

**An Assessment of the Attention Demand Associated with the Processing of
Information for In-Vehicle Information Systems (IVIS)**

John Paul Gallagher

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Industrial and Systems Engineering

APPROVED

Tom A. Dingus, Chair

Woodrow Barfield

Harold A. Kurstedt, Jr.

Vicki L. Neale

Walter W. Wierwille

April 25, 2001

Blacksburg, VA

Keywords: In-vehicle information systems, attention demand, situation awareness,
IVIS, ITS

Copyright 2001, John Paul Gallagher

An Assessment of the Attention Demand Associated with the Processing of Information for In-Vehicle Information Systems (IVIS)

John Paul Gallagher

(ABSTRACT)

Technological interventions are being considered to alleviate congestion and to improve the quality of driving on our nation's highways. These new technology interventions will be capable of increasing the amount of information provided to the driver; therefore, steps must be taken to ensure they do not require a high attention demand. (Limited attention resources can be diverted from the primary task of driving to a secondary in-vehicle task). The attention demand required as part of the process of extracting information has been studied relatively extensively. However, the processing required to make complex decisions is not well understood and provides cause for concern. This study investigated the attention demand required to perform several types of tasks, such as selecting a route, selecting the cheapest route, and selecting the fastest route. The three objectives of this study were:

- 1) To investigate driver performance during IVIS tasks that required additional processing of information after the extraction of information from a visual display.
- 2) To develop a method for evaluating driver performance with regard to safety. This task was accomplished by performing an extensive review of the literature, and developing two composite measures.
- 3) To provide descriptive data on the proportion of drivers who exceeded a threshold of driver performance for each of the different IVIS tasks.

An instrumented vehicle, equipped with cameras and sensors, was used to investigate on-road driver behavior on a four-lane divided road with good visibility. A confederate vehicle was driven in front of the instrumented vehicle to create a vehicle following situation. Thirty-six drivers participated in this study. Age, presentation format, information density, and type of task were the independent variables used in this study.

Results from this study indicate that a high proportion of drivers' will have substantially degraded performance performing IVIS tasks such as selecting a route or a hotel from several possibilities. Findings also indicate that tasks involving computations, such as selecting the quickest or cheapest route, require a high attention demand and consequently should not be performed by a driver when the vehicle is in motion. In addition, text-based messages in paragraph format should not be presented to the driver while the vehicle is in motion. The graphic icon format should be utilized for route planning tasks.

DEDICATION

This dissertation is dedicated to my parents John and Helen Gallagher. You have always stressed the importance of education. I know without your love and encouragement I could not have achieved this goal.

ACKNOWLEDGMENTS

I'd like to express my thanks and appreciation to all those who helped me in completing this research. First I'd like to thank my committee:

Tom Dingus, most importantly for being a friend and mentor through my successes and moments of uncertainty, and for his steadfast patience, understanding, and encouragement. Thanks for teaching me to express my thoughts scientifically.

Walter Wierwille, who first impacted me while I was a high school senior, as I toured the laboratories of Virginia Tech's engineering program and listened to him speak with admiration of the work of one of his students, Tom, who had just completed his dissertation research with in-vehicle information systems. Dr. Wierwille, thanks for stressing the importance of the fundamentals of measurements and analysis of data and for providing a strong foundation on which I based my research.

Harold Kurstedt, thanks for teaching me the Industrial Engineering skills that I have come to utilize and rely on a daily basis. Thanks for teaching me how to apply problem-solving methodologies.

Vicki Neale, who was always there to help me operationalize the psychology theories to solve engineering problems. Thanks for your help and encouragement.

Woody Barfield, I enjoyed our conversations about applications of findings to the larger picture of life. Thanks for being there when I needed guidance.

Next, I'd like to express special thanks to others who helped along the way: Myra, Wayne, Nancy, Melissa, Patrick, Rebecca, Stephanie, Lisa, John, Gail, Ihab, Helma, and Cara for their assistance in data collection and eye glance reduction. Andy, Brian, Tracy, and Mark for making this research possible by designing, installing, and maintaining the hardware and software systems used for data collection and analysis. Trina for her editorial revisions. Rich and Jon for their friendship and mentoring.

The statistical consulting department at Virginia Tech, in particular Sam Wilcock, Klaus Hinkelmann, and Marion Reynolds for their assistance in designing the statistical analysis used in this study.

The Federal Highway Administration for funding this research.

A very special thanks to my brothers, Bill and Tommy. Bill, for his inspiration, helping to put seemingly impossible struggles into perspective. Tommy, for the long hours and dedicated assistance with data reduction and presentation development.

And thank you Cheryl, Andy, Julie, Steve, Lisa, Patty, Tracey, Kerry, Terry, Charlie, Dennis, Marla, Stephen, Stacy, and other family, friends, and colleagues who helped me along the way.

TABLE OF CONTENTS

DEDICATION.....	III
ACKNOWLEDGMENTS.....	IV
TABLE OF CONTENTS.....	V
LIST OF TABLES.....	VIII
LIST OF FIGURES.....	XIII
CHAPTER 1: INTRODUCTION.....	1
1.1 Problem Statement.....	1
1.2 Objectives.....	2
1.3 Experimental Approach.....	2
1.4 Dissertation Overview.....	5
CHAPTER 2: BACKGROUND.....	6
2.1 IVIS Development.....	6
2.1.1 In-vehicle Routing and Navigation Systems (IRANS).....	7
2.1.2 In-vehicle Motorist Services and Information Systems (IMSI).....	8
2.1.3 In-vehicle Signing and Information Systems (ISIS).....	9
2.1.4 In-vehicle Safety Advisory and Warning Systems (IVSAWS).....	9
2.2 Objectives of the Study.....	10
2.2.1 Objective 1: To investigate driver performance during IVIS tasks that required supplemental information processing.....	11
2.2.2 Objective 2: To develop a method for evaluating driver performance with regard to safety.....	17
2.2.3 Objective 3: To provide descriptive data on the proportion of drivers who exceeded a safety threshold for each of the different IVIS tasks.....	37
CHAPTER 3: METHOD.....	39
3.1 Participants.....	39
3.2 Driving Conditions.....	39
3.3 Apparatus.....	40
3.3.1 Cameras and Sensors.....	40
3.3.2 In-vehicle Information System (IVIS).....	40
3.3.3 Confederate Vehicle.....	41
3.4 Experimental Design.....	42
3.4.1 Independent Variables.....	42
3.4.2 Dependent Variables.....	67
3.5 Procedures.....	69
3.5.1 Participant Screening and Training Procedures.....	69
3.5.2 Data Collection Procedures.....	70
3.5.3 Confederate Vehicle Procedures.....	72
3.5.4 Data Analysis Procedures.....	72
CHAPTER 4: RESULTS.....	77
4.1 Overview.....	77
4.2 Red-line and Yellow-line Thresholds.....	77
4.2.1 Red-line Thresholds.....	78
4.2.2 Yellow-line Thresholds.....	78
4.2.3 Results.....	79

4.3 Comparative Analysis of Attention Demands for IVIS Tasks.....	114
4.3.1 Low Density Level.....	115
4.3.2 Medium Density Level.....	121
4.3.3 High Density Level.....	130
CHAPTER 5: DISCUSSION AND FUTURE RESEARCH.....	138
5.1 Overview.....	138
5.2 Objective: To develop a method for evaluating driving performance with regard to safety.....	138
5.2.1 Red-line Threshold Measure.....	139
5.2.2 Yellow-line Threshold Measure.....	140
5.3 Objective: To investigate driver performance during IVIS tasks that required additional processing of information after the extraction of information from the display.....	142
5.3.1 Characteristics of the Intended Driver and Vehicle.....	142
5.3.2 Characteristics of the IVIS task.....	146
CHAPTER 6: CONCLUSIONS.....	152
Design Guidelines.....	152
REFERENCES.....	155
APPENDIX A – IVIS SUBSYSTEM DESCRIPTIONS.....	162
In-vehicle Information System (IVIS).....	163
In-vehicle Routing and Navigational Systems (IRANS).....	163
Information Description for Trip Planning.....	163
Information Description for Multi-Mode Travel Coordination and Planning.....	163
Information Description for Pre-Drive Route and Destination Selection.....	164
Information Description for Dynamic Route Selection.....	165
Information Description for Route Guidance.....	165
Information Description for Route Navigation.....	166
Information Description for Automatic Toll Collection.....	167
In-vehicle Motorist Services and Information Systems (IMSIS).....	167
Information Description for Broadcast Services/Attractions.....	167
Information Description for Services/Attractions Directory.....	168
Information Description for Destination Coordination.....	168
In-vehicle Signing and Information Systems (ISIS).....	169
Information Description of Displayed Roadway Sign Information.....	169
In-vehicle Safety Advisory and Warning Systems (IVSAWS).....	169
Information Description for Hazard Warning.....	169
Information Description for Road Condition Information.....	170
Information Description for Automatic Aid Request.....	170
Information Description for Manual Aid Request.....	170
Information Description for Vehicle Condition Monitoring.....	171
APPENDIX B – HCI GUIDELINES.....	172
APPENDIX C – SPECIFICATIONS FOR TEXT AND ICONS PRESENTED ON IVIS DISPLAYS.....	175
APPENDIX D – SPECIFICATIONS FOR EXPERIMENTAL VEHICLE.....	181
Cameras and Sensors.....	182
Eye Glance Camera.....	182

Forward-View Camera.....	183
Lane Marker Camera.....	183
Interior Camera.....	183
Sensors.....	183
Software and Hardware Interfaces.....	184
Multiplexer and PC-VCR.....	184
Data Collection System.....	184
Communications Equipment.....	184
Experimenter Data Flag Input Switch.....	184
In-vehicle Information System (IVIS).....	185
Safety Considerations.....	185
APPENDIX E – IVIS DISPLAYS PRESENTED.....	187
APPENDIX F – SCREENING QUESTIONNAIRE.....	221
APPENDIX G – INFORMATION SHEET FOR PARTICIPANTS.....	223
APPENDIX H – INFORMED CONSENT FOR PARTICIPANTS OF INVESTIGATIVE PROJECTS.....	229
APPENDIX I – HEALTH SCREENING QUESTIONNAIRE.....	236
APPENDIX J – TRAINING PROTOCOL.....	238
APPENDIX K – FRONT SEAT EXPERIMENTER PROTOCOL.....	268
APPENDIX L – CONFEDERATE DRIVER PROTOCOL.....	271
APPENDIX M – RED-LINE AND YELLOW-LINE THRESHOLDS FOR SP-HOTEL TASKS.....	273
APPENDIX N – RED-LINE AND YELLOW-LINE THRESHOLDS FOR SP-ROUTE TASKS.....	283
APPENDIX O – RED-LINE AND YELLOW-LINE THRESHOLDS FOR SPI-ALL TASKS.....	293
APPENDIX P – RED-LINE AND YELLOW-LINE THRESHOLDS FOR SPI-PARTIAL TASKS.....	301
APPENDIX Q – RED-LINE AND YELLOW-LINE THRESHOLDS FOR SC-DIVISION AND SC-DIVISION & ADDITION TASKS.....	311
APPENDIX R – RED-LINE AND YELLOW-LINE THRESHOLDS FOR SC-ADDITION TASKS.....	320
APPENDIX S – RED-LINE AND YELLOW-LINE THRESHOLDS FOR SPC TASKS.	329
APPENDIX T – RED-LINE AND YELLOW-LINE THRESHOLDS FOR SPIC TASKS..	334
APPENDIX U – RED-LINE AND YELLOW-LINE THRESHOLDS FOR S-GENERAL SEARCH TASKS.....	339
APPENDIX V – RED-LINE AND YELLOW-LINE THRESHOLDS FOR S-HP TASKS.	347
APPENDIX W – RED-LINE AND YELLOW-LINE THRESHOLDS FOR ROUTE SELECTION SEARCH TASKS, TABLE FORMAT.....	355
APPENDIX X – RED-LINE AND YELLOW-LINE THRESHOLDS FOR ROUTE SELECTION SEARCH TASKS, GRAPHIC MAP FORMAT.....	362
VITA.....	371

LIST OF TABLES

Table 2.1. Decision-making elements	12
Table 3.1. Participants' age and miles driven annually.....	39
Table 3.2. Independent Variables.....	44
Table 3.3. Categories of information presented in different density levels.....	47
Table 3.4. Categories of information presented to drivers during SP-hotel.....	51
Table 3.5. Density levels utilized for SP-hotel tasks.....	52
Table 3.6. Categories of information presented to drivers during SP-route tasks.....	54
Table 3.7. Density levels utilized for SP-route tasks.....	54
Table 3.8. Categories of information presented to drivers during SPI tasks.....	56
Table 3.9. Density levels utilized for SPI tasks.....	57
Table 3.10. Categories of information presented to drivers during SC tasks.....	58
Table 3.11. Density levels utilized for SC tasks.....	59
Table 3.12. Categories of information presented to drivers during SPC tasks.....	62
Table 3.13. Density levels utilized for SPC tasks.....	63
Table 3.14. Categories of information presented to drivers during SPIC tasks.....	64
Table 3.15. Density levels utilized for SPIC tasks.....	65
Table 3.16. Dependent measures.....	68
Table 3.17. Red-line Threshold values.....	74
Table 3.18. Yellow-line Threshold measures.....	75
Table 3.19. Mean values for the different time intervals.....	75
Table 4.1. Yellow-line Threshold for SP-hotel tasks.....	81
Table 4.2. Yellow-line Threshold for SP-route tasks.....	84
Table 4.3. Yellow-line Threshold for SPI tasks.....	88
Table 4.4. Proportion of drivers who exceeded the Red-line Threshold with SC-division tasks.....	91
Table 4.5. Yellow-line Threshold for SC-division tasks.....	92
Table 4.6. Proportion of drivers who exceeded the Red-line Threshold with SC-division & addition.....	92
Table 4.7. Yellow-line Threshold for SC-division & addition tasks.....	93
Table 4.8. Proportion of drivers who exceeded the Red-line Threshold with SC-addition tasks.....	95
Table 4.9. Yellow-line Threshold for SC-addition tasks.....	96
Table 4.10. SPC tasks.....	98
Table 4.11. SPIC tasks.....	100
Table 4.12. S-general tasks successfully completed.....	102
Table 4.13. Yellow-line Threshold for S-general tasks.....	103
Table 4.14. S-HP tasks successfully completed.....	105
Table 4.15. Yellow-Line Threshold for S-HP tasks	106
Table 4.16. Route selection Search tasks successfully completed in the table format.....	108
Table 4.17. Yellow-line Threshold for route selection Search tasks, table format.....	108
Table 4.18. Route selection Search tasks successfully completed in the graphic map formats.....	112
Table 4.19. Yellow-line Threshold for route selection Search tasks in the graphic map formats.....	113

Table 4.20. Types of information processing tasks presented in each of the presentation formats at the low density level.....	115
Table 4.21. Types of information processing tasks presented in each of the presentation formats at the medium density level.....	121
Table 4.22. Types of information processing tasks presented in each of the presentation formats at the high density level.....	130
Table B.1. Eight golden rules of dialogue design.....	173
Table B.2. Data display guidelines.....	173
Table B.3. Data entry guidelines.....	174
Table B.4. Effective wording guidelines.....	174
Table D.1. Mechanical specifications of the Dolch Computer Systems, Inc. 10-inch VGA DataView Display.....	185
Table M.1. Red-line and Yellow-line Thresholds for SP-Hotel tasks.....	274
Table M.2. Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for SP-Hotel tasks.....	275
Table M.3. Proportion of young drivers who exceeded the Red-line Threshold for SP-Hotel tasks.....	276
Table M.4. Proportion of middle age drivers who exceeded the Red-line Threshold for SP-Hotel tasks.....	277
Table M.5. Proportion of older drivers who exceeded the Red-line Threshold for SP-Hotel tasks.....	278
Table M.6. Paired T value, Yellow-line Threshold results for SP-Hotel, paragraph format tasks.....	279
Table M.7. Paired T value, Yellow-line Threshold results for SP-Hotel, table format tasks.....	280
Table M.8. Paired T value, Yellow-line Threshold results for SP-Hotel, graphic text format tasks.....	281
Table M.9. Paired T value, Yellow-line Threshold results for SP-Hotel, graphic icon format tasks.....	282
Table N.1. Red-line and Yellow-line Thresholds for SP-Route tasks.....	284
Table N.2. Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for SP-Route tasks.....	285
Table N.3. Proportion of young drivers who exceeded the Red-line Threshold for SP-Route tasks.....	286
Table N.4. Proportion of middle age drivers who exceeded the Red-line Threshold for SP-Route tasks.....	287
Table N.5. Proportion of older drivers who exceeded the Red-line Threshold for SP-Route tasks.....	288
Table N.6. Paired T value, Yellow-line Threshold results for SP-Route, paragraph format tasks.....	289
Table N.7. Paired T value, Yellow-line Threshold results for SP-Route, table format tasks.....	290
Table N.8. Paired T value, Yellow-line Threshold results for SP-Route, graphic text format tasks.....	291
Table N.9. Paired T value, Yellow-line Threshold results for SP-Route, graphic icon format tasks.....	292

Table O.1.	Red-line and Yellow-line Thresholds for SPI-all tasks.....	294
Table O.2.	Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for SPI-all tasks.....	295
Table O.3.	Proportion of young drivers who exceeded the Red-line Threshold for SPI-all tasks.....	296
Table O.4.	Proportion of middle age drivers who exceeded the Red-line Threshold for SPI-all tasks.....	297
Table O.5.	Proportion of older drivers who exceeded the Red-line Threshold for SPI-all tasks.....	298
Table O.6.	Paired T value, Yellow-line Threshold results for SPI-all, paragraph format tasks.....	299
Table O.7.	Paired T value, Yellow-line Threshold results for SPI-all, table format tasks....	300
Table P.1.	Red-line and Yellow-line Thresholds for SPI-partial tasks.....	302
Table P.2.	Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for SPI-partial tasks.....	303
Table P.3.	Proportion of young drivers who exceeded the Red-line Threshold for SPI-partial tasks.....	304
Table P.4.	Proportion of middle age drivers who exceeded the Red-line Threshold for SPI-partial tasks.....	305
Table P.5.	Proportion of older drivers who exceeded the Red-line Threshold for SPI-partial tasks.....	306
Table P.6.	Paired T value, Yellow-line Threshold results for SPI-partial, paragraph format tasks.....	307
Table P.7.	Paired T value, Yellow-line Threshold results for SPI-partial, table format tasks.....	308
Table P.8.	Paired T value, Yellow-line Threshold results for SPI-partial, graphic text format tasks.....	309
Table P.9.	Paired T value, Yellow-line Threshold results for SPI-partial, graphic icon format tasks.....	310
Table Q.1.	Red-line and Yellow-line Thresholds for SC-division and SC-division & addition tasks.....	312
Table Q.2.	Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for SC-division and SC-division & addition tasks.....	313
Table Q.3.	Proportion of young drivers who exceeded the Red-line Threshold for SC-division and SC-division & addition tasks.....	314
Table Q.4.	Proportion of middle age drivers who exceeded the Red-line Threshold for SC-division and SC-division & addition tasks.....	315
Table Q.5.	Proportion of older drivers who exceeded the Red-line Threshold for SC-division and SC-division & addition tasks.....	316
Table Q.6.	Paired T value, Yellow-line Threshold results for SC-division and SC-division & addition, paragraph format tasks.....	317
Table Q.7.	Paired T value, Yellow-line Threshold results for SC-division and SC-division & addition, table format tasks.....	318
Table Q.8.	Paired T value, Yellow-line Threshold results for SC-division and SC-division & addition, graphic text format tasks.....	319
Table R.1.	Red-line and Yellow-line Thresholds for SC-addition tasks.....	321

