 9: Number of participants recruited in previous studies**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Participant Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtness et al. (2013)</td>
<td>19</td>
</tr>
<tr>
<td>Mitsopoulos-Rubens et al. (2013)</td>
<td>19</td>
</tr>
<tr>
<td>Marcus and Gasperini (2006)</td>
<td>6</td>
</tr>
<tr>
<td>Garrison et al. (2012)</td>
<td>14</td>
</tr>
</tbody>
</table>
### Table 10: Driving Experiment Participant Demographics

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>18 Participants</td>
</tr>
<tr>
<td>Female</td>
<td>2 Participants</td>
</tr>
<tr>
<td>Age</td>
<td>37.48 ± 8.45 Years</td>
</tr>
<tr>
<td>Level of experience using MCT while driving</td>
<td>83.05 ± 13.68 %</td>
</tr>
<tr>
<td>Hours spend in vehicle per week</td>
<td>16.65 ± 12.44 Hours</td>
</tr>
</tbody>
</table>

4.3 Apparatus

The experiment made use of North Carolina State University Ergonomics Lab driving simulator, shown in Figure 20. The setup included three 38-inch high definition television monitors providing a 135-degree field of view of the driving environment. The minimum distance between the driver's eyes and the monitors was set as 1.58m which was calculated based on the resolution of the monitors (1082p) and their size. A 5.1 surround sound speaker system generated auditory feedback for drivers (vehicle and traffic sounds). Officers interacted with the simulator through a control unit, consisting of a modular steering unit with full-size wheel and a modular accelerator and brake pedal unit. The simulator recorded driver control actions and vehicle states to log files with a sampling frequency of 30Hz. Although a driver simulation study may not exactly match the real driving environment, and the approach has limitations in terms of reproducing stress levels that ordinarily occur in field situations, several prior studies have shown that data collected in actual and simulated driving are similar and simulators have good relative validity (e.g. Underwood et al., 2011). Another
advantage of using driving simulators, versus in-vehicle experimentation, is ensure participant safety from accidents, etc. that might occur in actual road driving.

In addition to the simulator displays, there was a 12.3-inch laptop positioned to the right side of the driver’s forward-view, which was used to present the MCT interface prototypes (also see Figure 20). The location of the computer and its display angle were based on measurements of MCT displays in actual police vehicles. The MCT presented the most demanding task (i.e. plate number check) that was identified based on the decision tree analysis and cognitive modeling effort.

Figure 20: Ergonomic Lab Driving Simulator Set up
In order to complement the cognitive model based analysis of MCT use, experiment participant visual attention allocation was recorded using a Facelab 5.1 eye tracking system (Seeing Machines, Australia). The system hardware, shown in Figure 21, consisted of two cameras and an infrared light-emitting pod and was non-intrusive in driver visual attention. The light emitted from the pod was reflected on the eyes and was captured by the cameras along with the outline of the pupil. The system recorded eye movements at 60 Hz with an accuracy of 0.5° to 1° of rotational error. The two points of reflection on the surface of the eye (the glint and edge of the pupil) allow for determination of gaze direction and projection onto a “world model”; that is, a model of the driving simulator setup within the Facelab software environment.

Figure 21: FacelAB System Hardware
4.4 Independent variables

The independent variables manipulated in the driving experiment included: (1) MCT interface design type; (2) driving condition; and (3) hazard exposure. The MCT interface design type consisted of two levels including enhanced and baseline designs (i.e. the current MCT interface used by the sample Police Department). The driving condition had two levels, including driving while performing a secondary in-vehicle task with the MCT, and driving without using the MCT (i.e., police officer baseline simulator driving performance). Hazard exposure had two levels including driving in the presence vs. absence of a roadway hazard.

4.5 Experiment design

The study followed a mixed between- and within-subjects experiment design. Each participant was randomly assigned to either the enhanced or the baseline MCT conditions. This approach was selected in order to reduce learning effects that could occur for officers as a result of working with both versions of the MCT interface across multiple test trials. Rosenthal (1976) offered that in behavioral research, it is recommended to use a between-subjects design in order to avoid ‘demand effects’; that is, participants can develop a sense of an experimenter’s intension during the study as a result of being exposed to all manipulations and may adapt their behavior accordingly. Since the main focus of the present experiment was to compare the effect of different MCT design interfaces on officer driving performance, a between-subject design at the whole plot level was preferred to mitigate potential ‘demand effects’. Charness et al. (2012) also identified between-subject designs as being more conservative in comparison to within-subject designs in terms of potential subject-condition
bias. Another motivation for using a between-subject design was to limit the duration of the experiment for participants. In the present study, if officers were exposed to all experiment conditions, the duration of the experiment would exceed 2 hours, which could increase the potential for simulator sickness. Related to this, Kennedy et al. (2000) found that duration of the experiment has a positive correlation with simulator sickness symptoms. Consequently, the need to limit the duration of the experiment was another major motivation for a between-subject design at the whole plot level.

Upon being assigned to a specific MCT interface type, all participants experienced four driving trials, including two requiring secondary task performance and two without a secondary task (within-subject design at the split plot level). Within-subject designs were preferred at this level of analysis since greater statistical power and internal validity of results can be achieved through repeated observations on a single experimental unit. In addition, there was no concern for ‘demand effects’ at the split plot level in the present study, as the main objective of the research remains a comparison of the baseline and enhanced MCT interface designs.

The secondary task involved use of the MCT to complete a plate number check. Replications were used for observation on within-subject performance variability. The four driving scenarios were similar in design, including intersections and pedestrians. Segments of each scenario were either hazard free or included vehicle hazard events. However, the location of occurrence of the hazard events varied among the trials to limit any potential officer condition learning effect from one trial to another. The driving scenarios are presented in Appendix G. On the basis of this design, a split-plot analysis was applied to some of the
experiment response measures in which officer/participants represented the whole-plot with the MCT interface type being a whole-plot factor and trials representing the split-plot with the MCT use and hazard exposure as split-plot manipulations. The whole-plot followed a completely randomized design and the split-plot followed a general complete block design.

4.6 Dependent variables

The dependent variables (DVs) were categorized into six different types, including driver performance, eye-tracking, secondary-task time, officer level of awareness, MCT interface usability scores, and perceived workload.

The first category of driving performance included lane maintenance, speed variance, number of crashes, and brake reaction time to the hazard situation. Lane maintenance was defined as the absolute lateral vehicle deviation from the center of a lane. Speed variance was defined as the absolute deviation in driver speed from posted limits in the simulation. Any type of collision, including a single-vehicle collision, collisions involving pedestrians, and collisions involving another vehicle were counted as crashes. Brake reaction time was calculated based on the simulator log data files by subtracting the time at which a vehicle/pedestrian hazard initiated movement to the time when a participant driver began to brake. It is important to note that the “windows” of data collection began 500 ft before the location of hazard (when the hazard became visible to the driver) until 200 ft after the hazard (for 700 ft of exposure in total).

The second category of response measurement was eye tracking. In order to collect meaningful eye-tracking data, it was necessary to define areas of interest (AOIs) for driver
glances within the simulator environment. In the driving domain, common AOIs include on-road, off-road, and the rear-view mirror. Since the focus of the present study was on distraction caused by in-vehicle technologies, the off-road and on-road AOIs were used. Glances to the MCT interface were considered to be within the off-road AOI. Eye-tracking measures included off-road glance frequency, and maximum off-road glance duration. These measures have been used in previous studies to assess the effect of different modalities of MCT information presentation on police officer glance patterns (Filtness et al. 2013). Furthermore, off-road glance frequency and maximum off-road glance duration have been used in prior studies as measures of driver distraction (Zhang et al., 2013). Fixation frequency was determined as the number of fixations to the off-road AOI divided by the total number of fixations in a trial. A fixation was defined as any participant gaze with a velocity less than 100 degrees/s for a minimum of 100 ms (Holmqvist et al., 2011). A glance was defined as the total time the focus of attention remained within the AOI, encompassing both fixations and saccades (rapid eye movements). Maximum off-road glance duration was also compared to a 2s threshold for a single off-road glance (due to in-vehicle interactions) leading to uncertainty in vehicle control, according to the U.S. National Highway Traffic Safety Administration (NHTSA, 2012).

The third category of response measurement was secondary task performance. Performance was defined as secondary task completion time. Task completion time began when participants completed the plate number data entry and ran until they verbally provided an answer to the experimenter regarding a plate status. Secondary task time also defines time spent away from primary task performance or driving. Green (1999) said that the more time
that a driver spends on the secondary task, the less time is available for him to pay attention to driving, which increases risk to safe driving.

The fourth category of response measurement was officer level of awareness. Although the focus of this research was on visual and cognitive distraction as a result of MCT use and not on driver situation awareness (SA), knowing the level of officer awareness of the driving environment may provide additional insight on the impact of MCT design. Garrison et al. (2012) also mentioned that monitoring the activities of vehicles and individuals in the external environment while driving is a requirement for law enforcement patrols. Driver awareness of the external environment in this experiment was measured in terms of subjective ratings. At the close of each trials, they completed a Likert scale rating from strongly unaware (“1”) to strongly aware (“5”). The subjective rating form that was presented to participant officer is shown in Appendix E.

The fifth category of response measurement was the usability score for the MCT interface. The System Usability Scale (SUS) was used for this purpose. The SUS was considered to be a reliable, low-cost usability scale that could be used for global assessments of systems usability across a range of contexts. As mentioned in the literature review section, this usability evaluation measure was first developed by Brooke (1996) and has been used in studies assessing the usability of in-vehicle technologies (e.g. Cůřín et al., 2011). The SUS rating scale was presented to participants upon completion of the experiment. The SUS rating form is shown in Appendix F. The SUS usability score was calculated according to the procedure defined by Brooke (1996).
Finally, the last DV in this experiment was driver perceived workload. As mentioned earlier, DALI is a method developed by Pauzié and Pachiaudi (1997) to measure subjective workload specifically in the driving context. Participants were asked to rate their perceived workload using DALI after each trial. The description of factors and the questionnaire for this method are shown in Appendix A.