Table R.2.	Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for SC-addition tasks.....	322
Table R.3.	Proportion of young drivers who exceeded the Red-line Threshold for SC-addition tasks.....	323
Table R.4.	Proportion of middle age drivers who exceeded the Red-line Threshold for SC-addition tasks.....	324
Table R.5.	Proportion of older drivers who exceeded the Red-line Threshold for SC-addition tasks.....	325
Table R.6.	Paired T value, Yellow-line Threshold results for SC-addition, paragraph format tasks.....	326
Table R.7.	Paired T value, Yellow-line Threshold results for SC-addition, table format tasks.....	327
Table R.8.	Paired T value, Yellow-line Threshold results for SC-addition, graphic text format tasks.....	328
Table S.1.	Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for SPC tasks.....	330
Table S.2.	Proportion of young drivers who exceeded the Red-line Threshold for SPC tasks.....	331
Table S.3.	Proportion of middle age drivers who exceeded the Red-line Threshold for SPC tasks.....	332
Table S.4.	Proportion of older drivers who exceeded the Red-line Threshold for SPC tasks.....	333
Table T.1.	Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for SPIC tasks.....	335
Table T.2.	Proportion of young drivers who exceeded the Red-line Threshold for SPIC tasks.....	336
Table T.3.	Proportion of middle age drivers who exceeded the Red-line Threshold for SPIC tasks.....	337
Table T.4.	Proportion of older drivers who exceeded the Red-line Threshold for SPIC tasks.....	338
Table U.1.	Red-line and Yellow-line Thresholds for S-General Search tasks.....	340
Table U.2.	Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for S-General Search Tasks.....	341
Table U.3.	Proportion of young drivers who exceeded the Red-line Threshold for S-General Search Tasks.....	342
Table U.4.	Proportion of middle age drivers who exceeded the Red-line Threshold for S-General Search tasks.....	343
Table U.5.	Proportion of older drivers who exceeded the Red-line Threshold for S-General Search tasks.....	344
Table U.6.	Paired T value, Yellow-line Threshold results for S-General Search, paragraph format tasks.....	345
Table U.7.	Paired T value, Yellow-line Threshold results for S-General Search, table format tasks.....	346
Table V.1.	Red-line and Yellow-line Thresholds for S-HP tasks.....	348
Table V.2.	Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for S-HP tasks.....	349

Table V.3. Proportion of young drivers who exceeded the Red-line Threshold for S-HP tasks.....	350
Table V.4. Proportion of middle age drivers who exceeded the Red-line Threshold for S-HP tasks.....	351
Table V.5. Proportion of older drivers who exceeded the Red-line Threshold for S-HP tasks.....	352
Table V.8. Paired T value, Yellow-line Threshold results for S-HP, graphic text format tasks.....	353
Table V.9. Paired T value, Yellow-line Threshold results for S-HP, graphic icon format tasks.....	354
Table W.1. Red-line and Yellow-line Thresholds for route selection Search tasks, table format.....	356
Table W.2. Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for route selection Search tasks, table format tasks.....	357
Table W.3. Proportion of young drivers who exceeded the Red-line Threshold for route selection Search tasks, table format tasks.....	358
Table W.4. Proportion of middle age drivers who exceeded the Red-line Threshold for route selection Search tasks, table format tasks.....	359
Table W.5. Proportion of older drivers who exceeded the Red-line Threshold for route selection Search tasks, table format tasks.....	360
Table W.6. Paired T value, Yellow-line Threshold results for route selection Search tasks, table format.....	361
Table X.1. Red-line and Yellow-line Thresholds for route selection Search tasks, graphic map format.....	363
Table X.2. Proportion of drivers from all age groups combined who exceeded the Red-line Threshold for route selection Search tasks, graphic map format tasks.....	364
Table X.3. Proportion of young drivers who exceeded the Red-line Threshold for route selection Search tasks, graphic map format tasks.....	365
Table X.4. Proportion of middle age drivers who exceeded the Red-line Threshold for route selection Search tasks, graphic map format tasks.....	366
Table X.5. Proportion of older drivers who exceeded the Red-line Threshold for route selection Search tasks, graphic map format tasks.....	367
Table X.6. Paired T value, Yellow-line Threshold results for route selection Search tasks, graphic text format.....	368
Table X.7. Paired T value, Yellow-line Threshold results for route selection Search tasks, graphic icon format.....	370

LIST OF FIGURES

Figure 2.1. Example of Heinrich’s triangle with hypothetical relative frequencies for driving ... 18

Figure 2.2. Illustration of Red-line and Yellow-line Thresholds..... 37

Figure 3.1. IVIS display in the experimental vehicle..... 41

Figure 3.2. Variables..... 42

Figure 3.3. Table format..... 45

Figure 3.4. Paragraph format..... 46

Figure 3.5. Graphic text format..... 46

Figure 3.6. Graphic icon format..... 46

Figure 3.7. Low density (3x2), graphic icon..... 48

Figure 3.8. Medium density (3x3), graphic icon..... 48

Figure 3.9. Medium density (5x2), graphic icon..... 49

Figure 3.10. High density (5x4), graphic icon..... 49

Figure 3.11. Very high density (5x6), graphic icon..... 49

Figure 3.12. An example of a SP-hotel..... 52

Figure 3.13. An example of an SP-route task..... 54

Figure 3.14. An example of an SPI-partial task..... 56

Figure 3.15. An example of an SPI-all task..... 57

Figure 3.16. An example of an SC-addition task..... 59

Figure 3.17. An example of an SC-division task..... 60

Figure 3.18. An example of an SC-division & addition task..... 60

Figure 3.19. An example of an SPC task..... 62

Figure 3.20. An example of an SPIC task..... 64

Figure 3.21. S-general task, table format..... 66

Figure 3.22. S-HP task, graphic icon format..... 66

Figure 3.23. S-RPI task, graphic icon format..... 67

Figure 4.1. Proportion of drivers who exceeded the Red-line Threshold with SP-hotel tasks..... 80

Figure 4.2. Proportion of drivers who exceeded the Red-line Threshold with SP-route tasks..... 83

Figure 4.3. Proportion of drivers who exceeded the Red-line Threshold with SPI-all tasks..... 86

Figure 4.4. Proportion of drivers who exceeded the Red-line Threshold with SPI-partial tasks. 87

Figure 4.5. Proportion of drivers who exceeded the Red-line Threshold with SC-division tasks.91

Figure 4.6. Proportion of drivers who exceeded the Red-line Threshold with SC-addition tasks 95

Figure 4.7. Proportion of drivers who exceeded the Red-line Threshold with S-general tasks....102

Figure 4.8. Proportion of drivers who exceeded the Red-line Threshold with S-HP tasks..... 104

Figure 4.9. Proportion of drivers who exceeded the Red-line Threshold with route selection
Search tasks, table format.....107

Figure 4.10. Proportion of drivers who exceeded the Red-line Threshold with route selection
Search tasks, graphic map format..... 110

Figure 4.11. Proportion of drivers who exceeded the Red-line Threshold with S-RP tasks..... 110

Figure 4.12. Proportion of drivers who exceeded the Red-line Threshold with S-RPI tasks..... 111

Figure 4.13. Proportion of drivers who exceeded the Red-line Threshold with
S-compute tasks.....111

Figure 4.14. Proportion of drivers who exceeded the Red-line Threshold when presented
with Search tasks and SP-route tasks in each of the presentation formats, at
the low density level..... 117

Figure 4.15. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold on each presentation format, at the low density level.....	117
Figure 4.16. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the paragraph format, at the low density level.....	118
Figure 4.17. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the paragraph format, at the low density level.....	119
Figure 4.18. Proportion of drivers who exceeded the Red-line Threshold with the table format, at the low density level.....	120
Figure 4.19. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold in the graphic icon format, at the low density level.....	120
Figure 4.20. Proportion of drivers who exceeded the Red-line Threshold when presented with Search, SP-route, and SPI-partial tasks in different presentation formats, at the medium density level.	123
Figure 4.21. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold on Search, SP-route, and SPI-partial tasks in different presentation formats, at the medium density level.	124
Figure 4.22. Proportion of drivers who exceeded the Red-line Threshold when presented with the SC-division task in different presentation formats, at the medium density level.	124
Figure 4.23. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the paragraph format, at the medium density level.....	125
Figure 4.24. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the paragraph format, at the medium density level.....	126
Figure 4.25. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the table format, at the medium density level.....	126
Figure 4.26. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the table format, at the medium density level.....	127
Figure 4.27. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the graphic text format, at the medium density level....	128
Figure 4.28. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the graphic text format, at the medium density level.....	128
Figure 4.29. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the graphic icon format, at the medium density level...	129
Figure 4.30. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the graphic icon format, at the medium density level.....	129
Figure 4.31. Proportion of drivers who exceeded the Red-line Threshold when presented with Search, SP-route, and SPI-partial tasks in different presentation formats, at the high density level.	132
Figure 4.32. Proportion of drivers who exceeded the Red-line Threshold when presented with computation tasks in different presentation formats, at the 5x4 density level.....	132
Figure 4.33. Proportion of drivers who exceeded the Red-line Threshold when presented with SP-hotel tasks in each of the presentation formats, at the high density level.....	133
Figure 4.34. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the paragraph format, at the high density level.....	134
Figure 4.35. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the table format, at the high density level.....	135

Figure 4.36. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the graphic text format, at the high density level.....	136
Figure 4.37. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the graphic text format, at the high density level.....	136
Figure 4.38. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the graphic icon format, at the high density level.....	137
Figure 4.39. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the graphic icon format, at the high density level.....	137
Figure D.1. Diagram of the instrumented vehicle.....	186
Figure E.1. Paragraph format – SP-hotel tasks.....	188
Figure E.2. Table format – SP-hotel tasks.....	189
Figure E.3. Graphic text format – SP-hotel tasks.....	190
Figure E.4. Graphic icon format – SP-hotel tasks.....	191
Figure E.5. Table format – SP-route tasks.....	192
Figure E.6. Paragraph format – SP-route tasks.....	193
Figure E.7. Graphic text format – SP-route tasks.....	194
Figure E.8. Graphic icon format – SP-route tasks.....	195
Figure E.9. Paragraph format – SPI-all tasks.....	196
Figure E.10. Table format – SPI-all tasks.....	197
Figure E.11. Paragraph format – SPI-partial tasks.....	198
Figure E.12. Table format – SPI-partial tasks.....	199
Figure E.13. Graphic text format – SPI-partial tasks.....	200
Figure E.14. Graphic icon format – SPI-partial tasks.....	201
Figure E.15. Paragraph format – SC tasks.....	202
Figure E.16. Table format – SC tasks.....	203
Figure E.17. Graphic text format – SC-tasks.....	204
Figure E.18. Paragraph format – SPC task.....	205
Figure E.19. Table format – SPC tasks.....	206
Figure E.20. Graphic text format – SPC tasks.....	207
Figure E.21. Paragraph format – SPIC tasks.....	208
Figure E.22. Table format – SPIC tasks.....	209
Figure E.23. Graphic text format – SPIC tasks.....	210
Figure E.24. Paragraph format – S-General tasks.....	211
Figure E.25. Table format – S-General tasks.....	212
Figure E.26. Graphic text format – S-HP tasks.....	213
Figure E.27. Graphic icon format – S-HP tasks.....	214
Figure E.28. Graphic text format – S-RP tasks.....	215
Figure E.29. Graphic icon format – S-RP tasks.....	216
Figure E.30. Table format – S-RPI tasks.....	217
Figure E.31. Graphic text format – S-RPI tasks.....	218
Figure E.32. Graphic icon format – S-RPI tasks.....	219
Figure J.1. Training Slide #1.....	241
Figure J.2. Training Slide #2.....	246
Figure J.3. Training Slide #3.....	247
Figure J.4. Training Slide #4.....	249
Figure J.5. Training Slide #5.....	250

Figure J.6. Training Slide #6..... 251
Figure J.7. Training Slide #7..... 253
Figure J.8. Training Slide #8..... 254
Figure J.9. Training Slide #9..... 255
Figure J.10. Training Slide #10..... 256
Figure J.11. Training Slide #11..... 257
Figure J.12. Training Slide #12..... 258
Figure J.13. Training Slide #13..... 263
Figure J.14. Training Slide #14..... 265
Figure J.15. Training Slide #15..... 265
Figure J.16. Training Slide #16..... 266
Figure J.17. Training Slide #17..... 266
Figure J.18. Training Slide #18..... 267

CHAPTER 1: INTRODUCTION

1.1 PROBLEM STATEMENT

A staggering number of lives have been lost and great financial cost has been incurred as a result of traffic accidents on our nation's roadways. In 2000, over 41,800 individuals died in motor vehicle accidents, an average of one person every thirteen minutes (National Highway Traffic Safety Administration, 2001). Costs associated with traffic accidents total \$70 billion annually, much of which is attributable to excessive traffic congestion (IVHS America, 1992). Human error, related to the processing of information, has been found to account for over 70% of traffic accidents (Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansifer, Castellan, 1979). In the past, when roadways became heavily traveled and congested, new roads were constructed. However, in many parts of the country, this is no longer economically or environmentally feasible (Committee on Public Works and Transportation, U.S. House of Representatives, 1989; IVHS America, 1992).

Technological interventions are now being considered to alleviate congestion and improve the quality of driving. Additional loss of life and financial costs may occur if those new technology interventions under development that are capable of increasing the amount of information provided to the driver are not designed with care. Limited attention resources can be diverted from the primary task of driving to a secondary in-vehicle task. The attention demand required as part of the process of extracting information has been studied relatively extensively. However, it is recognized that many of the new in-vehicle information systems (IVISs) under development could potentially require a driver to not only extract information from the visual display, but also to further process the displayed information to make a decision. For example, a driver uses the IVIS to display alternative routes to a destination and the associated delays for each of these routes. He/she then selects a route from this information. The attention demand required for processing the information to make a decision is a cause for concern. Research has found that individuals who talk on cellular phones while driving a vehicle are four times as likely to be involved in an accident; this finding is similar to the results found from driving with a blood alcohol level at legal limits (Redelmeirer and Tibshirani, 1997). The attention demand of

IVISs under development could create a similar unsafe situation, causing drivers to divert their visual attention away from the primary task of driving to complete the IVIS task.

1.2 OBJECTIVES

The objectives of this project were:

- 1) To investigate driver performance during IVIS tasks that required additional processing of information after the extraction of information from a visual display;
- 2) To develop a method for establishing safety criteria for driver performance, i.e. safety “red-lines” for modeling purposes; and
- 3) To provide descriptive data on the proportion of drivers who exceeded a safety threshold of driver performance for each of the different IVIS tasks.

1.3 EXPERIMENTAL APPROACH

This project built upon past studies conducted on the attention demand of IVISs. The attention demand of IVISs has been studied for more than 15 years. Recognizing the importance of minimizing the attention demand of IVISs, Kurokawa and Wierwille (1990) created a computer-based program to be used by design engineers. This program assisted designers in developing IVISs, including speedometers, gas/oil gauges, and radio/cassette players. Since the development of this design tool in 1990, new technological advances have provided drivers with a much greater amount of information about their driving environment.

Using the design tool developed by Kurokawa and Wierwille (1990), a project team at the Virginia Tech Transportation Institute at Virginia Tech developed another computer-based design tool that can be used by designers when designing IVISs made possible by new technological advances in recent years. Empirical data were needed for this new model, for IVIS tasks that involved additional information processing after the extraction of information from a visual display, such as when selecting a route or hotel.

The first objective — to investigate driver performance during IVIS tasks that required additional processing of information after the extraction of information from a visual display — was accomplished by conducting an on-road study. This study built from the work of Lee,

Morgan, Wheeler, Hulse, and Dingus (1997) which characterized the decision-making process in information-processing terms. Some IVIS tasks performed in this study simply required the driver to locate and extract information on a visual display. Other tasks required different types of information processing after the information was extracted, such as selecting a hotel, selecting a route, determining the cheapest route, or determining the quickest route. Tasks were also presented in different presentation formats to investigate the effects on attention demand. Data were collected while drivers from different age groups drove on a four-lane divided highway and performed IVIS tasks. Statistical analyses were performed to investigate the effect of type of information processing, presentation format, density level, and age on driver performance.

The second objective — to develop a method for establishing safety criteria for driving performance, i.e. safety “red-lines” for modeling purposes — was accomplished by performing an extensive review of the literature. Values were determined for different driver performance measures that, if exceeded, indicate high workloads and/or decreased situation awareness. Two composite measures were then created: a Red-line Threshold and a Yellow-line Threshold. Exceeding the Red-line Threshold indicate that one or more driver performance measures had exceeded a specific value of a safety parameter determined by past research and/or expert opinion (discussed in detail in Chapter 3). Exceeding the Yellow-line Threshold indicate that driver performance was significantly worse when compared to baseline driving. These two measures complemented one another. The Yellow-line Threshold provided a face valid indicator that driver performance was negatively affected, and the Red-line Threshold indicate if driver performance had exceeded safety parameters, based on expert opinion and past research.

The third objective — to provide descriptive data on the proportion of drivers who exceeded a safety threshold of driver performance for each of the different IVIS tasks — was accomplished by using the Red-line Threshold. Designers were questioned as to their needs for evaluating potential IVIS designs. Feedback indicate that designers would prefer not only mean values of driver performance measures, but also the proportion of drivers negatively affected when performing an IVIS task (T.A. Dingus, personal communication, May 1998 and A. Gellatly, personal communication, May 1998). It was recognized that designers may be designing for user

groups composed of different age ranges. Therefore, results are presented for young, middle age, and older drivers, as well as for the entire driving population.

The following hypotheses formed the cornerstone of this dissertation research:

- 1) The attention demand will vary depending on the type of information processing required of an IVIS task.
- 2) The attention demand will vary depending on the presentation format of the information displayed on the IVIS.
- 3) The attention demand will vary depending on the density level of information displayed.
- 4) The attention demand will be higher for older drivers than younger driver when completing IVIS tasks.

The attention demand for this study refers to attention demand required of the driver by the workload for the entire driving task, including any secondary task performed. The following hypotheses are discussed in terms of visual attention demand. The greater the attention demand of the task, the greater the number of glances to the display and the longer the eye glance time. Therefore, task completion time will be greater for tasks requiring a greater attention demand, and the time spent scanning the environment will be less.

With longitudinal driving performance measures, the greater the attention demand for the secondary task, the lower the minimum speed, due to drivers creating an “unconscious safety margin”. Therefore, there will be a greater decrease in speed and greater peak longitudinal deceleration. It is also expected that drivers will attend to speed less with greater attention demand; therefore, there will be a larger variance in speed maintenance.

With lateral driving performance measures, it is expected that drivers will pay less attention to the steering task, as the secondary task attention demand becomes greater. Therefore, there will be an increase in steering velocity measures, number of lane deviations, and lateral accelerations.

1.4 DISSERTATION OVERVIEW

This dissertation begins with an overview of how Intelligent Transportation Systems (ITS) may help solve some of the current problems being addressed on our nation's roadways. In particular, the development of IVISs is discussed. Next, the objectives of the current study are outlined, and the approach for accomplishing each objective is presented. A method for performing an evaluation of driver performance is outlined, and the measures used to perform this evaluation are operationalized and justified based on past research and expert opinion. Following a review of the pertinent literature, a review of the experimental apparatuses, experimental design, and experimental procedures is presented. Results of the data analyses and a discussion of ramifications and possible IVIS design solutions, conclusions, and suggestions for future work are then presented.

CHAPTER 2: BACKGROUND

Intelligent Transportation Systems (ITS) are at various stages of research, development, and implementation. Systems are being developed that have the goal of acquiring, analyzing, communicating, and presenting information to travelers (Campbell, Carney, and Kantowitz, 1998). Systems under development will provide information to drivers that traditionally has been obtained from road signs along roadways, through written information such as maps, and via radios. In addition, systems will provide information to drivers that traditionally has not been available, or at least has not been readily available, such as information on local attraction or arrival/departure information on airline flights. IVISs will be the interface between ITS and individual vehicles.

With the development of ITS, different types of attention demands will be required by the driver as an increasing number of information systems are added to the driver's domain. In the development of driver interfaces with ITS, it is important to identify the information needs of the driver and the best methods to present this information to minimize human error. ITS can greatly facilitate the driving task; but during development, designers need to ensure that optimization of task(s) does not occur at the expense of the safety of our nation's roadways.

This chapter discusses IVIS development, the objectives of the current study, and measures of driver performance.

2.1 IVIS DEVELOPMENT

A variety of IVISs, that utilize new technological advances are at different stages of development; some already have limited market distribution. One example of an IVIS that has been road tested is TravTek, which was designed with the following general objectives (adapted from Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, Fleischman, 1995):

- 1) Allows for more effective driver navigation, providing the benefit of saving time;
- 2) Provides easy access to valuable and convenient location information to alleviate stress and increase driving enjoyment;
- 3) Improves roadway efficiency and alleviation of congestion; and

- 4) Facilitates safety improvements by providing information for avoiding potential hazards and for emergency response, while allowing maintenance of safe driver performance during system use.

IVISs that have been identified to serve as an interface between the individual vehicles and ITS are divided into four subsystems as summarized below (Campbell, *et al.*, 1998)

- 1) In-vehicle Routing and Navigation Systems (IRANS),
- 2) In-vehicle Motorist Services and Information Systems (IMSIS),
- 3) In-vehicle Signing and Information Systems (ISIS), and
- 4) In-vehicle Safety Advisory and Warning Systems (IVSAWS).

The following sections provide an overview of the subsystems of IVISs under development. A more detailed listing of information provided by these subsystems is presented in Appendix A.

2.1.1 IN-VEHICLE ROUTING AND NAVIGATION SYSTEMS (IRANS)

(adapted from Campbell *et al.*, 1998; adapted from Lee *et al.*, 1997)

IRANS provide drivers with information on travel information that can include turn-by-turn guidance and information on congestion. IRANS could have the capability of calculating, selecting, and displaying optimum routes based on real-time traffic data. Listed below are descriptions of the IRANS subsystems:

- *Information Description for Trip Planning*: Coordination of long, multiple-stop/destination journeys.
- *Information Description for Multi-Mode Travel Coordination and Planning*: Provides transportation coordination on different modes of transportation (such as buses, trains, subways) in conjunction with driving a vehicle.
- *Information Description for Pre-Drive Route and Destination Selection*: Encompasses destination and route selection choices in which the driver engages when the vehicle is in park.
- *Information Description for Dynamic Route Selection*: Encompasses any route selection system characteristics in which the driver engages when the vehicle is not in park.

- *Information Description for Route Guidance*: Provides navigation directions in a turn-by-turn format, given a destination and current location.
- *Information Description for Route Navigation*: Provides information to help a driver select a destination that might include distance and time to destination, cost to get to a destination, and notification of incidents such as construction or accidents. It can also be used to enable a driver to explore an electronic map with pan and zoom features.
- *Information Description for Automated Toll Collection*: Allows a vehicle to travel through a toll roadway without the need to stop and pay tolls. Tolls would be automatically deducted as the driver passes through the toll station. Information could be supplied to the driver regarding the amount of toll credits and the current toll costs.

2.1.2 IN-VEHICLE MOTORIST SERVICES AND INFORMATION SYSTEMS (IMSIS)

(adapted from Campbell *et al.*, 1998; adapted from Lee *et al.*, 1997)

IMSIS enable drivers to quickly locate the nearest desired service that meets their needs. Drivers are provided with information on nearby lodging, restaurants, service stations, recreational areas, and historical sites. Specific information could also be attained on transit schedules, costs, travel times, and departure/arrival times. Listed below are descriptions of the IMSIS subsystems:

- *Information Description for Broadcast Services/Attractions*: Provides information that is usually found on commercial roadside signs.
- *Information Description for Services/Attractions Directory*: Contains information similar to that found in the yellow pages directory, and can facilitate information obtainability with a wide variety of search methods.
- *Information Description for Destination Coordination*: Enables a driver to make arrangements with the final destination (for example, making restaurant or hotel reservations).
- *Message Transfer*: Provides the capability for drivers to communicate with others.

2.1.3 IN-VEHICLE SIGNING AND INFORMATION SYSTEMS (ISIS)

(adapted from Campbell *et al.*, 1998; adapted from Lee *et al.*, 1997)

ISIS will provide drivers with advanced warning of upcoming intersections, highway exits, etc. Information that is currently depicted on external roadway signs will be presented on displays in the vehicle. Listed below are descriptions of the ISIS subsystems:

- *Presentation of Roadway Guidance Sign Information:* Helps guide a driver to a particular destination. Information that has been found on the roadways will be brought into the vehicle and displayed to the driver. Examples include street signs, landmarks, interchange graphics, and mile posts.
- *Presentation of Roadway Notification Sign Information:* Notifies drivers of potential hazards or changes in the roadway. Examples include merge signs, advisory speed limits, curve arrows, road closures, road maintenance, and road construction.
- *Presentation of Roadway Regulatory Sign Information:* Information that assists in regulating traffic and displays the rules of the road. Examples include speed limit signs, stop signs, yield signs, and turn prohibitions.

2.1.4 IN-VEHICLE SAFETY ADVISORY AND WARNING SYSTEMS (IVSAWS)

(adapted from Campbell *et al.*, 1998; adapted from Lee *et al.*, 1997)

IVSAWS provide warnings of unsafe conditions and situations affecting the driver on the roadway ahead. IVSAWS provide information with enough time that the driver can take appropriate action. However, these systems do not encompass in-vehicle warnings of imminent danger requiring immediate attention (for example, collision avoidance devices). Advisory messages provided by IVSAWS can also include recommended actions. Listed below are descriptions of the IVSAWS subsystems:

- *Information Description for Hazard Warning:* Provides information on immediate hazards which may include the relative location of a hazard, the type of hazard, the approach of emergency vehicles, accident immediately ahead, or stopped school bus.
- *Information Description for Road Condition Information:* Provides information within some pre-defined proximity to the vehicle or the route, and may include traction, visibility, congestion, construction, or weather conditions.

- *Information Description for Automatic Aid Request:* Provides a mayday signal in situations requiring an emergency response (for example, severe accidents). Signal would provide location and severity information to emergency response teams.
- *Information Description for Manual Aid Request:* Provides driver with immediate access to a variety of roadside assistance without requiring access to a phone or phone numbers (for example, police, ambulance, towing, and fire department).
- *Information Description for Vehicle Condition Monitoring:* Used to track the overall condition of the vehicle and inform the driver of any current or potential problems (for example, engine overheating, broken fan belt, low oil pressure). The system could also provide information on the appropriate actions to take, for example, drive no further than necessary to obtain service, or do not drive vehicle because engine damage will occur.

After reviewing these subsystems, the potential information to be presented to drivers and the ramifications on attention demand become apparent. Guidelines have been created for the development of these IVIS subsystems. However, not all guidelines are based on empirical data — some are based on expert opinion. One of the goals of the computer-based design tool developed at the Virginia Tech Transportation Institute was to provide IVIS designers with empirical data indicating the attention demands required of IVISs. Therefore, representative tasks for the IVIS subsystems discussed above were developed for this study to assess the attention demand required to extract information from a visual display and then process information to make a decision.

2.2 OBJECTIVES OF THE STUDY

As previously mentioned, after performing an extensive literature review, it was determined that empirical data were needed for IVIS tasks that required the additional information processing that occurs after the extraction of information from a visual display, such as when selecting a route or hotel. This additional information processing will henceforth be referred to as supplemental information processing. Campbell *et al.* (1998) created guidelines for the presentation of information via IVISs. These guidelines were developed based upon both expert opinion and a review of the current research performed on IVISs. For tasks that involved supplemental information processing, the guidelines stated that these tasks should not be

performed while the vehicle is in motion. These guidelines were based on expert opinion with limited empirical data.

The computer-based model developed at Virginia Tech serves as a tool to provide data to indicate whether a task is unsafe and thus should not be considered for implementation, and data that allows for comparisons between different IVIS designs. Therefore, even though some of the tasks presented to drivers were suspected of requiring exceedingly high attention demands to complete while the vehicle was in motion, it was desired to affirm this opinion and provide designers with data to support it. As mentioned previously, the purpose of this study was threefold:

- 1) To investigate driver performance during IVIS tasks that required supplemental information processing,
- 2) To develop a method for establishing safety criteria for driving performance, i.e. safety “red-lines” for modeling purposes, and
- 3) To provide descriptive data on the proportion of drivers who exceeded a safety threshold of driver performance for each of the different IVIS tasks.

2.2.1 OBJECTIVE 1: TO INVESTIGATE DRIVER PERFORMANCE DURING IVIS TASKS THAT REQUIRED SUPPLEMENTAL INFORMATION PROCESSING.

Information processing, age, density level, and presentation format of information were studied to accomplish this objective.

2.2.1.1 Information Processing

To identify tasks requiring undesirable attention demands, the method of characterizing IVIS tasks developed by Lee *et al.* (1997) was expanded upon. Lee *et al.* (1997) characterized IVIS tasks by the decision-making elements performed by the driver. Their work adapted the general structure of the decision process from Rasmussen (1986), and the specific decision-making elements were derived from Miller (1971, 1974). Decision-making elements from the work of Lee *et al.* (1997) were identified that pertained to supplemental information processing. These elements were further developed to enable data collection, and are listed in Table 2.1.

Table 2.1. Decision-making elements (adapted from Lee *et al.*, 1997).

Decision-Making Element	Description
Search	Involves scanning and the extraction of information from a visual display that meets predefined parameters.
Compute	Involves numerically calculating the answer to a problem.
Plan	Involves the matching of resources to the current objective when making a decision from definitive information.
Interpret	Involves extracting the meaning from a set of cues.

Rasmussen (1986) developed a model of human information processing that outlines the mental processes that occur during task performance. Depending on the person's experience and the nature of the task, he/she will move back and forth between the following three levels:

- 1) Knowledge-based processing,
- 2) Rule-based processing, and
- 3) Skill-based processing.

Knowledge-based processing occurs when actions must be planned at the time, using conscious analytical processes and stored knowledge. Knowledge-based processing is necessary when there is a lack of relevant rules or skills and a person is faced with a relatively unfamiliar task. Sensory input is first transformed into conceptual symbols, which are then used for reasoning about the task in processes such as goal formulation, plan selection, and plan evaluation.

Rule-based processing refers to the composition of subroutines in a familiar work situation that is typically controlled by a stored rule or procedure that has been created through previous experience. Performance is goal-oriented. Information is received in the form of signs that indicate a state in the environment with reference to certain conventions or acts. Signs cannot be processed directly; instead, they serve to activate stored patterns of behavior. Signs refer to situations or proper behavior by convention or prior experience.

Skill-based processing represents sensory-motor performance during activities that take place without conscious control as smooth, automated, and highly integrated patterns of behavior. Information is received in the form of signals, which are sensory data representing time-space variables from a dynamical spatial configuration in the environment. The distinction between the perception of information signals/signs/symbols is generally dependent on the context in which they are perceived and not on the form in which the information is presented.

2.2.1.2 Age

It is important to consider the age range of intended users. Results from previous studies indicate that driving population demographics are changing, and that the number of older drivers is increasing (National Safety Council, 1994; Stamatiadis, Taylor, and McKelvey, 1990). Therefore, the designers of IVISs must consider the needs, capabilities, and limitations of older drivers. Research has been conducted that provides evidence that IVISs benefit older drivers. Hanowski, Dingus, Gallagher, Kieliszewski, Neale (1999) performed a study and found that older drivers benefited from IVISs that provided information on route navigation. However, care must be taken when designing an IVIS to be used by older drivers. Hanowski, Bitter, Knippling, Byrne, Parasuraman (1995) outlined a taxonomy for organized research related to older driver crash involvement and safety interventions. Older drivers are at higher crash risk when their attentional and other dynamic information-processing capabilities are most challenged. Therefore, it was hypothesized and confirmed that older driver' driving performance would be more affected than younger drivers when completing IVIS tasks.

An understanding of why older drivers have problems with visual tasks is possible when one reviews the aging process and understands how these changes affect an individual's interaction with his/her environment. Changes that occur within the visual system of an individual as he/she grows older may include:

- 1) The lens of the eye hardening and becoming translucent,
- 2) Floaters developing in the vitreous humor,
- 3) Formation of cataracts, and
- 4) The individual may become farsighted, and lose his/her ability to read up close without the aid of bifocals.

These changes in the visual system have an effect on the ease with which individuals can extract visual information from their environment. Changes also occur with the auditory system that affect the extraction and processing of auditory information, and with the muscular and nervous system that affect reaction times. As individuals age, the needs, limitations, and abilities of the user can change due to biological changes occurring within the body.

2.2.1.3 Density

When developing guidelines for IVISs, it is important to assess the characteristics of information displayed on the screen. Tullis (1990) outlined and defined four characteristics of display density that affect alphanumeric display format: 1) overall density, 2) local density, 3) grouping, and 4) layout complexity. Overall density is the number of characters displayed on the screen or the percentage of total character spaces available. A general rule for overall density is to minimize the total amount of information on a single frame. Local density refers to the number of filled character spaces near each character. Jones (1978) and Stewart (1976) noted that spacing breaks up information into logical segments and provides structure. Grouping is the extent to which items form well-defined groups. Guidelines pertaining to grouping recommend that similar items be distinctly grouped. Finally, layout complexity is the extent to which items follow a predictable visual arrangement. Based on the location of information displayed on the screen, users should be able to predict the location of other information on the screen. Although these guidelines were developed for alphanumeric displays, these concepts are applicable to the design of IVISs.

If an IVIS requires a high attention demand, then a possible effect is the phenomenon called perceptual narrowing. Perceptual narrowing is characterized by one of two phenomena:

- 1) Operator workload is high and the operator fails to scan or does not perform an adequate scan; or
- 2) Operator performs a scan of the stimuli, but the stimuli do not capture the operator's attention and are not received by the brain for processing.

The units of information that can be stored in working memory have been researched and have been found to be 7 ± 2 units of information (Miller, 1956). If information is not kept active in working memory, it will rapidly decay. Thus, when subjects must divert their attention to another task, information will be lost and will need to be reobtained prior to subsequent supplemental information processing for decision-making.

2.2.1.4 Presentation Format

Another system characteristic assessed in this study was the presentation format of information. Screens were created to display information on the IVIS while the vehicle was in motion. The information displayed was presented in one of four presentation formats: 1) table format, 2) paragraph format, 3) graphic map with information displayed in alphanumeric format, and 4) graphic map with information displayed in iconic format.

The screens were created using both general human factor design guidelines found in human computer interaction (HCI) literature as well as specific guidelines for the design of IVISs (Shneiderman, 1992; Brown, 1988; Campbell *et al.*, 1998). Guidelines for the dialogue design, data display, data entry, and effective wording are listed in Tables B1-B4, respectively, in Appendix B. Pertinent design guidelines are highlighted below.

Strive for Consistency – The IVIS was designed such that there was both internal and external consistency. Internal consistency refers to consistency within the IVIS (for example, the scale of distance for the graphic maps was located in the lower right-hand corner of each graphic map screen). In addition, external consistency was maintained (for example, the icons used on the screens, when possible, were the standard road sign icons located in the Manual of Uniform Traffic Control Devices (Moeur, 1998)).

Permit Easy Reversal of Actions – The system was designed such that the driver could speak out loud while extracting the information displayed on the visual screen, eliminating options, and making a final decision. The information remained displayed on the screen until the driver stated a complete answer, such that when selecting a route, the driver always needed to state two roadways in his/her answer. The information remained on the display until the driver stated two

roadways. Some drivers would start an answer and then change their mind after they stated only one roadway.

Reduce Short-term Memory Load – The IVIS was designed such that all displays were simple to understand and all information needed to complete a task was presented on one screen. This reduced the short-term memory load and allowed for easy reference when making a decision. The use of abbreviations was limited and, when possible, “everyday” abbreviations were used. For unfamiliar abbreviations, drivers were trained and tested to ensure recognition prior to data collection.

Consistency of Data Entry Transactions –The nature of the IVIS was such that the task ended when the driver provided input (via voice) and a decision was made from the displayed information. Data entry was similar for like tasks. For example, with route selection tasks, tasks were created such that the driver had to specify two roadways, regardless of the presentation format of the information displayed.

Be Consistent in Labeling and Graphic Convention – As appropriate, the information was displayed in the same location on the screen. In addition, the same layout was used within a presentation format. For example, with the table format, the same grid-line system was used to specify rows and columns within the different IVIS tasks.

Use of Conversational Language Style – An editor reviewed the language used in the screens to insure that the meaning was conveyed in the most effective manner possible.

Guidelines adapted from Campbell, *et al.*, (1998) for the design of text, symbols, and color used in IVISs are summarized below. Appendix C contains the specifications of the text and icon presentations used in this study.

Text and Symbols

- Use a clear and simple font.
- Symbol height 0.50 degrees for titles and other key elements.

- Symbol height 0.33 degrees for dynamic or critical elements.
- Symbol height 0.266 degrees for static or non-critical elements.
- Symbols that are familiar or intuitive can be used without accompanying text labels.

Color Coding

- The number of colors used to code information should be kept to a minimum, not to exceed 4 colors for casual users and 7 colors for experienced users.
- Color codes should have the same meaning on different screens.
- Use compatible color combinations when colors are presented simultaneously.
- When using color, adhere to population stereotypes.

2.2.2 OBJECTIVE 2: TO DEVELOP A METHOD FOR EVALUATING DRIVER PERFORMANCE WITH REGARD TO SAFETY.

2.2.2.1 Overview

When evaluating IVISs, it is important to “remember that all the in-vehicle information a driver needs is current speed and fuel remaining to successfully drive the vehicle” (Dingus, 1997).

Treat *et al.* (1979) performed a study that revealed human error to be the main causative factor of automobile accidents. There were three main categories of accident causative factors: human, vehicular, and environmental. After performing on-site accident investigations and reviewing police reports, it was determined that 70.5% of accidents were directly attributable to human cause. Recognition errors and decision errors were identified as the leading causes of human error. Recognition error classification referred to inappropriate information acquisition and processing. Decision errors referred to errors that occurred as a result of a driver’s improper course of action or failure to take any action at all.

Accidents are the best direct measure of safety-related problems with the vehicle and/or the driver (Dingus *et al.*, 1995). However, the data can only be collected post hoc and, therefore, any recommendations resulting from the results are reactive. If the safety risk of systems could be predicted before accident data were generated, then needless injury and death could be avoided before mass market distribution. Dingus *et al.* (1995) proposed the use of near misses as

the best available proactive predictor of safety. Near misses occur more often than accidents of any severity, as illustrated in Figure 2.1. This figure, known as Heinrich's Triangle, is used in other safety applications to estimate future accident rates by counting near misses. Dingus *et al.*(1995) proposed that by counting the number of driver errors associated with a given configuration and driving circumstance, it is sometimes possible to estimate the number and severity of accidents that would have occurred with given levels of market distribution. Unfortunately, the numerical relationship between accidents and driver error does not yet exist for driving. However, this concept is useful for comparison of IVIS tasks because differences in the number of driver errors will reflect ordinal differences in accident rates at some level (Dingus *et al.*, 1995). The relative magnitudes shown in Figure 2.1 are hypothetical. However, regardless of their relative frequency, these measures provide a means for direct comparison between IVIS tasks tested.

In this study, two composite measures of driver performance were developed as safety indicators. One composite measure, Red-line Threshold, indicate if driver performance exceeded values determined a priori. The other composite measure, Yellow-line Threshold, indicate if driver performance during IVIS task completion was significantly worse from baseline driving. The specific measures used to develop these composite measures are discussed in the following sections.