4.7 Task

All driving simulations presented clear day conditions with no adverse weather. A dense urban setting was presented with six-lane roadway with three lanes on either side of a double yellow line with opposite directions of travel. In addition, there were several parked cars on either side of the road to increase the realism of the scenarios like an actual city driving situation. The speed limit on all roadways was 40 mph. It is important to note that the traffic density in all roadway simulations were comparable to level of service C which is defined as:

“Stable flow, at or near free flow. Ability to maneuver through lanes is noticeably restricted and lane changes require more driver awareness. Minimum vehicle spacing is about 220 ft. (67 m) or 11 car lengths. Most experienced drivers are comfortable, roads remain safely below but efficiently close to capacity, and posted speed is maintained. Minor incidents may still have no effect but localized service will have noticeable effects and traffic delays will form behind the incident. This is the target Level of Service for some urban and most rural highways.” (Transportation Research Board, 2010)
Law enforcement driving can be categorized into three general driving situations which include: standard patrol, emergency response, and vehicle pursuit (Crundall et al. 2003). In standard patrol, all roadway driving regulations are followed (e.g., speed limit). The driving scenarios simulated a standard patrol situation for officers. Although the probability and severity of police vehicle crashes in emergency situations might be much more than in non-emergency situations, operations in emergency mode represent a fairly small proportion of police vehicle driving time. In addition, several crash reports revealed that about half of emergency vehicle crashes occur in non-emergency situations (e.g. NHTSA FARS and GES reports, 2002-2012) offering further support for assessment of non-emergency operations in the present study. Related to this, the driving simulation environment included pedestrian and vehicle hazard events in order to facilitate a conservative comparison of the MCT interface designs; that is, identification of the extent to which distraction due to MCT use might compromise officer detection of common roadway events/hazards. Hazard events included vehicle and pedestrian obstructions to an officer’s vehicle. Pedestrians crossed a street, a parked car suddenly pulled-out from a roadside space and a lead vehicle suddenly braked with high rate of deceleration. These selected hazards were among the top pre-crash events identified by NHTSA crash causation survey (2008). These events remained the same for all four driving scenarios but occurred at different times during each trial.

Officers were instructed to drive the simulated roadway following all traffic controls and to maintain their vehicle in the middle lane at all times (except when maneuvering at intersections). At two pre-determined points along the drive (except in baseline driving
trials), officers were requested to perform a vehicle plate number check using the MCT. An automated voice from the simulator gave the instruction and the plate number information. For example, the officers started performing the secondary task once they heard this message from the simulator: “start running a tag, plate number is: ABC1000”. Once an officer entered the plate number and completed submission, they were posed with a specific question regarding the case. Questions and correct answers are shown in Table 11. These questions were selected based on the prior officer interviews identifying the most common types of legal violations. Although the secondary task involved a plate number check, the focus of the experiment was on officer reading of information from the MCT which was the most demanding method for goal identified based on the GOMSL model analyses. Each trial lasted approximately 5 minutes including officers reading plate information and responding to experimenters. The entire experiment took an officer approximately 2 hours to complete.

Finally, in order to make the simulated driving scenarios resemble as closely as possible real police vehicle operation, a real police radio broadcast was played during each experiment trial (Filtness et al. 2013).

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the status of driver license?</td>
<td>Suspended</td>
</tr>
<tr>
<td>What is the status of vehicle tag?</td>
<td>Expired</td>
</tr>
<tr>
<td>What is the insurance status?</td>
<td>Violated</td>
</tr>
<tr>
<td>Is it a stolen vehicle?</td>
<td>Yes/Stolen</td>
</tr>
</tbody>
</table>
4.8 Procedure

Officers initially completed an informed consent form, the demographic questionnaire (Appendix H), and a baseline simulator sickness questionnaire (SSQ; Kennedy et al., 1993). The SSQ was used to monitor potential motion sickness symptoms during the experiment. Officers were subsequently trained on using one of the MCT interfaces. The experimenter read the instructions on how to use the MCT for performing the “plate number check” task in the absence of driving. Subsequently, participants were given a sample plate number and were asked to perform the secondary task in front of the experimenter. Once they indicated understanding in performing the secondary task, they were provided instruction on user of the driving simulator.

Participants subsequently completed three driving training trials including MCT interface use. The training trials also presented simulation of an urban driving environment similar to the actual experiment trials. Specific vehicle maneuvers were required in training, including stopping at a red light, turning right or left at intersections, driving at the posted speed limit, and maintaining the vehicle in the middle of a lane. At the end of the training, officer speed and lane deviations were aggregated across trials to verify conformance with established performance criteria, including \(|\text{lane deviation}| \leq 1.37\text{ft}\) and \(|\text{speed deviation}| \leq 1 \text{ mph}\). The lane deviation criterion was based on Horrey and Wickens (2004) research and the speed deviation criterion was based on average speed deviation for five experienced simulator drivers. Participants were given extra training trials if they could not meet the established criteria in the first three trials. After each extra training trial, the average of last three trials were calculated and were compared to the criteria. Provided they met the
performance criteria, officers were administered another SSQ to ensure absence of simulator sickness symptoms. If they felt comfortable, the Facelab eye tracking system was calibrated for the individual driver.

For the experiment trials, officers were informed that driving was the primary task and they needed to complete plate number checks using the MCT as accurately and quickly as they could. It is important to note that no additional participant incentives were considered necessary for MCT task performance during the experiment since the participants were experienced police officers who use MCTs regularly and knew the value of the terminals for police operations. Also, they were told that roadway hazards could occur during trials. Upon completion of the instructions, participants began the driving task, as described in Section 4.7. The experiment consisted of four trials, including one trial with MCT use and another without use as a baseline with each condition being replicated. After each test trial, officers were asked to rate their situation awareness and complete the DALI forms. They were given a 5-minute break between trials. The SSQ was administered again after the second trial. None of the officers in the study indicated simulator sickness symptoms. Upon completion of all four trials, participants were given instructions on how to complete the SUS questionnaire and were given the opportunity to express any lack of clarity in the instruction. Subsequently, they were asked to complete the SUS regarding the usability of the MCT interface that they used during the experiment. Officers were compensated at the end of the experiment and were escorted out of the Lab.
4.9 Hypotheses

Based on the findings of the existing literature, the following hypotheses (H) were formulated.

- In regard to driving performance, using MCT while driving was expected to increase average lane deviation (H1), increase speed variance (H2), increase the number of simulated vehicle crashes (H3), and increase brake reaction time to hazard situations (H4). In addition, the enhanced MCT design was expected to decrease average lane deviation (H5), decrease speed variance (H6), decrease the number of simulated vehicle crashes (H7), and decrease brake reaction time to hazard situations (H8).

- In regard to the eye tracking measures, it was expected that the use of MCT while driving would increase off-road glance frequency (H9) and increase average off-road glance duration (H10). Also, it was expected that the enhanced MCT design would decrease off-road glance frequency (H11) and decrease average off-road glance duration (H12) as compared to the baseline MCT interface.

- In terms of driver level of awareness and secondary task performance, it was expected that the use of MCT while driving would decrease officer perceived level of environment awareness (H13). Furthermore, it was expected that the enhanced MCT design would increase officer perceived level of driving environment awareness (H14) and decrease task completion time (H15) as compared to the baseline MCT interface.

- In regard to the usability score, the enhanced MCT was expected to increase the SUS score in comparison to the baseline MCT design (H16).
- Finally, in terms of driver perceived workload, using MCT while driving was expected to increase driver workload (H17), as reflected by DALI scores. In addition, the enhanced MCT was expected to decrease driver workload as compared to the baseline MCT interface (H18).

4.10 Data analysis

Data screening was conducted in order to identify any outliers in the response measures due to equipment problems or participant failure to follow instructions correctly. Regarding driver workload responses, the data for one participant was removed since she did not follow the instruction in completing DALI forms. Regarding task completion time response, three data points were removed since the participant could not complete the secondary tasks in those cases before the end of driving scenarios. Regarding driver performance and attention allocation responses, three data points were excluded due to failure to follow the instructions during the experiment. After data screening, the data analysis process began with univariate analyses of variance (ANOVAs) on responses in order to assess conformance of data with parametric test assumptions of homoscedasticity and normality. Bartlett’s test (Snedecor and Cochran, 1989) and Shapiro-Wilk’s test (Shapiro and Wilk, 1965) were applied. If response measures failed to satisfy constant variance and residual normality assumptions, transformations were applied to the responses (e.g., log or square root transformations). If transformations were ineffective, a nonparametric procedure was used or ranked observations were submitted to a parametric test. If nonparametric results were similar ANOVA results on untransformed measures, analyses on the untransformed responses were considered valid.
(Montgomery, 1991). For the analysis of number of crashes, logistic regression was used due to the binary nature of the response. Regarding driver perceived workload, although there might be individual differences that influence the ratings, it was not possible to standardize the data due to the discrete nature of DALI scales.

Three separate data analyses were conducted based on the experiment data, as summarized in Figure 22. The objective of Phase 1 was to compare officer driving performance, attention allocation, workload and perceived roadway awareness while using the MCT vs. driving without MCT use. For the lane and speed deviation responses, observations for the present analysis did not include those collected when a roadway hazard was present as comparison was only made on driving while performing a secondary in-vehicle task with the MCT vs. driving without using the MCT. However, for brake reaction time and number of collision responses, only data windows in which a hazard was present were included in the analyses. Mixed between- and within-subject ANOVA was conducted in this phase with participant as a between-subject blocking variable and driving condition as a within-subject factor in the model.

Figure 22: Overview of Data Analysis Phases
In Phase 2, data analysis was only conducted on baseline driving conditions (i.e., no secondary task performance with the MCT) in order to assess driver performance in the presence or absence of a hazard. The objective of this phase was to further validate conformance of participants with experimenter instructions, specifically use of braking (vs. lane changes) in order to accommodate hazards. Mixed between- and within-subject ANOVA was also conducted in this phase with participant as a between-subject blocking variable and hazard exposure (hazard ON or OFF) as a within-subject factor in the model.