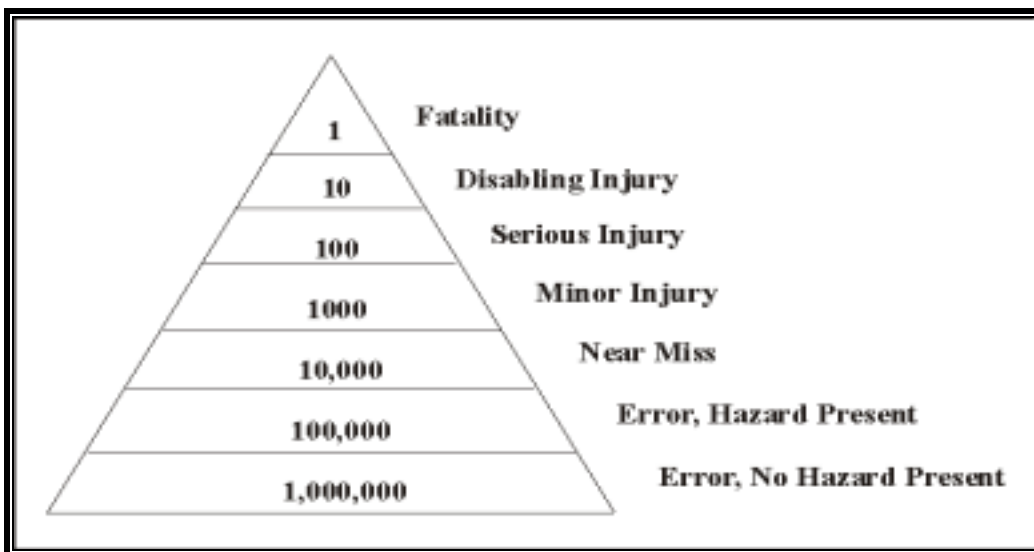


Figure 2.1. Example of Heinrich's triangle with hypothetical relative frequencies for driving (Dingus et al., 1995).

After an extensive review of the literature, it was determined that the assessment of both situation awareness and mental workload is important for the evaluation of advanced automation and display/control technology in complex systems and dynamic environments. A prime objective during testing and evaluation is to obtain an overall assessment of workload using techniques that have global sensitivity (Wierwille and Eggemeier, 1993). Situation awareness is a broad concept and encompasses critical components of multi-sensory integration, perception, interactions between working and long-term memory, and rapid decision-making in dynamic systems.

Endsley (1995b) stated that the relationship between situation awareness and workload is important. Attention serves as an important constraint on situation awareness; direct attention is needed for perception, working memory processing, decision-making, and forming response executions. The following describes four possible combinations of situation awareness and workload (adapted from Endsley, 1995c):

- 1) Low situation awareness and low workload: Driver has little idea of what is going on and is not actively working to develop an accurate and complete picture of situation.
- 2) Low situation awareness and high workload: Amount of information and demands of the task are too great. This leads to a loss of situation awareness because the driver is only attending to a portion of the incoming information.
- 3) High situation awareness and high workload: Driver is working hard and is successfully achieving an accurate and complete picture of the situation.
- 4) High situation awareness and low workload: Information is presented in a manner that is easy to process and results in an accurate and complete picture of the situation.

2.2.2.2 Situation Awareness

Situation awareness has become recognized as an important design criterion in complex systems and dynamic environments. Situation awareness difficulties have been found to arise when operators are associated with systems that have advanced automation and display/control technology in complex systems and dynamic environments. Situation awareness measures are widely used to assist with the recognition of military and commercial aviation problems that deal with mission performance and safety. United States Air Force F-15 and F-16 aircrew operators

have in the past complained of a lack of situation awareness. Poor situation awareness appears to be associated with accidents and incidents, and with reduced mission effectiveness. Therefore, a majority of past research on situation awareness has been performed in the aviation community, especially in military applications.

Situation awareness is important from a measurement viewpoint in driving because it is hypothesized that a reduction in situation awareness may result from increased attention demand and may lead to a higher frequency of accidents. Endsley's (1995b) definition of situation awareness is often referenced within human factors literature (p. 36):

“Situation awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.”

Situation awareness is not always acquired instantaneously, but is built up over time and is an important part of decision-making regarding the defined system (adapted from Endsley, 1995c). Endsley (1995b) described situation awareness as having three levels:

- Level 1 – Perception of elements in current situation;
- Level 2 – Comprehension of current situation; and
- Level 3 – Projection of future status.

Level 1 Situation Awareness is the perception of elements in the environment. The first step is to perceive the status, attributes, and dynamics of relevant changes in the environment. The narrowing of attention brought on by stress or high workload can lead to a total lack of situation awareness on all but the factor being considered. Errors associated with this level include:

- 1) Failure to perceive certain information that is important for situation awareness;
- 2) Lack of detectability or discriminability of the signal's physical characteristics due to some physical obstruction preventing perception (visual barrier or auditory masking); and
- 3) Failure of the system to make the information available to the operator.

Level 2 Situation Awareness is the comprehension of the current situation and includes an understanding of the significance of those elements in light of pertinent operator goals. The

operator forms a holistic picture of the environment, comprehending the significance of objects and events. Errors associated with this level include:

- 1) Inability to properly integrate or comprehend the meaning of perceived data in light of operator goals;
- 2) Improper assimilation of incoming data by novices who do not have the necessary model in memory to assimilate all the incoming data; and
- 3) Incorrectly choosing a model that results in data being interpreted to mean something quite different than what is actually occurring.

Level 3 Situation Awareness is the projection of future status — the ability to project the future actions of the elements in the environment, at least in the very near term. Errors associated with this level include:

- 1) Future status may be lacking or incorrect; and
- 2) It may be difficult to project future dynamics without a highly developed mental model.

Assessing situation awareness can be undertaken using one method or a combination of methods. There are four main categories of measurement for situation awareness. Each is discussed in detail below:

- 1) Performance-based,
- 2) Subjective evaluation,
- 3) Knowledge-based, and
- 4) Physiological measures.

2.2.2.2.1 Performance-based

Performance-based techniques require decisive and identifiable actions. Performance-based techniques also provide for a means to identify constraints on a user arising from his/her training and standard procedures (Pritchett, Hansman, and Johnson, 1995). Performance-based measures are able to determine perceived reliability of the knowledge that users gather from any number of sources. Three performance based measures are discussed below.

Global Measures suffer from diagnosticity and sensitivity problems in that they only measure the end result of many cognitive processes. Little information is provided about why poor performance may have occurred in a given situation, such as lack of information, poor sampling strategies, improper integration or projection, heavy workload, poor decision-making, or action errors (Endsley, 1995a).

External Task Measures involve artificially changing certain information or removing certain pieces of information from displays and then measuring the reaction time to respond to this change. This manipulation is very intrusive and alters the subject's ongoing task.

Imbedded Task Measures have the major limitation of assessing situation awareness on one element that may simultaneously reduce situation awareness on another unmeasured element.

2.2.2.2 Subjective Evaluation

Subjective evaluations can be performed by either the participant or the experimenter who is observing the study. Each technique has strengths and weaknesses that are discussed below.

Self Rating has the advantage of being low cost and easy to use. However, an operator's ability to estimate his/her own situation awareness will be limited because he/she does not know what is really happening in the environment. Operators will know when they have no idea what is happenings around them, but they will not know if and when their knowledge is incomplete or inaccurate. Endsley (1995a) speculated that self-ratings of situation awareness most likely convey a measure of a subject's confidence level regarding that situation awareness.

Observer Rating can detect process errors, poor scanning, and other actions, but has the disadvantage that the operator cannot verbalize what he/she thinks about the situation.

2.2.2.2.3 Knowledge-based

Questionnaires allow for detailed information about situation awareness to be collected on an element-by-element basis that can be evaluated against the actual surrounding environment.

Questionnaire at End of Trial is affected by the amount of time and the number of intervening events that occur between the activity of interest and the administration of the questionnaire. An advantage of this technique is that subjects can respond to a lengthy and detailed list of questions. People have trouble reporting detailed information about past mental events, and there is a tendency to overemphasize and overrationalize. Earlier misconceptions can easily be forgotten as the real picture unfolds during the course of events.

On-line Questioning asked while subjects perform tasks can create an ongoing secondary task-loading situation that may alter performance on the main task being performed. The questions could also cue the subject to attend to information that he or she believes will be evaluated later.

With the **Freeze Technique** displays are blanked and simulation is suspended while subjects quickly answer questions about their current perception of the situation. This technique has been found to overcome some of the limitations of other measures of situation awareness; however, this technique is obviously limited to simulator studies.

2.2.2.2.4 Physiological Measures

Stern, Wang, and Schroeder (1995) and Wilson (1995) performed studies that showed that there was potential for physiological measures to provide useful measures of situation awareness, in particular oculometric (eye) and heart rate measures. Eye tracking measures indicate where an individual is looking and therefore provide insight on his/her active involvement in the gathering of information from the environment. However, eye tracking does not indicate which elements in the periphery vision are observed, or if the individual processed the information in his/her visual field of view. Another potential oculometric measure is eye blink. Expectancy of an event leads to inhibition of blinking, and if one can't inhibit a blink at a point in time close to an imperative event, then the blink will be of shorter duration than normal (Stern *et al.*, 1995; Wilson, 1995). Heart rate is a measure of the cardiac system that has a relatively slow-reacting mechanism and is therefore seen as an overall indicator of task involvement (Stern *et al.*, 1995; Wilson, 1995). Wilson (1995) stated that heart rate is useful in determining duration of situation awareness and that a change in "operator state" has occurred.

2.2.2.3 Mental Workload

Mental workload measures are often used in the evaluation of IVISs. At present, workload assessment techniques are most appropriately applied to measuring workload on a relative basis, or as indicators of potential workload that require further analysis (Wierwille and Eggemeier, 1993). The choice of measurement should be matched with the assessment technique properties and the objective and constraints of the particular evaluation (Wierwille and Eggemeier, 1993). An evaluator is usually interested in both the levels of workload and the reasons for the workload levels. Measurement techniques can be used to obtain an overall assessment that has global sensitivity (Wierwille and Eggemeier, 1993). Other measurement techniques can be used for diagnostic purposes to determine what part(s) of the task is the most demanding.

Different methods are available for measuring mental workload, each with advantages and disadvantages. In the following sections, the properties of workload measures to consider and the different measurement techniques are discussed. Steps in selecting the appropriate workload assessment technique (adapted from Salvendy, 1997) include the following:

- 1) Delineate the objectives of the mental workload assessment:
 - Predicting the level of mental workload of a planned system.
 - Comparing alternative systems to determine the demands across different phases or conditions.
 - Diagnosing the potential cause of a non-optimal system by determining which part of the system is overly demanding.
- 2) Perform a task/mission/system analysis.
- 3) Evaluate the resources available (time and cost constraints, equipment, expertise).
- 4) Select the types of workload measures to be used (performance, physiological, subjective).

2.2.2.3.1 Properties of Workload Measures

Sensitivity is the ability of a measurement technique to detect changes in the mental workload experienced by the operator. The intent of workload measurement is to assess the differences in workload imposed by the system(s) under test; therefore, sensitivity is a major consideration in the choice of a measurement technique (Wierwille and Eggemeier, 1993). Performance

measures are believed to be insensitive at low workload levels and sensitive at high workload levels (Salvendy, 1997). Therefore, subjective and/or physiological measures should be considered in situations where the workload is expected to be low, and performance measures should be considered if the workload is expected to be high (Salvendy, 1997).

Diagnosticity refers to how precisely a measure can reveal the nature of the workload; it provides an explanation of workload driving elements, operator information processing capabilities, and resources that are being expended (Wierwille and Eggemeier, 1993). By systematically varying aspects of the task and measuring workload, it may be possible to infer whether a particular aspect of a task is the cause of the non-optimal level of workload (Salvendy, 1997).

Intrusiveness is an undesirable property in which the introduction of the workload measuring technique causes a change in the operator-system performance (Wierwille and Eggemeier, 1993). If the measurement process interferes with the performance of the task, then a contaminated workload measurement will result. In some cases, the measurement will interfere with the task that the operator is performing; in other cases, the measurement can be considered a second task for the operator to perform. Neither of these situations is desirable. The influence of variables such as context effects can be minimized by ensuring that operators have similar backgrounds (Wierwille and Eggemeier, 1993).

Reliability refers to whether the workload measures are stable and consistent over a period of time. Workload measures should be repeatable under similar measurement conditions (Salvendy, 1997).

Transferability refers to the ability of a technique to be used in various applications. Some measurement techniques vary from application to application, such as primary task measurements (Wierwille and Eggemeier, 1993).

Ease of Use/Implementation Requirements refers to any equipment or instrumentation that is necessary to present information or collect data. It also includes data collection procedures and

operator training that is associated with a measurement technique (Wierwille and Eggemeier, 1993). Demand characteristics for different measurements are listed below (adapted from Salvendy, 1997):

- Subjective measures are typically easy to administer and evaluate.
- Primary measures require modification of the system to record performance data.
- Secondary task measures require specialized knowledge to analyze the mental resources required by the primary task to select an appropriate secondary task.
- Physiological measures require specialized equipment and training to perform data collection, analysis, and interpretation.

Operator Acceptance is important since operators should feel comfortable with the selected measures to facilitate cooperation. Knowledge of performance or workload scores can be detrimental in some systems, especially where there is a competitive atmosphere between the operators. Subjective measures are usually well accepted because of their face validity, and operators like the opportunity to provide their evaluation of the system (Salvendy, 1997).

Time Considerations need to be evaluated because there may be a need to assess very short-term operator loading effects or very long-term effects. Short periods of overload can lead to operator postponement or neglect of task elements, acceptance of less precision in performing tasks, or complete failure to perform tasks. Momentary workload assessment can sometimes be more important than a standard assessment that covers a longer period of time. Long-term assessment needs to be performed under the following conditions (adapted from Wierwille and Eggemeier, 1993):

- Time on task causes a reduction in the operator's capacity to handle the load;
- Learning or changes in strategy over time reduce apparent workload; and
- Physical demands over time change the operator's ability to handle mental workload.

2.2.2.3.2 Assessment of Mental Workload

Different methods for assessing mental workload exist. Methods can be grouped into one of three categories: 1) subjective measures, 2) performance measures, and 3) physiological measures. The different methods available to be used are discussed below.

Subjective Measures require operators to rate the level of mental effort that they feel is required to perform a task. There is widespread use of this technique because of its ease of use, operator acceptance, and face validity. Subjective validity has been shown to be sensitive to a variety of task demand manipulations (Wierwille and Eggemeier, 1993) and has been shown to be reliable and to have significant concurrent validity with performance measures (Wierwille and Casali, 1983).

Rating scales are frequently used wherein operators select a term or phrase to best describe how they feel, or operators are asked to assign a number that represents the mental effort required (Salvendy, 1997). Ratings are either obtained immediately after performing a task, or retrospectively after having experienced all of the task conditions. Subjective measures can be susceptible to memory problems if ratings are made after the performance of the task. A 15-30-minute delay was not shown to significantly affect ratings, however, waiting 48 hours was shown to interfere with ratings (Eggemeier and Wilson, 1991). Open-ended questions in interviews with operators can also provide useful information about a system (Salvendy, 1997).

Differences in operator experience may be a confounding influence (Boff and Lincoln, 1988). Measures are susceptible to operator bias regarding the system or component being evaluated, and can be influenced by past experiences and degree of familiarity with the task or system being evaluated (Salvendy, 1997).

Relative scores are obtained by asking operators to compare the task condition of interest to either a single standard or a multiple-task condition. Scores can either be unidimensional or multidimensional. Unidimensional scores refer to a single rating that is obtained concerning the overall workload level. Multidimensional scores give ratings on several dimensions of workload, providing diagnostic information that can pinpoint the nature of the workload.

Modified Cooper-Harper (MCH; Wierwille and Casali, 1983), Subjective Workload Assessment Technique (SWAT; Reid and Nygren, 1988), and NASA-Task Load Index (TLX; Hart and Staveland, 1988) procedures represent globally-sensitive measures of operator workload.

NASA-TLX and SWAT permit the operator to rate the task on the basis of several dimensions. In both cases, the operator provides an absolute rating immediately after task performance. NASA-TLX sub-scales are mental demand, physical demand, temporal demand, performance, effort, and frustration level. SWAT sub-scales are time load, mental effort load, and psychological stress load. The NASA-TLX method calculates a weighted average for each operator, and the SWAT determines a derived workload scale for each operator. These are both standard procedures (weighted average and derived workload scale), but there has been some recent debate over the merits of each (Salvendy, 1997). SWAT is viewed as having the greatest potential for identification of factors such as cognitive mechanisms affecting mental workload judgments. NASA-TLX is seen as appropriate for problems in applied settings and is considered potentially more sensitive than SWAT at low levels of workload (Wierwille and Eggemeier, 1993).

Performance Measures include primary task measures and/or secondary task measures. Each of these measures is discussed. During the primary task, the actual performance of the operator and system are monitored and changes are noted as the demands of the task vary. When primary task measures are used to evaluate workload, deteriorated and/or erratic performance may indicate that workload is at, or is approaching, unacceptable levels (Salvendy, 1997). Characteristics of primary tasks are listed below:

- Face validity: High face validity (Salvendy, 1997).
- Sensitivity: Discriminates overload from non-overload situations (Boff and Lincoln, 1988), but primary task measures can sometimes prove insensitive to variations in workload. The operator might have the ability to expend extra processing resources to satisfy increased demands, in which case the primary task performance would be maintained at acceptable levels (Wierwille and Eggemeier, 1993).
- Diagnosticity: Non-diagnostic; a global index of workload (Boff and Lincoln, 1988).
- Data collection: May require instrumentation that would limit use in field situations (Boff and Lincoln, 1988).

Secondary task measures can be used in systems where primary task performance is difficult to obtain. Adding a secondary task will increase the overall task demand to a level where

performance measures may be more sensitive. Operators are instructed to use only their spare capacity (not needed by the primary task) to perform the secondary task. Since primary and secondary tasks compete for resources, the secondary task performance will decrease as resources are drawn upon to perform the primary task. Secondary task performance will only be a sensitive workload measure of the primary task demand if the two tasks compete for the same processing resources (Salvendy, 1997). Secondary tasks are a good tool for diagnosing the demands of a task. If the secondary task is not affected by the primary task, then the type of mental demand that the primary task does or does not require becomes evident. Characteristics of secondary tasks are listed below (adapted from Boff and Lincoln, 1988):

- Sensitivity: Discriminates levels of workload in non-overload situations; can assess reserve capacity not used by a primary task.
- Diagnosticity: Can discriminate differences in operator resource expenditure.
- Face Validity: There is a potential for lack of face validity.

Intrusion can occur when an operator is made to modify the allocation of processing resources devoted to the primary task. The requirement of performing a concurrent secondary task can often be associated with this reallocation when the secondary task imposes additional demands on processing resources. This is particularly true when the operator is under moderate to high levels of workload (Wierwille and Eggemeier, 1993).

Physiological Measures record changes in the operator's body that are related to the demands of the task being performed. Measures to consider include 1) the cardiac system, 2) brain activity, and 3) oculometric (eye) measures. The cardiac system, measured by heart beat, provides both an indication of situation awareness, as previously mentioned, and mental workload. Heart rate is a relatively slow-reacting mechanism and is seen as an overall level of task involvement (Wilson, 1995; Stern *et al.*, 1995). Electroencephalographs (EEGs) measure the transient cortical evoked response, a series of voltage oscillations, originating from the cortex of the brain in response to the occurrence of a discrete event. This response can be measured through the scalp of a conscious individual. EEGs are particularly strong in their diagnostic value, pinpointing the nature of the task demand (Salvendy, 1997). However, various artifacts such as eye and body

movement can create problems for the analysis of EEG data collection (Wierwille and Eggemeier, 1993).

Oculometric measures include eye blink and pupil size. Eye blink measures may be principally sensitive to visual demand rather than auditory or cognitive demands (Wilson and Eggemeier, 1991; cited in Wierwille and Eggemeier, 1993). Blink rate and duration are often sensitive when operators are performing two or more tasks with competing visual demands (Wierwille and Eggemeier, 1993). Blink duration has a tendency to decrease with an increase in the visual demand. Pupil diameter is another useful measure. Pupil diameter is non-diagnostic, however, it is related to the general degree of arousal and therefore is correlated with workload; general arousal can be attributed to both physical effort as well as psychological effort (Boff and Lincoln, 1988). Pupillary response is sensitive to lighting conditions, so these tests must usually be performed in a laboratory setting.

2.2.2.4 Operationalized Driver Performance Measures

Measures of situation awareness and workload were used to assess driver performance while performing IVIS tasks, and the situation awareness of the driver were assessed. To establish criteria for modeling purposes, several measures of driver performance were collected to differentiate “safe” driving performance from “unsafe” driving performance. Measures were divided into the following three classifications and are discussed below:

- Eye glance measures,
- Longitudinal driving performance measures, and
- Lateral driving performance measures.

2.2.2.4.1 Eye Glance Measures

Eye scanning measures were used to assess whether the driver exhibited behavior that allowed for rapid and continuous updating of information about the environment. The faster the vehicle’s speed, the higher the potential for rapid changes in the environment. Eye glance scanning behavior was a good indicator of situation awareness; if the driver was not scanning the environment, then he/she wasn’t acquiring information on how the environment was changing. If the eyes were off-road, such as looking at an in-vehicle display, then the driver’s situation

awareness decreased. It was also important to assess whether the driver was scanning all parts of the environment and not only the front roadway. To be aware of the surroundings, a driver must scan the mirrors to learn about the traffic on either side and to the rear. However, if eye glance measures gave the impression that a driver was scanning the environment or looking in a certain location, this did not necessarily mean that the driver was actually obtaining and processing information from the environment; he/she could simply have been staring. The following three eye glance measures were used in this study:

- 1) Number of eye glances to the IVIS display,
- 2) Peak single eye glance length to the IVIS display, and
- 3) Number of eye glances to mirrors.

Number of Eye Glances to the IVIS Display refers to the number of times that the driver's eyes were directed to the display during the task. If the driver's eyes left the display and then returned, the glance count increased by one. When using navigational systems, drivers tend to glance back and forth between the display and the forward roadway. Most experts in the field of driver safety would agree that a task that required nine or more glances to the IVIS display should be avoided (T. A. Dingus, personal communication, March, 1998). In fact, Zwahlen, Adams, and DeBald (1988) stated that the total number of eye glances for an in-vehicle task should not exceed 4 glances. Therefore, in this study, the number of drivers who took 1-4 glances, 5-8 glances, and 9 or more glances was determined for each task.

Peak Single Eye Glance Length to the IVIS Display refers to the longest continuous amount of time that the driver's eyes were directed toward the display without looking to another location during the task. Glance duration was recorded and data were reduced such that each glance to the nearest 0.1s could be identified. The external driving environment constantly changed, and the longer the driver's eyes were off-road and not monitoring these changes, the greater the danger of an event occurring with the driver having an insufficient time to react to avoid an accident. Bhise, Forbes, and Farber (1986) have suggested that based on speed and travel distance, a single glance greater than 2.5 seconds is inherently dangerous. Therefore, 2.5 seconds was used as a criterion to assess instances of unsafe behavior. It is also generally accepted that at a minimum, a 2.0-second headway should be maintained for safe operation of a

vehicle, and at fast speeds, this distance should be increased. Unfortunately, this distance is not often maintained. Even so, a task requiring an eye glance of 2.0 seconds could potentially create a situation where a driver does not have sufficient time to react to avoid a collision. Therefore, for this study, the number of drivers who had one or more glances over 2.0 seconds and over 2.5 seconds was determined for each task.

Number of Eye Glances to Mirrors refers to the number of times the driver's eyes were directed to either the right-side mirror, left-side mirror, or rear-view mirror during the task and baseline driving. If the driver's eyes left the mirror location and then returned, the glance count increased by one. For tasks in which there were no glances to a mirror, this measure was equal to zero. To determine if a task negatively affected the driver's scanning, the number of glances to the mirrors during task completion was compared to the number of glances during baseline driving. If the number of glances to the mirrors was significantly less during task completion, the task was identified as negatively affecting driver performance.

2.2.2.4.2 Longitudinal Driving Performance Measures

If a driver is to have sufficient time to react to changes in the environment, he/she must maintain an appropriate distance from the vehicle in front. In addition, a safe speed needs to be maintained. Vehicle speed can be considered a vehicle state that at some level must be held constant in most circumstances. Carpenter, Fleishchman, Dingus, Szczublewski, Krage, Means (1991) and Monty (1984) found velocity maintenance to be a sensitive measure to changes in the amount of attention demand by secondary driving tasks. Monty (1984) also determined braking behavior to be a sensitive measure of driving performance. The following five measures were used to assess a driver's headway and speed maintenance:

- 1) Change in speed,
- 2) Variance in speed,
- 3) Minimum speed,
- 4) Minimum headway, and
- 5) Peak longitudinal deceleration.

Change in Speed was determined by computing the difference between the speed at the start of the task or baseline, and the minimum speed reached during that task completion or baseline. If there was a significantly larger change in speed during task completion than baseline, driving performance was determined to be negatively affected.

Variance in Speed was determined for each task and baseline. The variance in the speed driven during task completion was compared to the variance in speed driven during baseline. If the variance was significantly larger during task completion than baseline, driving performance was determined to be negatively affected.

Minimum Speed driven during task completion and baseline was determined. Slow speeds due to glances at the display configuration indicated driver inattention to the driving task. Some drivers attempted to compensate for the attention demand required of the IVIS task by decreasing the speed at which they were driving. If there was a significantly lower minimum speed during the task than baseline, driving performance was determined to be negatively affected.

Minimum Headway was determined for each task and baseline driving. Headway was defined as the distance between the test vehicle and the vehicle in front, divided by the speed of the test vehicle. When drivers followed at close headway, the attention required to effectively avoid accidents increased greatly. Frequent or extended glances at the navigation information display rather than the forward roadway constituted an increase in accident potential. The less distance between two vehicles, the less time a driver has to respond to avoid an accident. The minimum headway reached during task completion was compared with minimum headway measures collected during baseline driving. If the headway was significantly less during IVIS task completion, then driving performance was determined to be negatively affected.

Peak Longitudinal Deceleration was determined for each task and baseline driving. If a driver looked away from the driving scene and then glanced back to realize that an unanticipated event was occurring, it was expected that the brake pedal would be depressed harder, resulting in a greater than normal deceleration. Therefore, if the peak deceleration was significantly greater

during task completion than baseline, driving performance was determined to be negatively affected.

2.2.2.4.3 Lateral Driving Performance Measures

When driving a vehicle, drivers make steering adjustments as needed to keep the vehicle “on track” in the roadway. If a driver continuously monitors the roadway, then he/she will continuously make small incremental inputs to the steering wheel. However, if a driver is distracted from tracking the vehicle, then a larger steering correction may become necessary. In this study, the following four measures were used to evaluate the driver’s tracking of the vehicle:

- 1) Lane deviation,
- 2) Peak steering wheel angular velocity,
- 3) Variance in steering wheel position, and
- 4) Peak lateral acceleration.

Lane Deviations were defined as the occurrence of the front wheels of the vehicle going over the inside edge of either the right or left lane marker during the task. During task completion, if a lane deviation occurred, lane deviations increased from 0 to 1. The value range for this measure was 0 or 1 for each driver for each task. The number of drivers who had a lane deviation for each task was determined.

All lane deviations were monitored with a lane-tracking camera view. Unplanned lane deviations provided a valuable face-valid measure of driving task interference resulting in performance degradation. If a driver deviated from his/her lane, this obviously could have caused an accident. However, if there was an acceptable reason for the lane deviation, such as passing a vehicle parked on the shoulder of the road and no vehicles were in the vicinity to make this an unsafe event, then the lane deviation was not recorded as a driver error.

Peak Steering Wheel Angular Velocity during each task completion and baseline driving was determined. Research has shown that changes in driver steering behavior occur when driver attention changes (Wierwille and Gutman, 1978). The rate of change in steering wheel position provided an indication of how suddenly/unexpectedly the driver had to respond to a situation.

Peak steering wheel angular velocity measures during task completion were compared with measures taken during baseline driving. If the velocity was significantly greater during the task than during baseline, driving performance was determined to be negatively affected.

Variance in Steering Wheel Position during each task completion and baseline was determined. When the driver tracks the road during baseline driving, there are small incremental movements of the steering wheel. If there was a significantly larger amount of variance in the steering wheel position during task completion than during baseline, driving performance was determined to be negatively affected.

Peak Lateral Acceleration was determined for each task completion and baseline. Large lateral acceleration was an indication that the driver had to make large corrections with the steering wheel. If the peak lateral acceleration was significantly larger during the task than during baseline, driving performance was determined to be negatively affected.

2.2.2.4.4 Secondary Task Performance Measures

Performance on secondary tasks provided an indication of the mental workload required to complete the IVIS task and the situation awareness of the driver while completing the task. The following four measures were used to characterize IVIS task performance:

- 1) Task completion time,
- 2) Number of drivers who skipped a task,
- 3) Number of tasks not presented to driver because of safety concerns, and
- 4) Number of errors on secondary task completion.

Task Completion Time started at the conclusion of instructions and ended when the driver stated the last word of his/her answer. Guidelines developed by Battelle for FHWA (Campbell, 1998) support restricted access if task completion time is greater than 10 seconds. Consensus on the SAE subcommittee for standards for navigation and route guidance function accessibility while driving could not be reached for a guideline limit of 10 seconds. However, the SAE subcommittee was able to arrive at a consensus that 15 seconds was the longest task completion

time (static task – vehicle stationary) that could be undertaken before driving would be unquestionably degraded (SAE 2364, 1998).

The time duration of 15 seconds was defined by the SAE subcommittee as the time to complete a task while the vehicle was stationary. Paul Green has performed research and found that under low to moderate driving demands, a multiplier of 1.2 to 1.4 can be used on task completion times to yield approximate task completion times when a vehicle is moving (P. Green, personal communication, December 1998). In this study, tasks were performed while the vehicle was moving. Therefore, task completion times greater than 13 seconds and 20 seconds were identified. (Using Green’s modifier, 10 seconds and 15 seconds were modified to 13 and 20 seconds, respectively.)

Number of Drivers Who Skipped a Task was determined. A task was considered to be skipped by the driver if the driver said “skip” rather than completing the task after the task was presented on the IVIS display. Drivers were instructed during training to say “skip” if they believed the task required too much attention to safely complete while driving. The number of drivers who skipped each task was determined.

Number of Tasks Not Presented to Driver, Safety Concern. Tasks were not presented if driver performance on a previously performed lower information density task was determined to be unsafe. For safety reasons, tasks with greater difficulty were not presented. Unsafe driver performance was determined by the experimenter in the vehicle as nine or more eye glances to the display, significant lane deviation, and/or significant headway or speed maintenance variations.

Number of Errors on Secondary Task Completion. An answer was determined correct for tasks that required the driver to either 1) search display for specific information, 2) determine the quickest route to the airport, or 3) determine the cheapest route to the airport. Clearly, errors are an undesired outcome. In this study, each of these tasks had only one correct answer. If an error was made, it indicated that insufficient mental resources were allocated to the task; had the driver

allocated additional resources, perhaps situation awareness would have been degraded and an accident would have resulted.

2.2.3 OBJECTIVE 3: TO PROVIDE DESCRIPTIVE DATA ON THE PROPORTION OF DRIVERS WHO EXCEEDED A SAFETY THRESHOLD FOR EACH OF THE DIFFERENT IVIS TASKS.

Driver performance, in this study, was characterized as being within a red zone, yellow zone, or green zone. The red, yellow, and green zones were operationally defined as driver performance that exceeded the Red-line Threshold, driver performance that exceeded the Yellow-line Threshold, and driver performance not significantly degraded from baseline driving, respectively. Figure 2.2 illustrates this concept. Driver performance data exist in the literature for IVIS tasks resulting in driver performance in the green zone; however, data are needed to indicate which IVIS tasks result in driver performance in the yellow and red zones. Exceeding the Yellow-line Threshold indicated there was a measurable degradation in driver performance. In contrast, exceeding the Red-line Threshold indicated that a composite group of surrogate safety measures of driver performance was substantially affected.

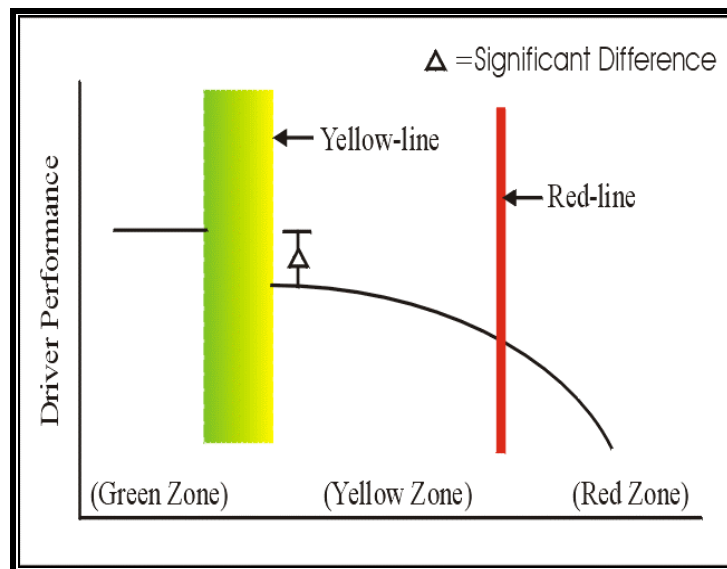


Figure 2.2. Illustration of Red-line and Yellow-line Thresholds.

A database was created that contains the proportion of drivers who exceeded the Red-line Threshold for each of the IVIS tasks in this study (refer to Appendices M-X). Also included in Appendices M-X are the results from the Yellow-line Threshold measure, indicating whether the

driver performance for each age group was significantly degraded during IVIS tasks from baseline driving.

The objective was to provide data and recommendations to designers and policy makers, not to determine the instrumentation to be placed in vehicles. When possible, the best approach to use for designing a safe system is to design out unsafe aspects based upon the user's needs, capabilities, and limitations. However, there are other methods to make a system safe that include training, policies and procedures, and warnings (Anton, 1989). Implementation of IVIS requires consideration of many issues. This study provides designers and policy makers with information to assist in determining how best to proceed with the implementation of this new technology.

CHAPTER 3: METHOD

3.1 PARTICIPANTS

Thirty-six drivers, ranging in age from 18 to 85 years, participated in the study. Drivers were grouped into one of three categories 1) young, 2) middle age, or 3) older drivers. A screening was performed to determine driver experience. Table 3.1 lists the average age and average miles driven for each age group. Drivers were recruited by advertisements in newspapers and flyers, and received \$10.00/hour for approximately five hours of research time. To participate in the study, drivers were required to:

- 1) Have a valid driver's license;
- 2) Pass a health screening questionnaire;
- 3) Have a minimum of 20/40 visual acuity, wearing corrective lenses if necessary;
- 4) Pass an informal hearing test; and
- 5) Drive a minimum of four times a week.

Table 3.1. Participants' age and miles driven annually.

Age	Gender	Avg. Age (years)	Age Range (years)	Average Miles/Year
Young	Male	21	19-24	16,083
	Female	22	20-25	10,750
Middle Age	Male	39	37-43	15,750
	Female	40	35-45	11,500
Older	Male	76	72-85	14,083
	Female	74	65-84	4,550

3.2 DRIVING CONDITIONS

Tasks were performed and data were collected on U.S. Highway 460, a four-lane divided road with good visibility, as participants drove from Blacksburg, Virginia to Princeton, West Virginia, and then back to Blacksburg. Data were only collected during daytime hours and during clear weather conditions with no rain, snow, or ice on the roadway. A confederate vehicle was driven in front of the test vehicle, throughout the drive, to create a vehicle following situation.

3.3 APPARATUS

An instrumented 1995 Oldsmobile Aurora four-door sedan was used to investigate on-road driver behavior. The primary apparatus used in the study, in addition to the automobile, were:

- 1) Cameras, sensors, and associated hardware and software;
- 2) An in-vehicle information system (IVIS); and
- 3) A confederate vehicle.

3.3.1 CAMERAS AND SENSORS

The vehicle was instrumented with cameras and sensors to monitor and record driver behavior.

Cameras were positioned to monitor and record:

- 1) Eye glance movements of the driver,
- 2) Forward roadway,
- 3) Position of the vehicle relative to the lane markers, and
- 4) Information being displayed on the IVIS.

Sensors were installed to monitor and record:

- 1) Longitudinal and lateral accelerations of the vehicle,
- 2) Speed of the vehicle,
- 3) Steering wheel position,
- 4) Headway distance, and
- 5) In-vehicle auditory sounds.

Data received from the cameras and sensors were time stamped and recorded both on a videotape and in a data file on a computer installed in the vehicle. Appendix D contains detailed information about the cameras, sensors, and associated hardware and software interfaces used in the instrumented vehicle.

3.3.2 IN-VEHICLE INFORMATION SYSTEM (IVIS)

The vehicle was equipped with an experimenter-operated IVIS. A PC laptop was used to operate the IVIS and a series of slides were created and stored in the computer's memory. Two experimenters were in the vehicle at all times during data collection. One experimenter sat in the

front passenger seat and the other experimenter sat in the back seat. When the rear seat experimenter typed a slide number into the keypad of the computer, a tone was presented to the driver to alert him/her that a task was to begin. Auditory instructions for the task to be performed were then presented to the driver. At the conclusion of the instructions, information needed to complete the task was instantaneously displayed on a screen mounted to the right of the driver. A button was located on the left side of the steering wheel that served to repeat the instructions when needed by the driver. If the driver depressed this button the data file was flagged, indicating that the driver requested that the instructions be repeated. A 10-inch LCD was mounted to the right of the driver. The distance from the right edge of the steering wheel to the display's midpoint was 6.25 in. The display swiveled on a ball and socket joint, allowing the driver to adjust the positioning of the display. Figure 3.1 illustrates the display used. Table D.1 in Appendix D lists the technical specifications of the LCD display.



Figure 3.1. IVIS display in the experimental vehicle.

3.3.3 CONFEDERATE VEHICLE

A vehicle was driven in front of the test vehicle at all times on the route. The vehicle was termed a "confederate vehicle" due to the fact that the participant of the study was unaware of the "help" that the confederate vehicle was providing to the experimenters in the test vehicle. The participant was made aware that a vehicle would be driven in front of his/her vehicle for the duration of the study with the purpose of creating a "traffic situation." However, the participant was not made aware that the confederate vehicle's speed would vary depending on whether

information was being displayed on the participant's IVIS. The confederate vehicle was equipped with a buzzer that was activated, via radio signal by the computer operated in the experimental vehicle by the rear seat experimenter, at the beginning and at the end of each task presentation and baseline condition.

3.4 EXPERIMENTAL DESIGN

This study utilized three within-subject variables (information processing, presentation format, and density level), and two between-subject variables (age and gender). The presentation order of the IVIS tasks was counter-balanced. The independent variables, dependent variables, and the variables held constant during the study are illustrated in Figure 3.2. Table 3.2 provides additional information about the independent variables studied.