It is important to note that the assessment of hazard exposure under the baseline driving condition was limited to data windows in which the hazard was OFF or there was exposure to an unexpected pedestrian crossing or a car pulling-out into traffic. Although there were three hazards presented in each trial, the vehicle braking hazard (dramatic decrease in lead vehicle speed) was not paired with any MCT exposure as part of the driving condition (i.e., performing a secondary task with the MCT). The reason for this design was that the urgency of the pedestrian crossing or car pull-out hazard events were such that participants had to respond immediately; whereas, with a braking hazard it was observed during simulation development that responses could be delayed. Therefore, in order to make accurate assessment of driver hazard responsiveness, data windows including exposure to braking hazards were excluded for the analysis of baseline driving.

In Phase 3, data analysis was only conducted on trials when officers were driving while performing the secondary in-vehicle task with the MCT. The objective of this phase was to compare driving task performance, secondary task performance, perceived workload,
level of officer roadway awareness while using the two MCT interface prototypes. Comparison was also made of the usability of the two designs. Mixed between- and within-subject ANOVA was conducted in this phase with participant as a between-subject blocking variable, hazard exposure (with two levels: hazard ON or OFF) and MCT interface type (with two levels: Baseline MCT vs. Enhanced MCT) as within-subject factors and their interaction in the model. As mentioned earlier, MCT exposure occurred when hazard was OFF or it was paired with a pedestrian crossing or car pulling-out into traffic. In addition, gender, officer level of experience using the MCT while driving, and trial number were initially included in the statistical models as covariate effects and were removed if found to be statistically insignificant.

4.11 Results

A significance level of \( \alpha=0.05 \) was used as the statistical criterion in this study. All plots of condition response measures include untransformed mean values at the top of bars in any graph. In addition, all error bars represent +/- 1 standard deviations from the mean. Covariates of gender and officer level of experience did not have significant effects on any of the response measures and were removed from all models.

4.11.1 Effect of using MCT while driving (Phase 1)

4.11.1.1 Driving performance

Regarding lane deviation and speed deviation responses, transformations could not resolve the ANOVA assumptions violation. Therefore, the data was ranked. However, since
nonparametric results were similar to the results of ANOVA on untransformed measures, the parametric results are reported here.

Table 12 presents descriptive statistics on police officer driving performance under the two driving conditions. Inferential tests revealed no significant effect of driving condition on lane deviation (F(1,63)=1.073, p=0.3042) or speed deviation responses (F(1,62)=1.3714, p=0.2460). There was also no significant effect of driving condition on brake reaction time response (F(1,43)=0.2667, p=0.6082). Furthermore, logistic regression on number of crashes did not show any significant effect of driving condition ($\chi^2(1)=0.0214$, p=0.8837).

<table>
<thead>
<tr>
<th>Response</th>
<th>Driving Without Using the MCT (Mean ± SD)</th>
<th>Driving While Performing a Plate Number Check Task with the MCT (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane Deviation</td>
<td>0.86±0.48 ft</td>
<td>1.01±0.99 ft</td>
</tr>
<tr>
<td>Speed Deviation</td>
<td>3.47±3.17 mph</td>
<td>4.61±4.20 mph</td>
</tr>
<tr>
<td>Number of Crashes</td>
<td>0.00±0.00</td>
<td>0.06±0.25</td>
</tr>
<tr>
<td>Brake Reaction Time</td>
<td>7581±1906 ms</td>
<td>7941±1256 ms</td>
</tr>
</tbody>
</table>

4.11.1.2 Attention allocation

An ANOVA on longest glance duration revealed a significant effect of driving condition (F(1,63)=75.3124, p<0.0001). Figure 23 shows that longest off-road glance duration was significantly longer when officers perform the secondary task with the MCT as compared to driving without MCT use. The mean of longest glance durations under both conditions were lower than the 2 sec vehicle control uncertainty threshold, according to NHTSA; however, some individual observations were over 2 sec. The longest glance duration was about 2.7 sec
and was observed with the baseline MCT. In total, 2.3% of all glance durations were greater than 2 sec.

Figure 23: Effect of Driving Condition on Longest Off-Road Glance Duration

An ANOVA on fixation frequency revealed a significant effect of driving condition (F(1,63)=114.17, p<0.0001). Figure 24 shows off-road glance frequency significantly increased when officers performed the secondary in-vehicle task with the MCT.
4.11.1.3 Driver perceived level of awareness

An ANOVA on officer perceived level of situation awareness score revealed a significant effect of driving condition ($F(1,59)=4.9801$, $p=0.0295$). Figure 25 shows officer level of awareness on the driving environment significantly decreased when they used the MCT as compared to driving without MCT use.
4.11.1.4 Driver perceived workload

An ANOVA on the overall DALI score revealed a significant effect of driving condition (F(1,55)=104.1729, p<0.0001). Figure 26 shows officer perceived workload significantly increased when they performed the secondary task with MCT as compared to no MCT use. In addition, ANOVAs on all sub-dimensions of the DALI, including attention (F(1,56)=52.2356, p<0.0001), visual demand (F(1,55)=24.9512, p<0.0001), auditory demand (F(1,56)=49.2449, p<0.0001), temporal demand (F(1,55)=62.8322, p<0.0001), interference (F(1,55)=105.2682, p<0.0001), and situational stress (F(1,55)=50.1385, p<0.0001) revealed a consistently significant effects of the driving condition. Driving while using MCT increased all DALI sub-dimensions as compared to driving without MCT use. Trial number also had a
significant effect on visual demand (F(1,55)=6.7336, p=0.0121). Officers perceived lower demand with more trials.

![Figure 26: Effect of Driving Condition on Workload](image)

### 4.11.2 Analysis on baseline driving conditions (Phase 2)

As mentioned earlier, the main objective of this phase was to further validate conformance of participants with experimenter instructions. An ANOVA on the lane deviation response did not reveal any significant effect of hazard exposure (F(1,59)=0.8774, p=0.3527) in baseline driving trials. Participants followed experimenter instructions in terms of maintaining a consistent position of their vehicle in the middle lane of the freeway at all times. In addition, an ANOVA on the ranked speed deviation response showed a significant effect of hazard exposure (F(1,59)=99.4788, p<0.0001). Results of the speed deviation comparison due to
hazard exposure in baseline driving trials also revealed participant conformance with instructions as they were asked to deal with hazards using the brake and not to change lanes.

### 4.11.3 Analysis on driving conditions including secondary MCT task (Phase 3)

#### 4.11.3.1 Driving performance

Table 13 shows the descriptive statistics on officer driving performance measures while performing the secondary task with the different MCT interfaces. An ANOVA on the log lane deviation response revealed no significant main effect of MCT interface type (F(1,53)=0.1889, p=0.6656) or hazard exposure (F(1,53)=0.00, p=0.9964). There was also no significant interaction effect of hazard exposure and MCT interface type on the response (F(1,53)=0.0001, p=0.9907).

Regarding speed deviation, an ANOVA revealed a significant effect of hazard exposure (F(1,51)=11.5436, p=0.0013). There was no significant effect of MCT interface type (F(1,51)=0.4755, p=0.4936). In addition, the interaction between hazard exposure and MCT interface type was found to be insignificant (F(1,51)=1.5006, p=0.2262). Results further supports the effect of following instructions as compared to any influence of MCT interface type on driving performance.

Logistic regression on the number of collisions did not show any significant effect of MCT interface type ($\chi^2(1)=0.00$, p=0.9995), hazard exposure ($\chi^2(1)=0.0028$, p=0.9581) or the interaction ($\chi^2(1)=0.00$, p=0.9995). In addition, an ANOVA on brake reaction time response did not reveal any significant effect of MCT interface design (F(1,7)=1.4661, p=0.2652).
### Table 13: Descriptive Statistics of Driving Performance for Different MCT Interface Types

<table>
<thead>
<tr>
<th>Response</th>
<th>MCT Interface Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline (Mean ± SD)</td>
</tr>
<tr>
<td>Lane Deviation</td>
<td>1.04±1.08 ft</td>
</tr>
<tr>
<td>Speed Deviation</td>
<td>5.60±4.89 mph</td>
</tr>
<tr>
<td>Number of Crashes</td>
<td>0.03±0.16</td>
</tr>
<tr>
<td>Brake Reaction Time</td>
<td>8181±1537 ms</td>
</tr>
</tbody>
</table>

#### 4.11.3.2 Attention allocation

An ANOVA on ranked off-road longest glance duration revealed a significant effect of MCT interface type (F(1,53)=60.2063, p<0.0001) and a significant interaction of hazard exposure and MCT interface type (F(1,53)=4.5197, p=0.0382). However, there was no significant effect of hazard exposure on the response (F(1,53)=2.8018, p=0.1001). Figure 27 shows the baseline MCT interface produced significantly longer off-road glance durations as compared to the enhanced interface. Figure 28 shows the significant interaction between hazard exposure and the MCT interface type. When officers were using the baseline MCT interface to perform the plate check, their off-road glance duration significantly increased when exposed to a hazard whereas the enhanced MCT interface led to shorter off-road glance durations during hazard exposure. It is important to note that the mean of longest glance durations for both MCT interfaces were lower than the 2 sec vehicle control uncertainty threshold, according to NHTSA; however, some individual observations were over 2 sec. The longest glance duration was 3 sec and was observed in use of the baseline MCT. In total, 11% of all glance durations were greater than 2 sec.
Figure 27: Effect of MCT Interface Type on Longest Off-road Glance Duration

Figure 28: Hazard Exposure and MCT Interface Type Interaction

An ANOVA on fixation frequency showed a significant effect of MCT interface type (F(1,53)=8.6053, p=0.0049). However, there was no significant effect of hazard exposure (F(1,53)=0.2608, p=0.6117) and no significant interaction of hazard and interface type.
(F(1,53)=0.0154, p=0.9018). Figure 29 shows the enhanced MCT interface significantly reduced off-road fixation frequency as compared to the baseline design.