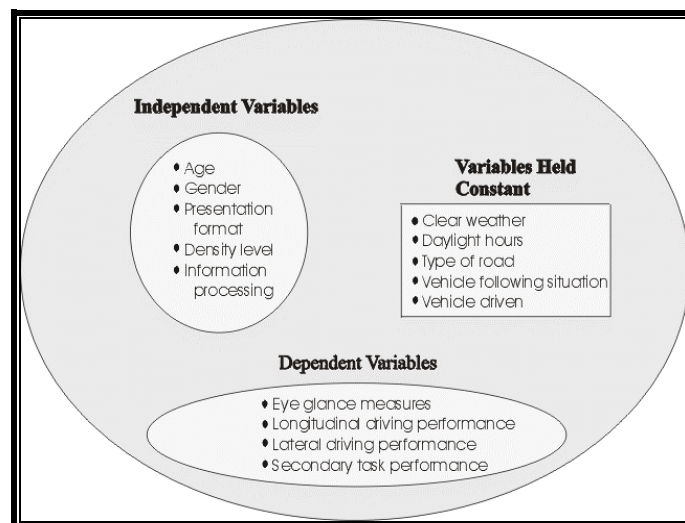


Figure 3.2. Variables.

3.4.1 INDEPENDENT VARIABLES

3.4.1.1 Age

The 36 drivers who participated in the experiment were divided into three groups based on age; each group had twelve drivers:

- 1) Young (18 and 25),
- 2) Middle age (35-45), and
- 3) Older (65⁺).

3.4.1.2 Gender

Within each age group, six drivers were male and six were female.

3.4.1.3 IVIS Tasks

IVIS tasks are characterized by three variables:

- 1) Presentation format: paragraph, table, graphic text, and graphic icon;
- 2) Density level: (number of options X number of categories of information); and
- 3) Information processing: Search; Search and Plan; Search and Compute; Search, Plan, and Interpret; Search, Plan, and Compute; and Search, Plan, Interpret, and Compute.
(Explained in detail in a later section)

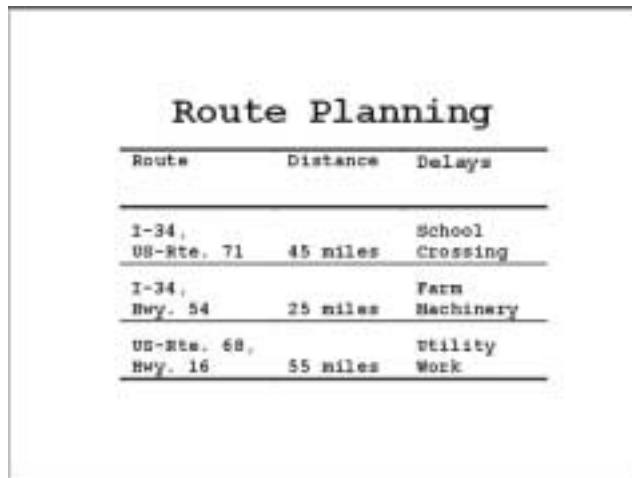
3.4.1.3.1 Presentation Formats

The presentation format refers to how information was displayed on the IVIS screen.

Information was displayed in one of the following four formats:

- 1) Table format: (refer to Figure 3.3),
- 2) Paragraph format: (refer to Figure 3.4),
- 3) Graphic text: (refer to Figure 3.5), and
- 4) Graphic icon: (refer to Figure 3.6).

Information displayed was presented using the guidelines outlined in the work of Campbell *et al.* (1998). Visual angles for title, critical elements, and non-critical elements were 0.50 degrees, 0.33 degrees, and 0.266, respectively. A simple and clear font, courier new, was utilized. Refer to Appendix C for additional specifications on the information presented.



Route	Distance	Delays
I-34, US-Rte. 71	45 miles	School Crossing
I-34, Hwy. 54	25 miles	Farm Machinery
US-Rte. 68, Hwy. 16	55 miles	utility Work

Figure 3.3. Table format.

Route Planning

I-29 to US-Rte. 39 is 35 miles and has a train crossing delay. US-Rte. 74 to Hwy. 38 is 84 miles and has a school bus delay. US-Rte. 39 to US-Rte. 64 is 91 miles and has a construction delay.

Figure 3.4. Paragraph format.

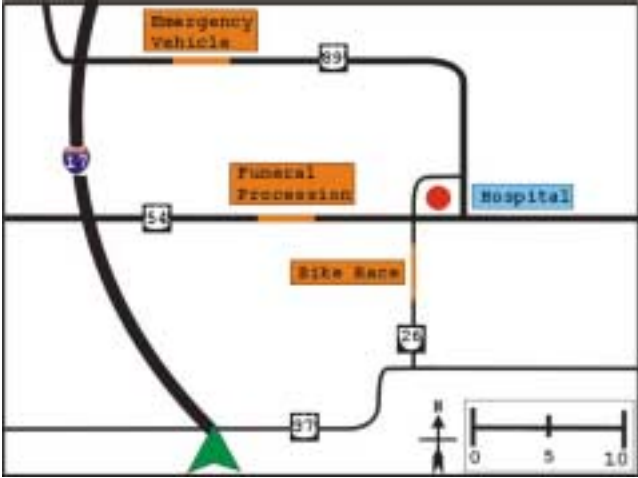


Figure 3.5. Graphic text format.

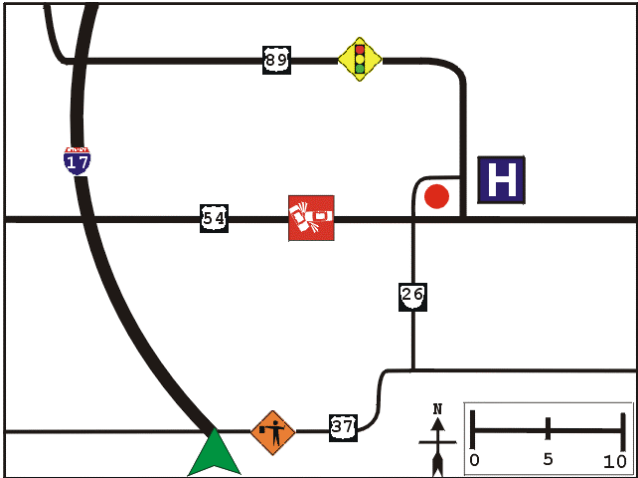


Figure 3.6. Graphic icon format.

3.4.1.3.2 Density Levels

The density level refers to the “number of options” and the “number of categories” of information to be considered for each option presented (number of options X number of categories of information). For example, a driver might have been presented a map with five possible routes to a destination and been provided the following information for each of the routes: type of road, distance, delays, and lanes closed. Each of these five routes or “options” had four “categories of information” to consider; therefore, this would be characterized as 5 options x 4 categories of information (5x4).

To further illustrate the concept of density levels, an example is provided below depicting a task and each of its density levels in the graphic icon format. This task involved selecting a route; there were five possible density levels in which information could have been presented to the driver when he/she completed this task. Table 3.3 contains the categories of information that were presented in each density level. The five density levels are listed below:

- Low (3x2): 3 options, 2 categories of information (refer to Figure 3.7),
- Medium (3x3): 3 options, 3 categories of information (refer to Figure 3.8),
- Medium (5x2): 5 options, 2 categories of information (refer to Figure 3.9),
- High (5x4): 5 options, 4 categories of information (refer to Figure 3.10), and
- Very High (5x6): 5 options, 6 categories of information (refer to Figure 3.11).

Table 3.3. Categories of information presented in different density levels.

Information Presented to Driver on IVIS				
<i>Low (3x2)</i>	<i>Medium (3x3)</i>	<i>Medium (5x2)</i>	<i>High (5x4)</i>	<i>Very High (5x6)</i>
Type of road	Type of road	Type of road	Type of road	Type of road
Distance	Distance	Distance	Distance	Distance
	Delays		Delays	Delays
			Hazards	Hazards
				Toll road
				Gas station

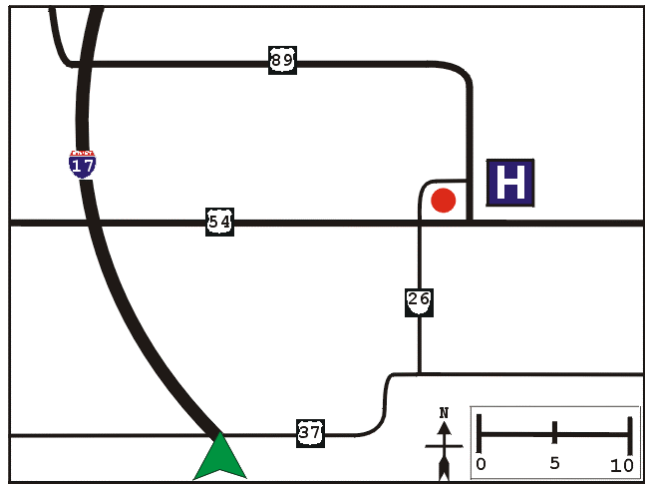


Figure 3.7. Low density (3x2), graphic icon.

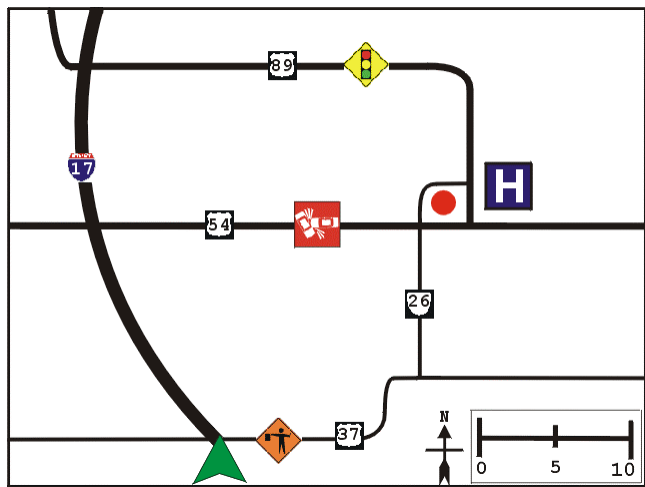


Figure 3.8. Medium density (3x3), graphic icon.

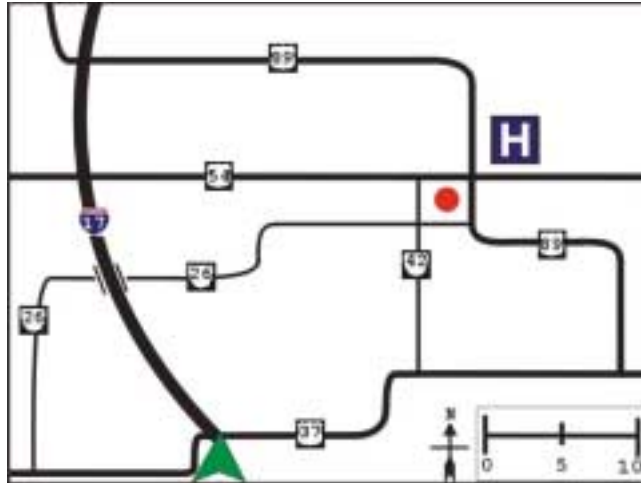


Figure 3.9. Medium density (5x2), graphic icon.

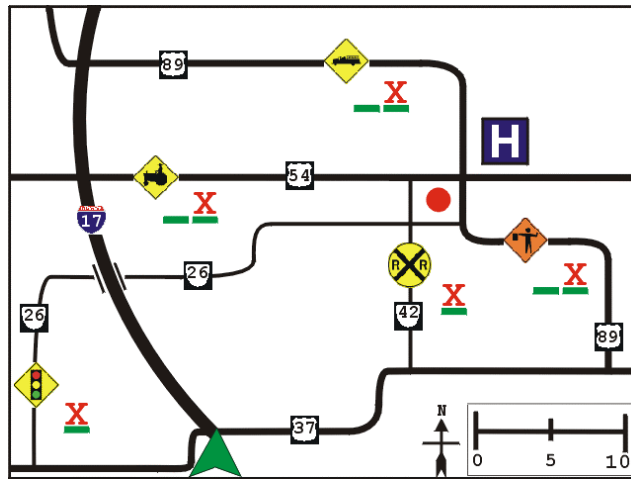


Figure 3.10. High density (5x4), graphic icon.

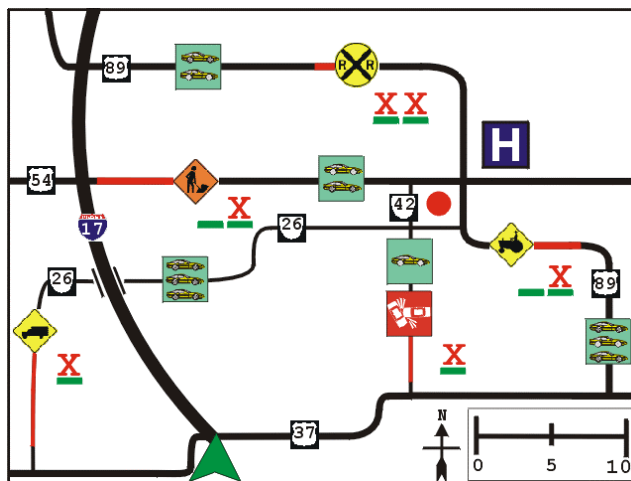


Figure 3.11. Very high density (5x6), graphic icon.

The space available on the visual display to present information restricted the combinations of density levels and presentation formats. The categories of information presented in each density level for each task are discussed further in the next section on information processing.

3.4.1.3.3 Information Processing

Tasks were characterized by the information processing required to complete the task. The classification scheme was adapted from the work of Lee *et al.* (1997). As discussed previously, four elements characterized the IVIS tasks: 1) Search, 2) Compute, 3) Plan, and 4) Interpret elements. Tasks were created such that they had one of the following combinations of elements:

- Search and Plan (SP task);
- Search, Plan, and Interpret (SPI task);
- Search and Compute (SC task);
- Search, Plan, and Compute (SPC task);
- Search, Plan, Interpret, and Compute (SPIC task); and
- Search task.

All tasks had a Search element since all tasks required the participant to scan the visual display for information. If a task required the participant to perform computations, then it was characterized as having a Compute element. Tasks that required the driver to select the “best” option from those presented were characterized as having a Plan element. If the information presented was ambiguous and the driver had to rely on personal judgment to infer the ramification(s) of the information, the task was characterized as having an Interpret element. The following section describes these tasks in more detail.

Search and Plan Tasks (SP task)

SP tasks involved the driver scanning and extracting information from the visual display and then further processing the information to determine how best to accomplish an objective. The information presented was characterized as definitive information; the

information did not need to be interpreted prior to using it to make a decision. Drivers were presented SP tasks that involved one of two objectives:

- 1) Selecting a hotel, or
- 2) Selecting a route.

SP-hotel Tasks

The low density level contained information about the name of the hotel and the distance from the vehicle’s current location for each hotel presented. All density levels provided this information, while additional information presented at higher density levels included information on vacancy, cost, quality rating, and restaurant availability. Tasks were created to determine the effect of presenting the same categories of hotel information in the different presentation formats. However, due to the nature of graphic maps, type of roadway information was also presented in the graphic text and graphic icon format.

- Table 3.4 outlines the information that was presented for selecting a hotel at the different density levels.
- Figure 3.12 provides an example of an SP-hotel task.
- Table 3.5 provides a listing of the density levels that were used with each of the presentation formats.
- Figures E.1-E.4 in Appendix E illustrate the IVIS screens presented for the SP-hotel tasks.

Table 3.4. Categories of information presented to drivers during SP-hotel.

Information Presented to Driver on IVIS			
<i>Low (3x2)</i>	<i>Medium (3x3)</i>	<i>High (5x4)</i>	<i>Very High (5x6)</i>
Hotel name	Hotel name	Hotel name	Hotel name
Distance	Distance	Distance	Distance
	Vacancy	Vacancy	Vacancy
		Cost	Cost
			Quality
			Restaurant

Hotels On-route		
Name	Vacancy	Distance
Best Western	Yes	18 miles
Marriott	No	35 miles
Sheraton	Yes	58 miles

Figure 3.12. An example of a SP-hotel.

Table 3.5. Density levels utilized for SP-hotel tasks.

Presentation Format	Density Level			
	<i>Low</i> (3x2)	<i>Medium</i> (3x3)	<i>High</i> (5x4)	<i>Very High</i> (5x6)
Table	X	X	X	X
Paragraph	X	X	X	
Graphic text*	X	X	X	X
Graphic icon*	X	X	X	X

* Type of roadway was also presented in the graphic text and graphic icon formats.

SP-route Tasks

The 3x2 and 5x2 density levels, contained information about the type of roadway and the distance from the vehicle's current location to the destination for all possible routes. All density levels provided this information, while additional information presented at higher density levels included the presence of delays (in minutes), safety hazards, tolls (no computation required), and/or gas stations on route.

- Table 3.6 outlines the information that was presented for selecting a route at the different density levels.
- Figure 3.13 provides an example of a SP-route task.
- Table 3.7 provides the density levels used with each of the presentation formats.
- Figures E.5-E.8 in Appendix E illustrate the IVIS screens presented for the SP-route tasks.

Table 3.6. Categories of information presented to drivers during SP-route tasks.

Information Presented to Driver on IVIS				
<i>Low (3x2)</i>	<i>Medium (3x3)</i>	<i>Medium (5x2)</i>	<i>High (5x4)</i>	<i>Very High (5x6)</i>
Type of road	Type of road	Type of road	Type of road	Type of road
Distance	Distance	Distance	Distance	Distance
	Delays		Delays	Delays
			Hazards	Hazards
				Toll road
				Gas station

Route	Distance	Delays
I-34, US-Rte. 71	105 miles	20 min
US-68, Hwy. 16	85 miles	45 min
I-34, Hwy. 54	160 miles	15 min

Figure 3.13. An example of an SP-route task.

Table 3.7. Density levels utilized for SP-route tasks.

Presentation Format	Density Level				
	<i>Low (3x2)</i>	<i>Medium (5x2)</i>	<i>Medium (3x3)</i>	<i>High (5x4)</i>	<i>Very High (5x6)</i>
<i>Table</i>	X		X	X	
<i>Paragraph</i>	X		X	X	
<i>Graphic text</i>			X	X	X
<i>Graphic icon</i>	X	X	X	X	X

Search, Plan, and Interpret Tasks (SPI tasks)

SPI tasks involved:

- 1) Scanning and extracting information from the visual display;
- 2) Interpreting the information, such as determining the implications of a car accident, or train crossing; and then
- 3) Deciding how best to accomplish an objective.

All SPI tasks involved selecting a route. Tasks were placed into one of the following groups based on the categories of information presented:

- 1) SPI-partial tasks presented categories of information that needed to be interpreted, but in addition, they also presented distance from current location to destination. Distance did not need to be interpreted; therefore, not all categories of information needed to be interpreted, hence the name SPI-partial. The SPI-partial tasks were presented in all presentation formats.
- 2) SPI-all task did not contain distance as a category of information; therefore, the SPI-all tasks were not presented in the graphic text and graphic icon formats.

Information displayed during SPI tasks is characterized in the following figures and tables:

- Table 3.8 outlines the information that was presented for selecting a route at the different density levels.
- Figures 3.14 and 3.15 illustrate an SPI-partial task and an SPI-all task, respectively.
- Table 3.9 provides a listing of the density levels that were used with each of the presentation formats.
- Figures E.9-E.14 in Appendix E illustrate the IVIS screens presented for the SPI tasks.

Table 3.8. Categories of information presented to drivers during SPI tasks.

	Information Presented to Driver on IVIS			
	<i>Low (3x2)</i>	<i>Medium (3x3)</i>	<i>High (5x4)</i>	<i>Very High (5x6)</i>
Partial - Interpret	N/A	Type of road	Type of road	Type of road
		Distance	Distance	Distance
		Delays	Delays	Delays
			Lane(s) closed	Lane(s) closed
				Congestion
				Traffic density
All - Interpret	Type of road	Type of road	Type of road	N/A
	Delays	Delays	Delays	
		Lane(s) closed	Lane(s) closed	
			Congestion	

Route	Distance	Delays
I-34, US-Rte. 71	45 miles	School Crossing
I-34, Hwy. 54	25 miles	Farm Machinery
US-Rte. 68, Hwy. 16	55 miles	Utility Work

Figure 3.14. An example of an SPI-partial task.

Route Planning		
Route	Delays	Lanes Closed
I-34, US-Rte. 71	Funeral Procession	1 of 2 Lanes, US-Rte. 71
I-34, Hwy. 54	Accident	1 of 1 Lanes, Hwy. 54
US-Rte. 68, Hwy. 16	Road Work	1 of 2 Lanes, US-Rte. 68

Figure 3.15. An example of an SPI-all task.

Table 3.9. Density levels utilized for SPI tasks.

	Presentation Format	Display Densities			
		<i>Low</i> (3x2)	<i>Medium</i> (3x3)	<i>High</i> (5x4)	<i>Very High</i> (5x6)
Partial- Interpret	<i>Table</i>		X	X	
	<i>Paragraph</i>		X	X	
	<i>Graphic text</i>		X	X	X
	<i>Graphic icon</i>		X	X	X
All - Interpret	<i>Table</i>	X	X	X	
	<i>Paragraph</i>	X	X	X	

Search and Compute Tasks (SC task)

SC tasks involved the driver scanning and extracting information from the visual display and then performing a computation with the information. Drivers were presented SC tasks that involved one of the following types of computations:

- 1) Addition — determine the cheapest route provided toll costs (SC-addition);
- 2) Division — determine the quickest route provided distance and speed limit (SC-division); and
- 3) Division & addition — determine the quickest route provided distance, speed limit, and delays in minutes (SC-division & addition).

Table 3.10 outlines the categories of information presented to drivers during SC tasks. Three categories of information was the minimum number needed to create an SC task, two categories with numbers for computations, and one category to identify the option. After a driver completed an SC task, he/she was asked if a computation was performed. If a computation was not performed, then the task was not characterized as an SC task, but rather as a Search and Plan task. The information presented during SC tasks is characterized in the following tables and figures:

- Figures 3.16, 3.17, and 3.18 provide examples of SC-addition, SC-division, and SC-division & addition tasks, respectively.
- Table 3.11 provides a listing of the density levels that were used with each of the presentation formats.
- Figures E.15-E.17 located in Appendix E illustrate the IVIS screens presented for the SC tasks.

Table 3.10. Categories of information presented to drivers during SC tasks.

	Information Presented to Driver on IVIS	
	<i>Medium (3x3)</i>	<i>High (5x4)</i>
Addition	Type of road	Type of road
	Toll cost	Toll cost
	Toll cost	Toll cost
		Distance
Division	Type of road	Type of road
	Distance	Distance
	Speed limit	Speed limit
		Toll cost
Addition & Division	N/A	Type of road
		Distance
		Speed limit
		Delays

Table 3.11. Density levels utilized for SC tasks.

	Presentation Format	Density Level	
		(3x3)	(5x4)
Addition	<i>Table</i>	X	X
	<i>Paragraph</i>	X	X
	<i>Graphic text</i>		X
Division	<i>Table</i>	X	X
	<i>Paragraph</i>	X	X
	<i>Graphic text</i>	X	X
Addition & Division	<i>Table</i>		X
	<i>Graphic text</i>		X

Route Planning		
Route	Toll Cost	Toll Cost
I-34, Hwy. 16	\$2.50	\$5.25
US-Rte. 68, Hwy. 54	\$6.00	\$3.50
I-34, US-Rte. 33	\$4.75	\$3.75

Figure 3.16. An example of an SC-addition task.

Route Planning

Route	Distance	Speed Limit
I-34, US-Rte. 33	364 miles	65 mph
US-Rte. 68, Hwy. 16	199 miles	50 mph
I-34, Hwy. 54	245 miles	55 mph

Figure 3.17. An example of an SC-division task.

Route Planning

Route	Distance	Speed Limit	Delays
US-Rte. 68, Hwy. 54	270 miles	50 mph	40 min
US-Rte. 68, Hwy. 16	205 miles	55 mph	28 min
I-34, US-Rte. 33	325 miles	65 mph	5 min
I-34, Hwy. 28	191 miles	50 mph	72 min
I-34, US-Rte. 71	180 miles	55 mph	30 min

Figure 3.18. An example of an SC-division & addition task.

Search, Plan, and Compute Tasks (SPC task)

SPC tasks involved scanning and extracting information from a visual display, choosing whether to perform a computation with the information, and then selecting a route from those presented. The same categories of information were presented to drivers during SPC tasks as during SC tasks; however, the instructions were different. During a SC task, the driver was instructed to “Select the quickest route to the airport” or “Select the cheapest route to the airport.” During SPC tasks, drivers were instructed to “Select a route to the airport.”

Drivers were questioned after the completion of SPC tasks to determine if the driver actually performed a SPC task or simply a SP task. If the driver stated that he/she performed a computation in deciding which route to take, then the task was characterized as an SPC task. However, if no calculation was performed, then the task was characterized as a SP task.

The number of categories of information required to perform computations did not allow SPC tasks to be presented in all combinations of presentation formats and density levels. SPC tasks were not presented in the graphic icon format due to the fact that numbers (text) had to be displayed for computation tasks. Information displayed during SPC tasks is characterized in the following figures and tables:

- Table 3.12 outlines the information that was presented for selecting a route at the different density levels.
- Figure 3.19 provides an example of an SPC task.
- Table 3.13 provides a listing of the density levels that were used with each of the presentation formats.
- Figures E.18-E.20 in Appendix E contain the IVIS screens presented for the SPC tasks.

Table 3.12. Categories of information presented to drivers during SPC tasks.

	Information Presented to Driver on IVIS	
	<i>Medium (3x3)</i>	<i>High (5x4)</i>
Addition	Type of road	Type of road
	Toll cost	Toll cost
	Toll cost	Toll cost
		Distance
Division	Type of road	Type of road
	Distance	Distance
	Speed limit	Speed limit
		Toll cost
Addition & Division	N/A	Type of road
		Distance
		Speed limit
		Delays

Route Planning			
Route	Distance	Toll Cost	Toll Cost
I-34, Hwy. 16	71 miles	\$2.50	\$6.50
I-34, US-Rte. 71	14 miles	\$4.50	\$9.00
US-Rte. 68, Hwy. 54	33 miles	\$2.50	\$3.75
US-Rte. 68, US-Rte. 28	52 miles	\$1.50	\$5.25
I-34, US-Rte. 33	26 miles	\$1.75	\$4.00

Figure 3.19. An example of an SPC task.

Table 3.13. Density levels utilized for SPC tasks.

	Presentation Format	Density Level	
		<i>Medium</i> (3x3)	<i>High</i> (5x4)
Addition	<i>Tabular</i>		X
	<i>Paragraph</i>		X
	<i>Graphic text</i>		X
Division	<i>Tabular</i>	X	X
	<i>Paragraph</i>	X	X
	<i>Graphic text</i>	X	X

Search, Plan, Interpret, and Compute Tasks (SPIC tasks)

SPIC tasks involved scanning and extracting information from a visual display, choosing whether to perform a computation with the information, interpreting information, and then deciding how best to accomplish the objective of selecting a route from those presented. During SPIC tasks, drivers were instructed to “Select a route to the airport.”

Drivers were questioned after the presentation of SPIC tasks to determine if the driver actually performed a SPIC task, a SPI task, a SPC task, or a SP task. A task was only considered to have a Compute element if the driver performed a computation, while a task was only considered to have an Interpret element if the driver used the category of information that required interpretation.

The number of categories of information required to perform computations did not allow SPIC tasks to be presented in all combinations of presentation formats and density levels. A minimum of four categories of information were required to create SPIC tasks; therefore, they were not presented in the low and medium density levels. SPIC tasks were not presented in the graphic icon format due to the fact that numbers (text) had to be displayed for computation tasks. Information displayed during SPIC tasks is characterized in the following figures and tables:

- Table 3.14 outlines the information that was presented for selecting a route.

- Figure 3.20 provides an example of a SPIC task.
- Table 3.15 provides a listing of the density levels that were used with each of the presentation formats.
- Figures E.21-E.23 in Appendix E contain the IVIS screens presented for the SPIC tasks.

Table 3.14. Categories of information presented to drivers during SPIC tasks.

	Information Presented to Driver on IVIS
	<i>High (5x4)</i>
Addition	Type of road
	Toll cost
	Toll cost
	Distance
Division	Type of road
	Distance
	Speed limit
	Toll cost

Route Planning			
Route	Distance	Speed Limit	Delays
I-34, US-Rte. 71	320 miles	65 mph	Construction
I-34, Hwy. 16	245 miles	55 mph	School Bus
US-Rte. 68, Hwy. 54	195 miles	45 mph	Hazmat Spill
US-Rte. 68, US-Rte. 28	139 miles	50 mph	Drawbridge
I-34, US-Rte. 33	205 miles	55 mph	Fire Truck

Figure 3.20. An example of an SPIC task.

Table 3.15. Density levels utilized for SPIC tasks.

	Presentation Format	Density Level
		<i>High (5x4)</i>
Addition	<i>Tabular</i>	X
	<i>Paragraph</i>	X
	<i>Graphic text</i>	
Division	<i>Tabular</i>	X
	<i>Paragraph</i>	X
	<i>Graphic text</i>	X

Search Tasks

Search tasks involved the driver scanning a visual display and extracting information. Drivers scanned for information that met predefined parameters; no further processing of the information was necessary. Search tasks were created with the goal of comparing the attention demand of scanning and extracting information from a visual display with tasks which required both the attention demand of scanning and extracting information from a visual display as well as performing additional information processing. Search tasks were grouped into the following categories:

- *Search on general information screens of text (S-general task)*
Tasks were created in the table and paragraph format that contained general information for drivers to scan and extract information (Figure 3.21). Figures E.24 and E.25 in Appendix E contain the IVIS screens presented for the S-general task.
- *Search on hotel selection tasks (S-HP task)*
Tasks were created in the graphic text and graphic icon formats that were similar to hotel selection tasks (Figure 3.22). Figures E.26 and E.27 in Appendix E contain the IVIS screens presented for the S-HP tasks.

- *Search on route selection tasks*

Tasks were created in the table, graphic text, and graphic icon formats that were similar to route selection tasks (Figure 3.23).

- SP route slides (S-RP task). Figures E.28 and E.29 in Appendix E contains the IVIS screens presented for the S-RP task.
- SPI slides (S-RPI task). Figures E.30-E.32 in Appendix E contain the IVIS screens presented for the S-RPI tasks.
- SC slides (S-compute task). Figure E.33 in Appendix E contains the IVIS screens presented for the S-compute tasks.

Local Attractions		
Option	Parking Cost	Admission Cost
1	No cost	\$4.50
2	High	\$0.00
3	No cost	\$0.00

Figure 3.21. S-general task, table format.
 Instructions: “Which option has no monetary cost?”

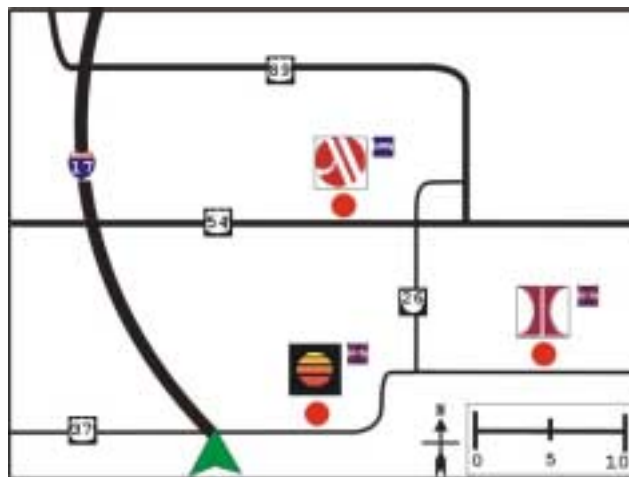


Figure 3.22. S-HP task, graphic icon format.
 Instructions: “Which hotel has a vacancy?”

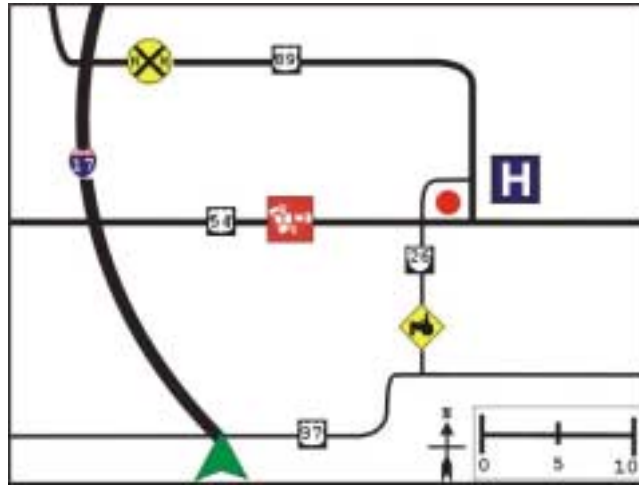


Figure 3.23. S-RPI task, graphic icon format.
Instructions: "Which roadway has a railroad crossing delay?"

3.4.2 DEPENDENT VARIABLES

Several measures were used to analyze driver performance during task completion and baseline driving. Task completion refers to the time starting at the completion of the instruction presentation and ending when the participant stated the last word of the answer. Information was displayed on the IVIS immediately after the instructions were presented. The effects of performing IVIS tasks on driver performance were determined with the following measures:

- Eye glance measures,
- Longitudinal driving performance measures,
- Lateral driving performance measures, and
- Secondary task performance measures.

The dependent measures used in this study are listed in Table 3.16.

Table 3.16. Dependent measures.

	Measure	Description
Eye Glance Measures	<i>Number of eye glances to IVIS display (number)</i>	The number of times the driver's eyes were directed to the display during task completion.
	<i>Peak single eye glance length to IVIS display (seconds)</i>	The longest continuous amount of time the driver's eyes were directed toward the display without looking to another location during task completion.
	<i>Number of eye glances to mirrors (number)</i>	The number of times the driver's eyes were directed to either the right-side mirror, left-side mirror, or rear-view mirror during task completion and baseline driving.
Longitudinal Driving Performance	<i>Minimum speed (mph)</i>	The minimum speed driven during task completion and baseline driving was determined.
	<i>Change in speed (mph)</i>	The difference between the speed at the start of either a task or baseline and the minimum speed reached during that task or baseline.
	<i>Variance in speed</i>	The variance in speed during task completion and baseline driving was determined.
	<i>Minimum headway (seconds)</i>	Headway was defined as the distance between the test vehicle and the vehicle in front, divided by the speed of the test vehicle. The minimum headway reached was determined for each task completion and baseline driving.
	<i>Peak longitudinal deceleration (G's)</i>	The peak longitudinal acceleration reached during task completion and baseline driving.
Lateral Driving Performance	<i>Lane deviation (number)</i>	The occurrence of the front wheels of the vehicle going over the inside edge of either the right or left lane marker, during task completion and baseline driving.
	<i>Peak steering wheel angular velocity (degrees/sec)</i>	The maximum velocity the steering wheel was turned during task completion and baseline driving.
	<i>Variance in steering wheel position</i>	The variance in steering wheel position during task completion and baseline driving.
	<i>Peak lateral acceleration (G's)</i>	The peak lateral acceleration reached during task completion and baseline driving.
Secondary Task Performance	<i>Task completion time (seconds)</i>	The length of time needed to complete the task, the time from the completion of instructions to when the driver stated the last word of the answer.
	<i>Number of drivers who skipped a task (number)</i>	A task was considered skipped by the driver if after the start of the task the driver said "skip" rather than complete the task and provided an answer.
	<i>Number of drivers not presented a task, safety concern (number)</i>	A task was not presented to a driver if driving was determined to have exceeded the Red-line Threshold at a lower density level for the same task.
	<i>Errors on secondary task completion (number)</i>	Correct/not correct was determined for the answer to the secondary task (IVIS task).

3.5 PROCEDURES

The method used during this study is divided into four components. Detailed procedures for each of these components are outlined below:

- 1) Participant screening and training,
- 2) Data collection,
- 3) Confederate vehicle, and
- 4) Data analysis.

3.5.1 PARTICIPANT SCREENING AND TRAINING PROCEDURES

Participants were screened over the telephone regarding age, gender, and driving experience (Appendix F). If participants qualified, a time was scheduled for testing. Participants were instructed to meet experimenters at the Virginia Tech Transportation Institute (VTTI), Blacksburg, VA. After arriving at the VTTI, the participant was given an overview of the study (Appendix G) and he/she completed the following:

- 1) Informed consent form (Appendix H).
- 2) Health screening questionnaire (Appendix I).
- 3) Vision test, to ensure minimum of 40/20 distance vision.

If no health problems were identified and the driver passed the vision test, the participant continued with training. The training process is outlined below; for a detailed description, refer to Appendix J.

- 1) Participant received instructions on the IVIS, using a computer mockup of the IVIS located in a laboratory.
- 2) Participant performed sample IVIS tasks on the computer mockup.
- 3) At the completion of the training on the computer mockup (approx. 1 hour), the participant was shown the vehicle that he/she was to drive during the study, and received instructions on vehicle operations.
- 4) Operations of the IVIS were reviewed, and in-vehicle vision and hearing tests were administered.

- a) Vision test was administered to determine the participant's ability to read the text presented on the IVIS display.
 - b) Hearing test was administered to determine the participant's ability to understand verbal navigational commands and hear the auditory alert cues.
- 5) Participant then received driving instructions to follow throughout the drive.
- a) Remain in the right-hand lane unless asked to pass a slow-moving vehicle.
 - b) Drive at a comfortable speed, not to exceed the speed limit.
 - c) Observe all traffic regulations, such as turn restrictions, traffic lights, regulatory and warning signs, etc.
 - d) Say "skip" if an IVIS task requires too much attention to safely perform while driving.
- 6) Participants then drove around a practice route to become familiar with the handling of the vehicle; during this time, no IVIS tasks were presented.
- 7) Once the participant stated that he/she was comfortable with the handling of the vehicle, training of IVIS tasks began while the vehicle was in motion.
- a) Task was presented on the IVIS system.
 - b) Participant completed the task.
 - c) Front seat experimenter asked participant for the categories of information used.
 - d) Front seat experimenter prompted the participant to complete the modified NASA-TLX subjective rating.
 - e) Front seat experimenter then stated what he heard the participant say and what this meant to him, the experimenter.
 - f) Front seat experimenter then asked the participant if this was how he/she intended to answer.
- 8) If the participant felt comfortable performing the IVIS task, then he/she was instructed to drive to U.S. Route 460, and additional training tasks were presented. At this time, the participant was not aware that these were practice tasks.
- 9) After completion of training tasks, data collection began on U.S. Route 460.

3.5.2 DATA COLLECTION PROCEDURES

Two experimenters were in the vehicle with the driver. The experimenter in the front seat interacted with the driver as needed, prompted the rear driver to present a task on the IVIS, and

served as the safety officer, using the emergency brake as needed. Appendix K contains the protocol followed by the front seat experimenter.

The experimenter in the rear seat presented information on the IVIS via laptop computer inputs, as instructed by the front seat experimenter, that was stored as slide format in the laptop computer's hard-drive. The data set was flagged automatically when new information was presented on the IVIS display. The sequence of data collection was as follows:

- 1) Front seat experimenter stated "Present task #___".
- 2) Rear seat experimenter presented the appropriate task on the IVIS.
 - a) Beep was sounded by IVIS, notifying the participant that a task was to be presented.
 - b) Auditory instructions were presented over the vehicle's sound system, such as "Select a hotel."
 - c) Visual information was displayed on the IVIS display at the conclusion of the auditory instructions.
 - d) The subject could, at any time, press the button on the left side of the steering wheel to have the instructions replayed.
 - e) Driver used the information displayed on the IVIS to complete the task.
 - f) Driver auditorily stated answer.
 - g) IVIS display went blank, and the task ended.
- 3) Driver was asked which information was used and, if applicable, whether a computation was performed.
- 4) Driver was asked for a modified NASA-TLX subjective evaluation and subjective evaluation of situation awareness (Appendix G).
- 5) A brief rest period; duration depended on road conditions (minimum of 10 seconds).