Figure 29: Effect of MCT Interface Type on Fixation Frequency

4.11.3.3 Secondary task performance

An ANOVA on ranked secondary task completion time revealed a significant effect of MCT interface type (F(1,54)=112.3858, p<0.0001). However, there was no significant effect of hazard exposure (F(1,54)=1.3639, p=0.2480) or the interaction of hazard exposure and interface type (F(1,54)=0.1555, p=0.6948). Trial number was significant effect in task completion time (F(1,54)=5.6429, p=0.0211). Figure 30 shows the enhanced MCT interface significantly reduced secondary task completion time compared to the baseline design. Regarding the effect of trial number, task completion time appeared to decrease across
experiment trails suggesting some additional officer learning of use of the MCT with the driving simulator.

![Figure 30: Effect of MCT Interface Type on Secondary Task Completion Time](image)

4.11.3.4 Driver perceived level of awareness

An ANOVA on driver perceived level of awareness did not show any significant effect of MCT interface type (F(1,20)=2.5789, p=0.1240). Table 14 shows the descriptive statistics regarding driver level of awareness for both interfaces.

Table 14: Descriptive Statistics of Driver Level of Awareness for Different MCT Types

<table>
<thead>
<tr>
<th>Response</th>
<th>MCT Interface Type</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline (Mean ± SD)</td>
<td>Enhanced (Mean ± SD)</td>
<td></td>
</tr>
<tr>
<td>SA Score</td>
<td>4.25±0.64</td>
<td>3.9±1.16</td>
<td></td>
</tr>
</tbody>
</table>
4.11.3.5 MCT usability score

An ANOVA on SUS score did not show any significant effect of MCT interface type (F(1,18)=0.1118, p=0.7420). Table 15 presents the descriptive statistics regarding the SUS score for both interfaces.

<table>
<thead>
<tr>
<th>Response</th>
<th>MCT Interface Type</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline (Mean ± SD)</td>
<td>Enhanced (Mean ± SD)</td>
<td></td>
</tr>
<tr>
<td>SUS Score</td>
<td>80.5±11.29</td>
<td>82.25±12.10</td>
<td></td>
</tr>
</tbody>
</table>

4.11.3.6 Driver perceived workload

An ANOVA on overall DALI score did not reveal a significant effect of interface design type on driver workload (F(1,19)=0.2606, p=0.6156). However, there was an effect of interface type on the temporal demand sub-dimension of the DALI (F(1,18)=12.91, p=0.0021). Trial number also appeared to have a significant effect on temporal demand (F(1,18)=6.9060, p=0.0171), auditory demand (F(1,18)=11.8125, p=0.0029), and situational stress (F(1,18)=6.6494, p=0.0189). No other DALI sub-dimensions were significantly changed by the interface manipulation (visual demand, F(1,19)=0.0474, p=0.83; auditory demand, F(1,18)=0.32, p=0.5786; interference, F(1,19)=1.2484, p=0.2778; and situational stress, F(1,18)=0.0017, p=0.9673). Figure 31 shows the enhanced MCT interface significantly reduced officer perceived temporal demand (i.e. time demand when performing the plate check task) as compared to the baseline design. In addition, temporal demand, auditory demand and situational stress all decreased substantially across the experiment trials.
4.11.4 Correlation analysis among driving simulation experiment responses

Since response data was not normally distributed, Spearman’s nonparametric correlation analysis procedure was used in this study. As shown in Table 16, workload as measured by DALI score was significantly correlated with driver perceived situation awareness, longest off-road glance duration, and fixation frequency. Results revealed that driver perceived situation awareness regarding the driving environment significantly decreased as workload increased. In addition, longest off-road glance duration and fixation frequency significantly increased as drivers perceived higher workload. Scatter plots of significant correlations are shown in Appendix J.
### Table 16: Correlation among Responses

<table>
<thead>
<tr>
<th>Response 1</th>
<th>Response 2</th>
<th>Spearman’s $\rho$</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workload</td>
<td>Situation Awareness</td>
<td>-0.3079</td>
<td>0.0079*</td>
</tr>
<tr>
<td>Workload</td>
<td>Usability Score</td>
<td>-0.1657</td>
<td>0.3200</td>
</tr>
<tr>
<td>Workload</td>
<td>Longest Glance Duration</td>
<td>0.6103</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Workload</td>
<td>Fixation Frequency</td>
<td>0.5792</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Workload</td>
<td>Lane Deviation</td>
<td>-0.0806</td>
<td>0.2795</td>
</tr>
<tr>
<td>Workload</td>
<td>Speed Deviation</td>
<td>-0.0811</td>
<td>0.2791</td>
</tr>
<tr>
<td>Workload</td>
<td>Brake Reaction Time</td>
<td>0.1068</td>
<td>0.2855</td>
</tr>
<tr>
<td>Usability Score</td>
<td>Longest Glance Duration</td>
<td>-0.0349</td>
<td>0.6398</td>
</tr>
<tr>
<td>Usability Score</td>
<td>Fixation Frequency</td>
<td>-0.0449</td>
<td>0.5473</td>
</tr>
<tr>
<td>Usability Score</td>
<td>Lane Deviation</td>
<td>0.0325</td>
<td>0.6635</td>
</tr>
<tr>
<td>Usability Score</td>
<td>Speed Deviation</td>
<td>-0.0264</td>
<td>0.7250</td>
</tr>
<tr>
<td>Usability Score</td>
<td>Brake Reaction Time</td>
<td>0.0160</td>
<td>0.8730</td>
</tr>
</tbody>
</table>

### 4.11.5 Comparison of GOMSL time estimates and secondary task completion time

GOMSL models developed for the baseline and enhanced MCT interfaces, and the different use scenarios, were compared with the task completion time results from the experiment. The objective of this comparison was to identify any effect of the multi-tasking behavior of driving on secondary task performance. Consequently, only those secondary task performance observations that occurred in the absence of hazard exposure were compared with the results of GOMSL models. The two use scenarios considered in this comparison included: (1) identifying vehicle tag status; and (2) identifying driver’s license status. Table 17 presents the GOMSL model time estimates for the two scenarios. It is important to note that for the enhanced MCT design, during the driving simulation experiment, it was observed that officers mainly used the summary page to identify legal violations while driving. Therefore, the time estimates of the GOMSL models considered in the present analysis are shorter than the values presented in Table 8 for the initial task models. In addition, there was no
difference in performance time with the enhanced interface when using the mouse controller vs. keyboard, since there was no need for officer use of the detailed information page. For both interfaces, time estimates for Scenario 2 (identify driver license status) were less than Scenario 1 (identify vehicle tag status), as driver license information was presented on a second page of information and the status was “suspended”. Vehicle tag information was presented on the third page and the status was “violated”. The information for the vehicle tag was also more extensive than for the driver’s license.

Table 17: GOMSL Model Time Estimates

<table>
<thead>
<tr>
<th>MCT Interface Type</th>
<th>Scenario 1 Time Estimation (sec)</th>
<th>Scenario 2 Time Estimation (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mouse</td>
<td>Keyboard</td>
</tr>
<tr>
<td>Baseline</td>
<td>10.050</td>
<td>11.110</td>
</tr>
<tr>
<td>Enhanced</td>
<td>2.200</td>
<td>2.200</td>
</tr>
</tbody>
</table>

Results of secondary task completion time for different scenarios are shown in Table 18. Similar to the GOMSL time estimates, the average time for completing the secondary task in Scenario 1 was longer than Scenario 2 for both interfaces.

Table 18: Descriptive Statistics for Multi-Tasking Times

<table>
<thead>
<tr>
<th>MCT Interface Type</th>
<th>Scenario 1 Multi-Task Time (sec)</th>
<th>Scenario 2 Multi-Task Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Baseline</td>
<td>12.545</td>
<td>4.367</td>
</tr>
<tr>
<td>Enhanced</td>
<td>3.727</td>
<td>1.848</td>
</tr>
</tbody>
</table>
As shown in Figure 32, on average, MCT task completion time increased as a result of multi-tasking with both interfaces (i.e., simultaneous performance of driving). This increase in secondary task performance time is directly attributable driving task demands.

Results of the comparison of multi-task times and GOMSL model estimates between the baseline and enhanced MCT interfaces revealed that the enhanced design could reduce the cost of multi-tasking ($m_3 < m_1$ and $m_4 < m_2$). Therefore, officers were faster in multi-tasking when they were using the enhanced MCT as compared to the baseline interface.

![Figure 32: Comparison of GOMSL Time Estimates with Multi-Tasking Times](image-url)
4.12 Discussion

4.12.1 Driving performance

Hypotheses regarding driving performance posited that using MCT while driving would increase average lane deviation (H1), speed variance (H2), the number of simulated vehicle crashes (H3), and brake reaction time to hazard situations (H4). All of these hypotheses were refuted as there was no significant effect of MCT use, in performing a plate check, on officer driving performance. Results indicate that officers maintained high levels of driving performance even when they were required (in this experiment) to use the MCT. A police officer’s main priority in field operations is to protect the driving task and their safety and they are aware that the on-board computer may be distracting. Another explanation for these results is that in the current experiment, officers were asked to maintain a consistent position of their vehicle in the middle lane of the freeway and to maintain their speed at the posted speed limit at all times (i.e. 40 mph). The lack of variation in lane and speed responses further confirms officer conformance with the driving instructions. Some studies have found the use of in-vehicle technologies to impact driver performance (e.g. Kaber et al., 2012). The results of this study are in line with findings of Williams et al. (2013) who did not find negative effects of in-vehicle devices on police officer driving performance. With respect to these differences in findings, it is important to note that the officers in our study were required to be expert professional drivers and to make regular patrols. Although law enforcement vehicle crash reports from different states identified distraction to MCT as one of the main causes of accidents (Yager, 2015), findings of the present study did not find any significant differences in the number of collisions as a result of using the MCT while driving.
In addition, the officers were only asked to perform a plate number check task while driving and there was no other interaction between an officer and the MCT. Other studies finding effects of driver distraction on performance (e.g., Zhang & Kaber, 2016) have posed very challenging combinations of visual and cognitive secondary tasks during freeway and urban driving simulations. In real patrol situations, officers may receive emergency phone calls or need to respond to the radio while driving which might increase their visual and cognitive demands and degrade their driving performance while using the MCT.

Hypotheses regarding the comparison of enhanced and baseline MCTs posited that the enhanced MCT design would decrease average lane deviation (H5), decrease speed variance (H6), decrease the number of simulated vehicle crashes (H7), and decrease brake reaction time to hazard situations (H8). All of these hypotheses were refuted as there was no significant effect of MCT interface type on any of driving performance responses. As mentioned previously, officers are conscientious of their driving performance and they are aware of the potential distraction due to the MCT. They work to protect the driving task from potential degradations due to in-vehicle activities. In addition, the results further support officer conformance with the experiment instructions to achieve lane and speed maintenance.

### 4.12.2 Attention allocation

Hypothesis 9 posited that the use of MCT while driving would increase off-road glance frequency. This hypothesis was supported by the data. Results revealed substantial increases in off-road fixation frequency when officers made use of the MCT for a plate check vs. no MCT use. In fact, using MCT while driving reduced officers’ visual attention to the roadway.
Although the effect of MCT use on officer visual attention has not been studied before, the findings of this study are in line with similar studies (e.g., Filtness et al., 2013) which contended that visual-manual MCT interfaces would lead to highest off-road glance frequency as compared to other interface modalities. In addition, the results are similar to the findings of Liang and Lee (2010) regarding the effect of in-vehicle visual distraction on driver fixation frequency.

Hypothesis 10 stated that the use of MCT while driving would increase off-road glance duration. This hypothesis was supported by the data. Results revealed that longest off-road glance duration significantly increased when officers were performing the secondary in-vehicle task with the MCT as compared to driving without using the MCT. Findings were in-line with the results of Liang and Lee (2010) on the effect of in-vehicle visual distraction on glance duration for normal drivers. In the context of emergency vehicles, Mitsopoulos-Rubens et al. (2013) also found that visual-manual interfaces led to significantly longer, safety-critical off-road glances as compared to other modalities of information presentation.

Hypothesis 11 posited that the enhanced MCT design would decrease off-road glance frequency as compared to the baseline MCT. The hypothesis was supported by data. Results revealed that off-road fixation frequency significantly decreased when officers were using the enhanced MCT interface as compared to the baseline MCT. Ranking display information, providing a summary list of legal violations, and improving the interaction between the MCT and drivers while reading messages in the plate number check task decreased their off-road fixation frequency as compared to reading the plain text in several pages of information. Findings suggest that even basic usability improvements in the design of MCT interface
could reduce officer off-road fixation frequency and increase their visual attention to the driving task.

Hypothesis 12 posited that the enhanced MCT design would decrease off-road glance duration as compared to the baseline MCT. The hypothesis was supported by the data. Similar to fixation frequency response, the significant reduction in longest off-road glance duration as a result of usability changes could increase visual attention of drivers to the roadway and improve safety. Regarding the significant interaction between MCT interface type and hazard exposure in longest off-road glance duration, it is possible that officers realized the baseline MCT interface was complex; thus, they decided to prioritize the roadway hazard and then look back at the MCT to complete the plate check or verify a response to an experimenter. Therefore, longest off-road glance duration increased as a result of hazard exposure while using the baseline MCT. However, for the enhanced design, the interface was simple and officers could complete the task during hazard exposure and there was no need for them to look back at the display and double-check their responses to questions.

4.12.3 Driver level of awareness

Hypothesis 13 posited that use of the MCT while driving would decrease officer perceived level of environment awareness. The hypothesis was supported by the data. Officer ratings of perceived level of driving environment awareness were substantially reduced in trials requiring the MCT for the plate check. However, results of this study were not in-line with the findings of Williams et al. (2013) as they did not observe any negative effect of in-
vehicle technology on officer situation awareness. It is important to note that Williams et al. used the MCT for presenting detailed information about a call but the officers did not have any other interaction with the device. The secondary task presented in this study required MCT manipulation for information retrieval.

Hypothesis 14 stated that the enhanced MCT design would increase officer perceived level of driving environment awareness as compared to the baseline MCT interface. This hypothesis was refuted by the data as there was no significant effect of MCT interface type on driver level of awareness. Results suggest that when using the enhanced MCT interface, officers felt as knowledgeable regarding the driving environment as when they were using the baseline MCT. However, one major limitation regarding this response was that officers were asked to rate their level of awareness at the end of each trial. It is possible that their ratings were based on other events during the trial (e.g. drivers might have an accident at the intersection when they were not using MCT) which were not related to the use of MCT.

4.12.4 Secondary task performance

Hypothesis 15 posited that the secondary-task completion time would decrease by using the enhanced MCT as compared to the baseline MCT interface. The hypothesis was supported by the data. Again, the basic usability changes in the design of MCT interface made the information search and reporting task much easier for the officers and significantly reduced the plate check completion time. As mentioned earlier, Marcus and Gasperini (2006) found several usability issues with the MCT including poor filtering of important information, and information poorly laid out. Findings of this study supported their recommendation regarding
improving the MCT using user-centered design and considering police officers in the design process as indicated by significant reduction in secondary task completion time. It is likely that the reduced secondary-task time led to the increases in on-road attention for the new interface, as well. Based on the findings of Green (1999), the less time that a driver spends on a secondary task, the more time available for him/her to pay attention to driving, which can increase safety. In general, the results provide evidence that even basic usability improvements in MCT design could increase driving safety for officers.

4.12.5 MCT usability score

Hypothesis 16 stated that the enhanced MCT would increase the SUS score in comparison to the baseline MCT design. This hypothesis was refuted as there was no significant effect of MCT interface type on the response. This insignificant result might have been due to the novelty of changes in the enhanced design including ranking the information, providing a summary page, etc. for the officers who were accustomed to the current information layout in the baseline MCT interface. Although participants were instructed to evaluate the interface only for the sub-task of reading plate information as part of the plate number check task, it is possible that their ratings were influenced by other segments of the task including data entry which was similar in both interfaces.

4.12.6 Driver perceived workload

Hypothesis 17 posited that using MCT while driving would increase officer workload as reflected by DALI scores. This hypothesis was supported by the data. Officers perceived
substantially higher overall workload when using the MCT for the plate check. In addition, all DALI sub-dimensions including attentional demand, visual demand, auditory demand, temporal demand, interference, and situational stress, revealed higher levels under MCT use compared to driving without the secondary task requirement. Although no prior study has examined the effect of MCT use on officer workload, the results of this experiment are in line with the findings of similar studies on the effect of in-vehicle technologies on driver workload, in general. The secondary task in this experiment was a combination of visual and cognitive distraction, as officers needed to find specific information and identify the status of violation. Related to this, Kaber et al. (2012) found that both visual and cognitive distraction due to secondary tasks significantly increased driver perceived workload over normal driving conditions.

Hypothesis 18 stated that the enhanced MCT would decrease driver workload as compared to the baseline MCT interface. This hypothesis was refuted in general as there was no effect of MCT interface type on overall workload, visual demand, auditory demand, interference, and situational stress. However, results revealed that driver temporal demand significantly decreased by using the enhanced MCT interface as compared to the baseline design. Although the findings of GOMS modeling revealed reduction in visual and cognitive operators as a result of using the enhanced MCT interface design for the similar task, results of subjective workload measures did not show any significant difference among the two interfaces. Since DALI was administered at the end of each trial, it is possible that participants forgot the amount of workload they were feeling during a particular segment of a driving task in which they were using the MCT. It is also possible that their ratings were
influenced by other events during a trial which were unrelated to the use of MCT (e.g. officers might have a crash at intersections). However, the results of temporal demand suggest that the enhanced MCT could significantly reduce the time pressure for the officers while driving which is in-line with the findings regarding secondary task completion time.

4.12.7 Correlations among measures

The correlation results revealed that higher officer perceived workload was associated with decreased time of eyes on-road and degraded perceptions of driving environment awareness. It can also be inferred that the eye tracking measures (longer off-road glance durations and fixation frequencies) may be effective indicators of officer workload in MCT use.
5 Conclusions

5.1 Determination of the most demanding MCT task

The first phase of this research was aimed at determining the most demanding MCT tasks for officers while driving, which had four main objectives: (1) identification of the perceived importance and frequency of use of police in-vehicle technologies and different MCT tasks; (2) analyzing the MCT tasks with the highest expected outcome values to identify goals, plans, and methods for goals; (3) identifying the tasks with significantly longer durations than others; and (4) identifying the perceptual, cognitive and motor requirements of the selected task and quantify the amount of cognitive and visual demands for drivers during performance. Results revealed that the MCT was the most demanding in-vehicle technology for officers. In addition, the tasks of “access call notes”, “plate number check”, and “find location on map” were the most important and frequently performed MCT tasks for police officers while driving. Findings of HTAs and task time analyses revealed that the subtasks of “orientation on map”, “reading plate information”, and “plate number entry” were the most time consuming sub-tasks and were further analyzed using cognitive task performance modeling. Using the GOMSL modeling technique, it was found that “reading plate information” was the most visually and cognitively demanding sub-task for police officers while driving. Results of this phase of research served as a basis for proposing an enhanced MCT interface in the next phase.
5.2 MCT interface design

The objectives of this phase were to: (1) identify usability violations of the current MCT interface and to formulate design recommendations for an enhanced MCT interface design; (2) apply those recommendations and guidelines in order to prototype an enhanced design, which might improve officer performance and safety; and (3) objectively demonstrate potential benefits of the enhanced design in terms of minimizing task complexity, task completion time and visual and cognitive demands. Results revealed that the principles of “simple and natural dialog” followed by “minimizing user’s memory load” were strongly violated by the current MCT interface design. Recommendations for addressing the usability issues included providing a summary page, ranking the information, improving display information presentation format, and enhancing navigation between different pages of information to improve police officer interaction with the MCT. Findings of the HTA and cognitive modeling comparisons revealed that the enhanced MCT interface reduced the complexity of specific MCT task performance, and substantially reduced the number of cognitive operations, cognitive overload potential, and task completion time, as compared to the current MCT used by police officers in this study.

5.3 Driving simulation study

The main objective of this study was to assess the effects of MCT interface design variations on police officer driving performance, visual behavior, secondary-task performance, perceived workload and driving environment awareness. Baseline and enhanced interfaces were compared in driving simulation study presenting a near-congestion urban setting.
Findings suggest that officers are protective of their driving performance while using MCTs, in general, for critical secondary tasks. However, use of the MCT appears to significantly degrade officer visual attention to a roadway as compared to driving without MCT use. Related to this, results revealed that basic usability changes to the MCT interface can help substantially increase officer visual attention to the driving task. In addition, results indicate that MCT use while driving significantly degrades officer perceived level of driving environment awareness and increases perceived workload. Furthermore, the enhanced MCT design appeared to reduce officer perceptions of temporal stress in using the device while driving. More sensitive measurement techniques of situation awareness and workload need to be applied to determine whether such outcomes are directly attributable to usability enhancements in the MCT interface. Another major finding of this study was that MCT usability enhancements significantly reduced secondary task completion time for officers allowing for more time with eyes on-road. In addition, using the enhanced interface decreased the cost of multi-tasking for officers while driving, as compared to the current MCT interface design.

Finally, the findings of this study may be useful for manufacturers who design MCT interfaces for police departments and for police officers as users of these systems. The work provides some information on the effects of very basic usability changes in MCT interface designs on officer performance. The changes we proposed appear to have substantial potential for increasing officer and civilian safety in police operations.
5.4 Limitations

There are several aspects of this study that may limit generalizability of findings. First, the experiment was conducted using a fixed-base driving simulator which did not convey motion or kinesthetic cues to drivers during simulation runs limiting realism. Second, the driving scenarios simulated a standard patrol situation for officers. Although crash fact reports indicate that ~50% of emergency vehicle crashes occur in non-emergency situations, the results of this study may not be generalizable to emergency operations. Third, this study was focused on “reading plate information” task. Although this selection was based on the findings of decision tree analysis and cognitive performance modeling, there are other tasks (e.g. find location on map) that maybe challenging for the officer in specific circumstances (e.g. being dispatched to an unknown area for an emergency call). Forth, this study did not investigate any potential effect of police officer fatigue on driver performance and attention allocation while using the MCT, which might be critical in driving simulation studies of longer duration. In addition, due to the limited sample size (20 police officers), some of the manipulations did not reveal significant effects on the responses which could be significant with a higher sample size. Finally, all participants were sampled from a mid-sized suburban southern Police Department. Results may not be generalizable for other police departments using customized MCT designs or other technologies to support patrol operations.

5.5 Future work

Future research should investigate the effect of using the MCT in emergency operations and whether usability enhancements can reduce driver distraction and improve performance in
those situations. Although this research was focused on improving the MCT interface for performing the most demanding task (i.e. reading plate number information), there is a need to assess how the interface could be improved to support other MCT tasks, such as finding location on map or accessing call notes. In addition, this study explored basic usability solutions to improve MCT interface design which could be easily implemented by manufacturers. However, future studies should investigate more enhanced in-vehicle technologies as alternatives for improving the interaction between police officers and the MCTs. Related to the generalizability of findings, it is necessary to conduct similar studies with a broader sample from different police departments and officers with a wider range of technology use experiences. Finally, this study used subjective ratings to measure driver workload and situation awareness, which were largely insensitive to the MCT interface manipulations. There is a need to consider use of real-time measures of operator workload responses (such as physiological measures, like HR) and measures of dynamic officer knowledge, including real-time probes based on rigorous analysis of patrol tasks.
REFERENCES


Chapter 20. Motor Vehicles. Retrieved from:  
http://www.ncga.state.nc.us/EnactedLegislation/Statutes/PDF/ByChapter/Chapter_20.pdf


Cuřín, J., Labský, M., Macek, T., Kleindienst, J., Young, H., Thyme-Gobbel, A., ... & König, L. (2011, November). Dictating and editing short texts while driving: Distraction and task completion. In *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 13-20). ACM.


Manes, D., & Green, P. (1997). Evaluation of a driver interface: Effects of control type (knob versus buttons) and menu structure (depth versus breadth) (No. HS-042 742,).


And http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+(NASS)/NASS+General+Estimates+System


North Carolina 2012 traffic crash facts. Retrieved from

North Carolina 2013 traffic crash facts. Retrieved from

North Carolina Line of Duty Deaths. Retrieved from
https://www.odmp.org/search/browse/NC


148


Appendix A: Driving Activity Load Index

During the test you have just completed you might have experienced some difficulties and constraints in regard to the driving task.

You are asked to evaluate this experience by considered six factors, as described below. Please read each factor and its description carefully and ask the experimenter to explain anything you do not fully understand.

<table>
<thead>
<tr>
<th>Title</th>
<th>Endpoints</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort of attention</td>
<td>Low/high</td>
<td>To evaluate the attention required by the activity-to think about, to decide, to choose, to look for and so on</td>
</tr>
<tr>
<td>Visual demand</td>
<td>Low/high</td>
<td>To evaluate the visual demand necessary for the activity</td>
</tr>
<tr>
<td>Auditory demand</td>
<td>Low/high</td>
<td>To evaluate the auditory demand necessary for the activity</td>
</tr>
<tr>
<td>Temporal demand</td>
<td>Low/high</td>
<td>To evaluate the specific constraint owing to timing demand when running the activity</td>
</tr>
<tr>
<td>Interference</td>
<td>Low/high</td>
<td>To evaluate the possible disturbance when running the driving activity simultaneously with any other supplementary task such as phoning, using systems or radio and so on</td>
</tr>
<tr>
<td>Situational stress</td>
<td>Low/high</td>
<td>To evaluate the level of constraints/stress while conducting the activity such as fatigue, insecure feeling, irritation, discouragement and so on</td>
</tr>
</tbody>
</table>
For each of the pairs below, circle the scale title that represents the more important contributor to workload when you are performing the driving task.

- Effort of attention or Visual demand
- Effort of attention or Auditory demand
- Effort of attention or Temporal demand
- Effort of attention or Interference
- Effort of attention or situational stress
- Visual demand or auditory demand
- Visual demand or Temporal demand
- Visual demand or Interference
- Visual demand or Situational stress
- Auditory demand or temporal demand
- Auditory demand or Interference
- Auditory demand or situational stress
- Temporal demand or Interference
- Temporal demand or situational stress
- Interference or Situational stress
For each factor you are asked to rate the level of constraint felt during the test on a scale from 0 (very low level of constraint) to 5 (very high level of constraint), as a result of the driving task.

**Global attention demand:**

Think about the mental (i.e. to think about, to decide...), visual and auditory demand required during the test to perform the whole activity.

![Global attention demand scale]

**Visual demand:**

Think about the visual demand required during the test to perform the whole activity.

![Visual demand scale]

**Auditory demand:**

Think about the auditory demand required during the test to perform the whole activity.

![Auditory demand scale]

**Stress:**

Think about the level of stress (i.e. fatigue, insecurity, irritation, feelings of discouragement) during the whole activity.

![Stress scale]
Temporal demand:

Think about the specific constraints felt due to time pressure of completing tasks during the whole activity.

Interference:

Think about the disturbance to the driving task when completing supplementary tasks (i.e. via the in-vehicle information system) simultaneously.
Appendix B: Demographic questionnaire

Age: ........ Date: ........

Please circle your gender: Male Female

Did you attend a police academy? Yes No

If so, how long was the training? ..................................

Have you received any additional formal training in police driving since the academy? Yes No What kind? ...................................

Years of experience as a police officer: ..................

Years served as primary patrol officer: ..................

On average, how many hours per work shift are you spending in car? ..................

Please identify the frequency of use (0% to 100%) for each of these in-vehicle technologies.

<table>
<thead>
<tr>
<th>In-vehicle technology</th>
<th>Frequency of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Computer Terminal</td>
<td></td>
</tr>
<tr>
<td>Video cameras</td>
<td></td>
</tr>
<tr>
<td>Radio systems</td>
<td></td>
</tr>
<tr>
<td>Siren and light controller panel</td>
<td></td>
</tr>
<tr>
<td>Radar system</td>
<td></td>
</tr>
<tr>
<td>Cell phone</td>
<td></td>
</tr>
<tr>
<td>Lo Jack</td>
<td></td>
</tr>
<tr>
<td>Printer</td>
<td></td>
</tr>
</tbody>
</table>
Please identify the benefit/cost of having/not having an access to the following in-vehicle technologies while driving in emergency situations.

0: no benefit, 10: high benefit

0: no cost, -10: high cost

<table>
<thead>
<tr>
<th>In-vehicle technology</th>
<th>Benefit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Computer Terminal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video cameras</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radio systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siren and light controller panel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radar system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell phone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lo Jack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Printer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

On the scale below, please mark the spot that represents the amount of experience you have driving while using a Mobile Computer Terminal (MCT).

No Experience | High Experience
Appendix C: Subjective rating survey of MCT tasks

Please identify the benefit/cost of having/not having an access to the following MCT tasks while driving in emergency situations.

0: no benefit,  10: high benefit

0: no cost , -10: high cost

<table>
<thead>
<tr>
<th>Task</th>
<th>Benefit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Find locations on Map</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to call notes (CAD Qry)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication among patrols (Messaging)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Status check</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plate number check</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile Field Reporting (MFR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please identify the frequency of use (from 0% to 100%) for each of these MCT tasks while driving in emergency situations.

<table>
<thead>
<tr>
<th>Task</th>
<th>Frequency of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Find locations using GPS/ Map</td>
<td></td>
</tr>
<tr>
<td>Access to call notes (CAD Qry)</td>
<td></td>
</tr>
<tr>
<td>Communication among patrols (Messaging)</td>
<td></td>
</tr>
<tr>
<td>Status check</td>
<td></td>
</tr>
<tr>
<td>Plate number check</td>
<td></td>
</tr>
<tr>
<td>Mobile Field Reporting (MFR)</td>
<td></td>
</tr>
</tbody>
</table>
Appendix D: Virtual storyboards

Current MCT Interface

Step 1) Status page: Press “NCIC” button to start running a tag

Step 2) NCIC page: Press ‘vehicle’ or ‘3’ key to enter the vehicle information
Step 3) Data entry page: Enter license number or vehicle tag; press enter or ‘S’ to submit

Step 4) Plate information: Page 1
Step 5) Plate information: Page 2 including the violation
Enhanced MCT Interface

Step 1) Status page: Press “NCIC” button to start running a tag

Step 2) NCIC page: Press ‘vehicle’ or ‘3’ key to enter the vehicle information
Step 3) Data entry page: Enter license number or vehicle tag; press enter or ‘S’ to submit

Step 4) Plate information: Summary page including the violation
Step 5) Plate information: Driver license page including the violation
Appendix E: Situation Awareness Subjective Rating

On the scale below, please identify your perceived level of awareness of the driving environment in test trial that you just completed.

<table>
<thead>
<tr>
<th>Strongly unaware</th>
<th>Strongly aware</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Scale" /></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
</table>
Appendix F: System Usability Scale

1. I think that I would like to use this system frequently
   | Strongly disagree | Strongly agree |
   | 1 | 2 | 3 | 4 | 5 |

2. I found the system unnecessarily complex
   | 1 | 2 | 3 | 4 | 5 |

3. I thought the system was easy to use
   | 1 | 2 | 3 | 4 | 5 |

4. I think that I would need the support of a technical person to be able to use this system
   | 1 | 2 | 3 | 4 | 5 |

5. I found the various functions in this system were well integrated
   | 1 | 2 | 3 | 4 | 5 |

6. I thought there was too much inconsistency in this system
   | 1 | 2 | 3 | 4 | 5 |

7. I would imagine that most people would learn to use this system very quickly
   | 1 | 2 | 3 | 4 | 5 |

8. I found the system very cumbersome to use
   | 1 | 2 | 3 | 4 | 5 |

9. I felt very confident using the system
   | 1 | 2 | 3 | 4 | 5 |

10. I needed to learn a lot of things before I could get going with this system
    | 1 | 2 | 3 | 4 | 5 |
Appendix G: Driving Scenarios

Driving Scenario 1: Baseline

Driving Scenario 2: Baseline
Driving Scenario 3: With MCT

Driving Scenario 4: With MCT
Appendix H: Driving Experiment Demographic Questionnaire

Age: ………..                   Date: ………..

Please circle your gender:            Male                        Female

Did you attend a police academy?                 Yes                      No

If so, how long was the training? …………………………………………..

Have you received any additional formal training in police driving since the academy?

Yes                          No                    What kind? ……………………………..

Years of experience as a police officer: ……………………………..

Years served as primary patrol officer: ……………………………

On average, how many hours per work shift are you spending in car? ………………………

On the scale below, please mark the spot that represents the amount of experience you have
driving while using a Mobile Computer Terminal (MCT).

No Experience | High Experience
Appendix I: Experiment Instructions

1. Checklist before starting Introduction

<table>
<thead>
<tr>
<th>No.</th>
<th>List</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>STISIM Driving Simulator operational</td>
<td>☐</td>
</tr>
<tr>
<td>2</td>
<td>Facelab System operational</td>
<td>☐</td>
</tr>
<tr>
<td>3</td>
<td>Eyeworks System operational</td>
<td>☐</td>
</tr>
<tr>
<td>4</td>
<td>Driving simulator controller (e.g., steering box, pedals, etc.)</td>
<td>☐</td>
</tr>
<tr>
<td>5</td>
<td>MCT system operational</td>
<td>☐</td>
</tr>
<tr>
<td>6</td>
<td>Informed Consent Forms available</td>
<td>☐</td>
</tr>
<tr>
<td>7</td>
<td>Driver Background Questionnaire, DALI, SUS, SA Forms available</td>
<td>☐</td>
</tr>
<tr>
<td>8</td>
<td>Simulator Sickness Questionnaire Form available (Excel file)</td>
<td>☐</td>
</tr>
<tr>
<td>9</td>
<td>Payment forms are available</td>
<td>☐</td>
</tr>
<tr>
<td>10</td>
<td>Laptop for playing the radio and the speakers are ready</td>
<td>☐</td>
</tr>
</tbody>
</table>

   a. Preparing Equipment

[Start up all equipment]

Turn on all equipment, including the three STISIM desktop computers, speakers, MCT laptop and the faceLAB eye-tracking system laptop. Please refer to how to start the STISIM hardware using this website:

http://www.ise.ncsu.edu/ergolab/driving/STISIM_Training.php

[THREE STISIM DESKTOP COMPUTERS]

To avoid the sleep mode on the three screens, press Channel 1 on the keyboard, video and mouse (KVM) switch, and move the mouse. The same procedure can be followed for Channels 2 and 3 on the KVM. The STISIM scenarios are controlled from Channel 2, so leave Channel 2 activated (center screen).

[faceLAB Setup]

Once the faceLAB software is running, open the recalibration dialog and check the following:

- Camera resolution is clear and crisp.
- Cameras point directly at the participant.
- Verify that the calibration is acceptable using "verify calibration".
[Training Verification and SSQ Excel Sheets]
Open the “SSQ-Template.xls” from the shared Google Drive before beginning the training session.

[Open EyeWorks Record]
Open EyeWorks Record before each experiment trial, confirm that the new save file is appropriately named to match the STISIM save file (e.g. S01_T01). Confirm that the frame rate is 10 frames per second.

2. Orientation
   a. Introduction

   [Escort a participant into the conference room (D456).]

   Thank you for participating in this experiment. First, please understand this experiment is not a test of your personal ability or driving skills. The objective of this research is to characterize officer use of mobile computer terminals while driving.

   b. Informed Consent Form

   [Prepare the informed consent form and a pen.]

   This form summarizes information you need to know about the experiment. Please read the document and feel free to ask any questions you may have.

   [Give the participant some time to read the form.]

   If you consent to participate in this study, please sign and date the form.

   Before we start, I need you to turn off your cell phone. You will be able to take breaks between trials, but in order to prevent distractions during simulator training and experiment trials, your phone needs to be deactivated.

   c. Driver Background Questionnaire (DBQ)

   [After signing the informed consent form, present the DQ.]

   Now you will complete a background questionnaire.

   [Verify that a participant completes all information correctly. Once complete, enter participant number at the end of the form.]
d. MCT Familiarization

[Before starting the training scenario, instruct the participant on how to perform the plate number check task using the MCT interface (baseline or enhanced).]

We will now move on to the training phase of the experiment. First, I am going to show you how to use the MCT to perform a sample plate number check in the absence of vehicle driving.

[Instruction for baseline MCT]
You are currently viewing the “status page” of the MCT prototype. Whenever you hear an auditory message saying “start running a tag”, you need to click on the NCIC tab or press the F8 key to see the NCIC page. On this page, you will need to click on the “vehicle” button or press “3” to advance to the plate entry page. In the plate entry page, you need to input the tag number that will be given to you by an auditory message. Once you have entered the number, you need to click on the “submit” button or press “S” to submit the plate number.

Now, you will see several message pages. You will be asked to find specific information for each case. For example, the question might be, “What is the status of the driver’s license?” You will need to find this information (in this case, the license will be active or expired) and report aloud your finding to an experimenter. You can go to the next message by pressing the “N” key or clicking on the “next” button. You can go to the previous message by pressing the “P” key or clicking on the “previous” button.

Once you have completed this task, you will need to return to the status page by clicking on the “status” tab or pressing the F5 key.

[Instruction for enhanced MCT]
You are currently viewing the “status page” of the MCT prototype. Whenever you hear an auditory message saying “start running a tag”, you will need to click on the NCIC tab or press the F8 key to see the NCIC page. On this page, you will need to click on the “vehicle” button or press the “3” key to advance to the plate entry page. On the plate entry page, you will need to input the tag number that will be given to you via an auditory message. Once you have entered the number, you need to click on the “submit” button or press the “S” key to submit the plate number.

Now, you will see a summary page in front of you. This page presents information about the status of the driver’s license, vehicle tag, insurance, etc. You will be asked to find specific information for each case that will be presented to you. For example, the question might be, “What is the status of the driver’s license?” You will need to find this information (in this case, the license will be active or expired) and report aloud
your finding to an experimenter. You may only look at the summary page to find the information you need or you can click on each section or press the number associated with each section to see more detail regarding a specific issue. As you might have noticed, there is a summary table at the top right of the screen, which shows all the information pages for each driver. It will also identify the page that you are currently viewing (highlighted tab) and which page includes a violation for the specific case (red text). You can navigate through different pages by clicking on each tab or by pressing the number associated with each tab (1-4). You can also return to the main summary page by clicking on the “Home” icon.

Once you have completed this task, you will need to return to the status page by clicking on the “status” tab or pressing the F5 key.

[Show the plate number check task. Once they are comfortable with MCT itself, start the training scenario description]

e. Simulator Sickness Questionnaire (SSQ)

[Escort a participant into the lab (D457).]
[Open the SSQ from the shared Google Drive folder]
[Escort participant to driving simulator and ask participant to sit at computer with SSQ loaded on the screen]

This form assesses your risk of developing simulator sickness caused by divergence between the visual sense of body orientation and motion, and realistic (kinesthetic) sensations of physical motion. Symptoms include disruptions in balance and coordination, nausea, dizziness, eye-strain, and headaches. If you demonstrate simulator sickness symptoms during the experiment that exceed your baseline responses, you will be provided with an additional 20-minute rest period before resuming the experiment. If symptoms persist, your participation will be terminated and you will be compensated for any time provided.

There are 16 symptoms in the form. We will go through each symptom and you need to give a rating from 0 to 4, where 0 represents no symptoms and 4 represents severe symptoms. This represents your feelings RIGHT NOW. You will be asked fill-out this form again after the training session and after every two test trials.

[Enter the participants’ answers onto the spreadsheet. Verify that the participant answered all information correctly and that they are not exhibiting significant symptoms (see below SSQ grading procedure).]

[Grading SSQ]
- If any column is >25, or if the sum of the columns is >50, the participant may have simulator sickness and the experiment should be postponed or suspended until their
symptoms have decreased. If symptoms do not improve sufficiently, the participant should be escorted out of the experiment.

f. Equipment Introduction

[START Equipment Familiarization]

In this experiment, we will use a high-fidelity driving simulator with a wide field of view, realistic cab and controls, etc. [POINT OUT CAB AND CONTROLS] The driving controls include an accelerator, brake pedal, steering wheel, and turn signals. [POINT OUT STEERING] The steering provides a speed-sensitive feel. You can move the seat forward or backward based on how you would normally sit in your car when driving. [IDENTIFY SPEAKER SET] The cab also integrates audio speakers for roadway sounds and driver warnings. [IDENTIFY MONITORS] You will see the roadway appear on these three monitors.

g. Training Session

[START Training Scenario]
- Turn on cab dashboard light so the participant can see the speedometer
- Make sure the center screen source is “HDMI 1”
- Load scenario or project file: “…\STISIM3\Projects\ZahabiDissertation\Zahabi_Training.evt”
- Enter “Training.Dat” as output file name

[Play the radio from this link: https://www.youtube.com/watch?v=78934D7CvY8]

The training scenario will present a normal urban driving environment. You will learn how to use each element of the simulation controller, including the steering wheel and pedals. We ask that you maintain a consistent position of your vehicle in the middle lane of the freeway and that you maintain speed at the posted limit (40 mph). In addition, at a certain point while driving, you will be asked to perform a plate number check using the laptop in front of you. The simulation will be automatically terminated at the end of the training trial. Please read the displayed instructions first. When you are ready, I will start the experiment.

[Turn off lights in lab]

[Click “Drive the simulator” (The car icon).]

[During the training, replay the audio message for the participant if (s)he asks.]
[Perform three training sessions for each participant, and calculate the average speed deviation and lane deviation using the “training assessment” application on the desktop. Compare the average speed and lane deviation with the criteria. Ask the participant if (s)he feels comfortable with the driving simulator and working with the laptop. Repeat the training session until the participant feels comfortable with the simulator or his/her training performance becomes consistent.]  

[Require completion of the SSQ after the training session to ensure that the participant is not developing any motion sickness symptoms. Ask the participant to leave the cab between the trials and walk to rest.]  

h. Calibration of Eye Tracking System  

[Switch the center monitor to Facelab Eye-tracking system. IDENTIFY THE EYE-TRACKING CAMERAS.]  

A FaceLab eye-tracking system is integrated with the simulator and is used to capture your gaze pattern during vehicle control. The Eye-tracking system provides real-time data on your gaze direction as well as eye closure and blink rates. We will calibrate the system to your eyes now.  

[Calibrate Eye-tracking System]  
- Ask the participant to sit upright and look forward at the center of the screen.  
- Adjust cameras to capture participant’s face  
- Ask participant to exit the cab, then calibrate the cameras by clicking on “Recalibrate” in the “Controls” window  
- Ask the participant to re-enter the driver’s seat  
- In FaceLab, go to "SET MODEL"  
- Take snapshot  
- Allow the participant to look around at the screens for 10 to 15 seconds in order for the FaceLab system to make adjustments.  
- For each new participant, go to "New Head Model" (Manual) under the "Head Model" group.  
- Save the participant’s head model under their Participant ID.  
- Verify that the reference points are accurate to the eye and mouth corners.  
- Verify feature templates; make sure that no features, such as glasses, hair or features that may change (e.g., dimples), are selected by the system.  
- Under calibrate, follow the on-screen instructions as participants look directly into each camera.  
- Finish the head model calibration.  
- In the world model, go to "calibrate."  
- Verify the center TV is showing in the FaceLab interface.  
- Complete the eye-calibration to the world model.  
- Change the TV setting back to the STISIM.]
3. Test Trials
   a. Preparing Simulator and Equipment (i.e., STISIM, Eye tracking)

   [Load appropriate scenario]
   “...\STISIM3\Projects\ZahabiDissertation\Zahabi_Baseline Scenario1.evt”
   “...\STISIM3\Projects\ZahabiDissertation\Zahabi_Baseline Scenario 2.evt”
   “...\STISIM3\Projects\ZahabiDissertation\Zahabi_Scenario 3.evt”
   “...\STISIM3\Projects\ZahabiDissertation\Zahabi_Scenario 4.evt”

   [Insert “OUTPUT” Data File Name]
   - Select the file name based on the participant number, trial identifier and date.
     o e.g., Participant 1, Trial 1, May 20, 2016 → S01_T1_0520.dat

   [Open EyeWorks Record]
   Once the “Blue page” is shown to the participant, do the following:
   - Press Alt+ tab -> now click on the “start” icon on the bottom left of the screen.
   - Select “Eyeworks” from the start menu.
   - Confirm that the new save file is appropriately named to match the STISIM save file.
   - Confirm that the frame rate is 10 frames per second.
   - Press “start.”
     o The EyeWorks “start” button should be pressed at the same time as the number 1 at the Facelab window (Control window/login/number 1 at the bottom of the window)

   [Open screen recording software]
   Click on the “FFsplit” icon on the desktop of MCT laptop. Press “start”. At the end of the trial, press “stop”.

   NOTE: Recording files will be saved in the video folder. Make sure that you have four recording files for each participant. Name the recording files as “P#_T#” at the end of each experiment. For example, the recording file for Participant 1 and Trial 1 should be named as: “P1_T1”.

   [Open appropriate MCT interface]
   Look at the randomization sheet on the Google Drive folder and load an appropriate MCT interface (baseline or enhanced) for the participant. Make sure that the “Caps lock” and “Fn” lights on the laptop are turned on. Expand the MCT scenario image to full screen.
b. Test Trials
(Consider the scenario file name and the output data file name before starting a test trial to verify correct selection.)

Now you will begin a test trial. You will be driving in an urban environment. Please recall that you need to maintain the posted speed limit at all times. Stay in the middle lane unless you are asked to turn right or left at the intersections. During the course of each trial, you may be asked to perform a plate number check using the laptop in front of you. You need to perform the task as quickly and as accurately as possible. The simulation includes several intersections at which you may need to turn left or right based on the instruction given prior to each. Please read the displayed instructions first. When you are ready, I will start the experiment.

[AT THE END OF THE TRIAL]
[Ask the participant to exit the driver’s seat and stretch their legs.]

C. Distribution of forms
[The following list presents the sequence with which forms should be delivered to officers during experimental testing:
- Trial 1
  - SA and DALI forms (see instructions below)
- Trial 2
  - SSQ 2
  - SA and DALI forms (see instructions below)
- Trial 3
  - SA and DALI forms (see instructions below)
- Trial 4
  - SA, DALI, and SUS forms (see instructions below)

Instructions for SA form:
On a scale from 1-5, please identify your perceived level of situation awareness of the driving environment during the test trial that you just completed.

Instruction for DALI form:
The Driver Activity Load Index (DALI) is a method to measure cognitive workload, specifically in a driving context. The first page of the DALI form describes all the dimensions for assessing workload using this method, which include: effort of attention, visual demand, auditory demand, temporal demand, interference, and situational stress. Please read the descriptions carefully and let me know if you have any questions in this regard. The second page of the form asks you to select the contributor to workload that is more important when performing the driving task. Finally, on the last page, for each workload factor, you are asked to rate the level of constraint felt during the test trial using a scale from 0 (very low) to 5 (very high), as a result of driving demands.

Instruction for SUS form:
This form is intended to assess the usability of the MCT interface that you used during the
experiment. The form contains 10 questions on different usability principles, including ease of use, consistency, etc. You are asked to provide ratings from 1 (strongly disagree) to 5 (strongly agree) for each question.

4. Debrief
   a. Payment Form

   [Hand the participant a Payment Form and a pen.]
   [Calculate the total compensation for the participant. Multiply $35.00 x (number of hours + (number of minutes / 60))]
   [Give the participant the payment form.]

   Now the experimental session has finished. Please fill in the payment form. Your compensation for participation in the experiment today is $70.

   [Let the participant fill out the payment form and then have an experimenter sign the form.]

   [Copy the payment form for Lab records.]

   [Inform the participant that payment for the experiment can be immediately received from Hakan Sungur in Room 423.]

   b. Copy of the Consent Form

   [Prepare the copy of the consent form.]

   The data collected today will be used to study the effects of MCT interface design on officer driving performance and visual attention allocation. We will make comparison between multiple variations on the MCT design. If you are interested in future information about this study or have any questions, please contact Dr. Kaber. His contact information is listed in the consent form that you will take home today.

   [Give the participant a copy of the consent form and an original copy of the payment form.]

   Thank you for participating in this study.

   [Escort the participant to Hakan Sungur in Daniels 423.]
Appendix J: Scatter Plots of Significant Correlations

Driver Workload vs. Situation Awareness

![Driver Workload vs. Situation Awareness](image1)

Driver Workload vs. Longest Off-road Glance Duration

![Driver Workload vs. Longest Off-road Glance Duration](image2)
Driver Workload vs. Off-road Fixation Frequency