This series of events was repeated for each IVIS task presented to the driver. Each type of task (Search, SP, SC, etc.) was presented in each of the possible presentation formats. After all tasks had been presented one time, each task was then repeated at a higher or lower density level. This process continued until it was determined at what density level the Red-line Threshold was exceeded for each type of task in each of the presentation formats. Therefore, the total number of slides presented varied among participants. The presentation order of the tasks was counter-

balanced between drivers, based on type of task and presentation format. Baseline data collections were also counterbalanced with task presentations.

During the drive, tasks were evaluated on whether they exceeded the Red-line Threshold with an estimate of driver performance. The front seat experimenter evaluated lateral deviations, speed, and headway. The rear seat experimenter estimated the number of eye glances to the IVIS display; nine or more eye glances indicated that the Red-line Threshold had been exceeded. Also, if the driver said “skip” when a task was presented, then the Red-line Threshold had been exceeded.

Tasks were not performed along parts of the route that had poor visibility and/or sharp curves. Breaks were provided at rest areas and gas stations along the route, as needed. Once all tasks were completed, the driver was instructed to return to the Virginia Tech Transportation Institute where the driver was debriefed and paid for his/her time.

3.5.3 CONFEDERATE VEHICLE PROCEDURES

A passenger vehicle was driven in front of the test vehicle for the duration of the drive during which time it matched the speed of the Aurora. The confederate driver was signaled at the start of each IVIS task and baseline condition. An FM radio transmitter/receiver unit sent a signal to the confederate vehicle; a buzzer sounded once to indicate the start of a task, and twice to indicate the end of a task. The confederate driver decelerated at the onset of a task presentation. The confederate vehicle remained in the right-hand lane for the duration of a task. Appendix L contains protocol followed by the confederate driver.

3.5.4 DATA ANALYSIS PROCEDURES

Two groups of analysis were performed; procedures for each are discussed in the following sections:

- 1) Procedure for determination of Red-line and Yellow-line Thresholds, and
- 2) Procedure for comparative analysis of attention demand for IVIS tasks.

3.5.4.1 Procedure for Determination of Red-line and Yellow-line Thresholds

As mentioned previously, Red-line Thresholds and Yellow-line Thresholds were created to assess driver performance while completing IVIS tasks. A conservative Red-line Threshold was determined with the expectation that experts will agree on the threshold values that should not be exceeded. However, data are available if the need to modify the threshold values arises. If the Red-line Threshold values are modified, then the data will indicate the minimum number of drivers who would have exceeded the lower modified Red-line Threshold value. For example, it was expected that experts would agree that nine or more eye glances to the IVIS display indicated that the Red-line Threshold had been exceeded. However, if an expert instead chose to use five eye glances to the IVIS display as the Red-line Threshold, then the results would need to be interpreted as at least X% of drivers exceeded the Red-line Threshold. Drivers who made 5-8 eye glances to the display were not presented a lower density level; therefore, it is not known for all drivers if a modified Red-line Threshold of five eye glances to the IVIS display would have been exceeded.

A combination of six measures was used to create the Red-line Threshold. Three measures indicated the occurrence of a particular event and three other measures were used which indicated specific values had been exceeded.

The occurrence of one of the following three events indicated that the Red-line Threshold had been exceeded:

- 1) Lane deviations,
- 2) Task skipped by the participant, and
- 3) Task not presented to the driver because of safety concerns due to the driver's performance on a previous task at a lower density level.

The following three measures each had a range of values for which safety parameters were established from past research and expert opinion. Table 3.17 lists the values used to define the Red-line Threshold.

- 1) Number of glances to the IVIS display,
- 2) Peak eye glance length to IVIS display, and

3) IVIS task completion time.

Table 3.17. Red-line Threshold values.

	Measure	Red-line
Threshold Determined from Past Research and Expert Opinion	Number of eye glances to IVIS display	9 or more glance
	Peak single eye glance length to IVIS display	Greater than 2.5 seconds
	Task completion time	Greater than 20 seconds

As discussed in previous sections, the Yellow-line Threshold was determined to be exceeded if driving performance during IVIS task completion was negatively affected when compared to baseline driving. The measures listed in Table 3.18 were used to compare driver performance. The time to complete IVIS tasks varied; therefore, baselines were taken at time intervals representative of task completion times. The baseline measures were counterbalanced with the task presentations. Baseline values were determined for the performance measures by collecting four baselines for each of the different time intervals for each driver. Mean values for each performance measure were then determined for each driver. Table 3.19 contains the mean length of time for baselines and IVIS tasks for each time interval.

The performance of each driver was compared to his/her performance during task completion; a paired T-test was performed to determine if there was a significant difference ($p < 0.05$). This procedure was repeated for each of the three age groups. If performance was found to be significantly degraded with one or more of these measures during the IVIS task completion, then performance was said to be negatively affected and the Yellow-line Threshold was exceeded.

Table 3.18. Yellow-line Threshold measures.

	Measures
Eye-Scanning Behavior	Number of eye glances to mirrors
Lateral Driving Performance	Peak lateral acceleration
	Peak steering wheel velocity
	Variance in steering wheel position
Longitudinal Driving Performance	Peak longitudinal deceleration
	Minimum headway
	Change in speed
	Minimum speed
	Variance in speed

Table 3.19. Mean values for the different time intervals.

		Time Interval			
		<6 secs.	6-13 secs.	13-20 secs.	>20 secs.
Young	Baseline	5	9.1	16.7	29.1
	IVIS task	4.4	9.2	16.6	29
Middle Age	Baseline	5.2	9.1	16.8	30.3
	IVIS task	4.4	9.1	16	29
Older	Baseline	5.1	9.9	17.2	32.5
	IVIS task	4.4	9.3	16.4	34

3.5.4.2 Procedure for Comparative Analysis of Attention Demand for IVIS Tasks

Statistical analysis was performed using the SAS v6.12 software package. Due to missing data, typical of field experiments, all ANOVAs were conducted with the GLM Procedure. For this experiment, the 0.05 significance level was used (95% probability that the reported results reflect actual differences). Similarly, due to missing data, LSmeans was used when performing post hoc tests. The adjusted Tukey post hoc test was used to control for alpha inflation.

It was recognized that there would be a wide range of abilities in both driving the vehicle and performing the IVIS tasks. Therefore, tasks were presented at different density levels with the goal of determining when a driver's performance exceeded the Red-line Threshold. A disadvantage to this approach is that comparing individual measures is not possible. Due to the

method used, the mean number of glances for the high density version of a task might actually be less than the low density version. The reason for this result is that the excellent drivers and those drivers with excellent cognitive abilities performed the high density tasks, whereas the less skilled drivers and those with lower cognitive abilities performed the lower density tasks. Therefore, the number of drivers who exceeded the comprehensive Red-line Threshold measure was used to compare tasks.

There were 106 tasks for each driver that were either 1) presented, 2) not presented – assumed above Red-line Threshold, or 3) not presented – assumed below Red-line Threshold. Thirty-six drivers participated in the study; therefore, there were a total of 3816 tasks. Of these 3816 tasks, data were missing for 139 tasks (3.6%). Data were missing for one of two reasons:

- 1) Equipment failure, such as sensors, cameras, VCR occurred during data collection. The Red-line Threshold was a composite measure; therefore, not all sensors and/or cameras needed to be operating to determine if a Red-line Threshold had been exceeded for a particular task. For example, if the eye glance camera was not working but the lane-tracking camera detected a lane deviation, then the driver was determined to have exceeded the Red-line Threshold for the task. As another example, if both the data collection computer and the lane-tracking camera were fully operational and both indicated that the Red-line Threshold had not been exceeded, but the eye glance camera was not working, then the data were determined to be inconclusive and the task was coded as having missing data for the Red-line Threshold measure.
- 2) A task that was assumed to be below the Red-line Threshold by an in-vehicle experimenter but was later determined to be inconclusive. As discussed in previous sections, some tasks were not presented because the in-vehicle experimenters did not detect that the driver had exceeded a Red-line Threshold at a higher density level. It was assumed that the lower density level tasks would also not exceed the Red-line Threshold. However, if after data analysis a driver was found to have actually exceeded the Red-line Threshold on a task categorized by the in-vehicle experimenters as below Red-line Threshold, any task not presented because of this and assumed below Red-line Threshold was reclassified as missing data.

CHAPTER 4: RESULTS

4.1 OVERVIEW

Results from this study are presented in two sections within this chapter:

- 1) Determination of Red-line and Yellow-line Thresholds, and
- 2) Comparative Analysis of Attention Demands for IVIS Tasks.

The first section, Determination of Red-line and Yellow-line Thresholds, presents data for evaluating a potential IVIS on the criteria of:

- The proportion of drivers who exceeded the Red-line Threshold, developed based on findings from past studies and expert opinion which should not be exceeded due to safety implications; and
- Whether the Yellow-line Threshold was exceeded and thus driver performance significantly affected ($p < 0.05$) compared to baseline driving.

The second section of this chapter, Comparative Analysis of Attention Demands of IVIS Tasks, presents the results found from studying the effects of the following design parameters on the attention demand required of IVIS tasks:

- Type of information processing,
- Presentation format,
- Density level, and
- Age.

4.2 RED-LINE AND YELLOW-LINE THRESHOLDS

This section presents results indicating whether the Red-line Threshold and/or Yellow-line Threshold were exceeded. After brief descriptions of Red-line and Yellow-line Thresholds, results are presented for each of the following IVIS tasks:

- Hotel selection planning (SP-hotel tasks),
- Route planning with definitive information (SP-route tasks),
- Route planning with ambiguous information (SPI tasks),
- Determining the quickest route (SC-division tasks and SC-division & addition tasks),

- Determining the cheapest route (SC-addition tasks),
- Route planning with computations (SPC and SPIC tasks), and
- Scanning the IVIS to find an item matching specified criteria (Search tasks).

4.2.1 RED-LINE THRESHOLDS

Results pertaining to the proportion of drivers from all age groups who exceeded the Red-line Threshold for each of the different tasks are presented in this section. Data are also available for each age group in the tables located in Appendices M-X. As discussed in Chapter 3: Method, the Red-line Threshold was determined based on the following six measures:

- 1) Task skipped by driver,
- 2) Task not presented – assumed to exceed Red-line Threshold,
- 3) Number of eye glances to the IVIS display,
- 4) Peak single eye glance length to the IVIS display,
- 5) Task completion time, and
- 6) Lane deviations.

4.2.2 YELLOW-LINE THRESHOLDS

As discussed in Chapter 3, the Yellow-line Threshold was determined by comparing several driver performance measures during IVIS tasks to baseline driving. However, after analyzing the data, some of the measures discussed in Chapter 3 were not used to determine the Yellow-line Threshold. Variance in steering wheel position, variance in speed, change in speed, peak lateral acceleration, peak longitudinal deceleration, and minimum headway measures were determined to not be sensitive indicators of a negative change in driver performance.

Therefore, only the following three measures were used as indicators of driver performance being significantly negatively affected during IVIS task completion:

- 1) Number of eye glances to mirror locations,
- 2) Peak steering wheel angular velocity, and
- 3) Minimum speed driven.

When interpreting the results of the Yellow-line Threshold, it is important that the results from the Red-line Threshold also be considered. A total of twelve drivers from each age group participated in the study; if data were available for fewer than six drivers, then the Yellow-line Threshold results were said to be inconclusive. Also, if driver performance was not found to be significantly degraded from baseline driving, then the number of drivers who either skipped the task or were not presented the task for safety reasons was so indicated.

4.2.3 RESULTS

4.2.3.1 Hotel Selection Planning (SP-hotel Tasks)

As described in Chapter 3, SP-hotel tasks were characterized as requiring a decision from definitive information, but requiring no interpretation of meaning to accomplish an objective. These tasks involved searching for information and then using the information to make a decision on what hotel to stay at for the evening. All SP-hotel tasks provided the following information:

- Name of hotel, and
- Distance from current location to hotel.

Higher density level SP-hotel tasks contained additional information, including one or more of the following:

- Vacancy,
- Cost,
- Quality rating, and
- Restaurant availability.

The number of categories of information (2, 3, 4, or 6) that was presented was used to classify displays into one of four density levels: low, medium, high, and very high, respectively. Refer to Chapter 3 for more details on the information displayed in each density level.

As shown in Figure 4.1, when the name of the hotel and the distance from the current position to the hotel were presented, 25%, 17%, 14%, and 17% of drivers exceeded the Red-line Threshold in the paragraph, table, graphic text, and graphic icon formats, respectively. As shown in Table 4.1, results were inconclusive for young and middle age drivers with the Yellow-line Threshold; less

than 6 young drivers and 6 middle age drivers completed the SP-hotel task in the low density level. However, results from the Yellow-line Threshold indicate that the performance of older drivers' was significantly negatively affected in all presentation formats with the exception of the graphic text format.

When the additional information of vacancy was presented in the medium density level paragraph, table, graphic text, and graphic icon formats, 33%, 31%, 19%, and 33% of drivers exceeded the Red-line Threshold, respectively. As shown in Table 4.1, the Yellow-line Threshold results indicate that the performance of young drivers' was significantly affected in the paragraph format but not in the table format; results were inconclusive with the graphic text and graphic icon formats. The performance of middle age drivers' was significantly affected in all presentation formats with the exception of the graphic icon format, and the performance of older drivers' was significantly affected in all presentation formats.

When the additional information of cost, quality rating, and/or restaurant availability was added to the visual display, creating the high and very high density levels, more than 50% of drivers exceeded the Red-line Threshold, regardless of presentation format. For these tasks in either the high or very high density levels in which six or more drivers within an age group completed the task, driver performance was found to be significantly degraded from baseline driving.

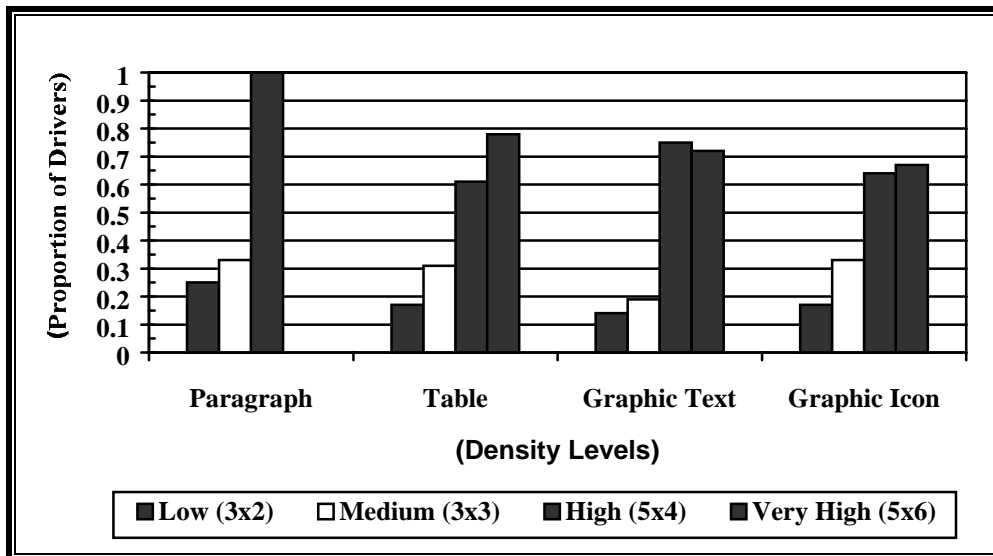


Figure 4.1. Proportion of drivers who exceeded the Red-line Threshold with SP-hotel tasks.

Note: 1) Task did not exist in the very high (5x6) density level paragraph format.

2) Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.1. Yellow-line Threshold for SP-hotel tasks.

		Presentation Format			
		<i>Paragraph</i>	<i>Table</i>	<i>Graphic Text</i>	<i>Graphic Icon</i>
Density Level					
Young Drivers	<i>Low (3x2)</i>	0 [#]	0 [#]	0 [#]	0 [#]
	<i>Medium (3x3)</i>	B	0	0 [#]	0 [#]
	<i>High (5x4)</i>	D	B	B	B
	<i>Very High (5x6)</i>	n/a	B	B	B
Middle Age Drivers	<i>Low (3x2)</i>	0 [#]	0 [#]	0 [#]	0 [#]
	<i>Medium (3x3)</i>	M	M	B	0
	<i>High (5x4)</i>	B	B	B	B
	<i>Very High (5x6)</i>	n/a	B	7 [#]	M
Older Drivers	<i>Low (3x2)</i>	D	D	1	B
	<i>Medium (3x3)</i>	D	M	M	B
	<i>High (5x4)</i>	10 [#]	B	B	10 [#]
	<i>Very High (5x6)</i>	n/a	11 [#]	12 [#]	12 [#]

D– Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), $p < 0.05$.

M– Scanning of mirrors was significantly less than baseline driving, $p < 0.05$.

B – Both driving performance and scanning of mirrors were significantly worse from baseline driving, $p < 0.05$.

– Data were available for fewer than six drivers.

n/a – Task did not exist in this presentation format.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendix M, Table M.1 for a summary of the Red-line and Yellow-line Thresholds exceeded; Table M.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables M.3 – M.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Tables M.6 – M.9 for the paired T-test results used to determine the Yellow-line Threshold.

4.2.3.2 Route Planning Tasks with Definitive Information (SP-route Tasks)

As described in Chapter 3, SP-route tasks were characterized as requiring a decision from definitive information; the displayed information required no interpretation of meaning to accomplish the objective. These tasks involved searching the IVIS display for information and then using the information to make a decision on which route to select. All SP-route tasks presented the following information:

- Type of road, and
- Distance from current position to destination.

In addition, higher density levels contained one or more of the following:

- Delays in minutes,
- Hazards,
- Toll booth locations, and
- Gas station locations.

The number of categories of information (2, 3, 4, or 6) that was presented was used to classify displays into one of four density levels: low, medium, high, and very high, respectively. Refer to Chapter 3 for more details on the information displayed in each density level.

As shown in Figure 4.2, when completing the SP-route tasks a large proportion of drivers exceeded the Red-line Threshold regardless of presentation format or density level. Even in the low (3x2) density level, where only three routes were presented with type of road and distance to destination, at least 25% of drivers exceeded the Red-line Threshold. The performance of young drivers was significantly worse from baseline driving with the exception of the paragraph format; the performance of middle age drivers was significantly worse with the exception of the graphic icon format; and the performance of older drivers was significantly affected in all presentation formats.

When the route information “delay in minutes” was added to each of the three possible routes, creating the medium (3x3) density level, at least 35% of drivers exceeded the Red-line Threshold. The performance of young drivers was significantly degraded from baseline driving in all

presentation formats with the exception of the graphic icon format. The performance of middle age drivers was significantly degraded from baseline driving regardless of presentation format. The performance of older drivers was significantly degraded from baseline driving in all presentation formats in which data were available for six or more drivers.

As shown in Figure 4.2, when five possible routes to a destination each having type of roadway and distance information, were presented to the driver creating the medium (5x2) density level, 31% of drivers exceeded the Red-line Threshold. As shown in Table 4.2, regardless of age, driver performance was significantly degraded from baseline driving.

Also, as shown in Figure 4.2, when the additional route information of delay in minutes, hazards, toll booth locations, and/or gas station locations were presented creating the high (5x4) and very high (5x6) density levels, over 70% of drivers exceeded the Red-line Threshold. Regardless of age or presentation format, if six or more drivers completed the task, driver performance was significantly degraded from baseline driving.

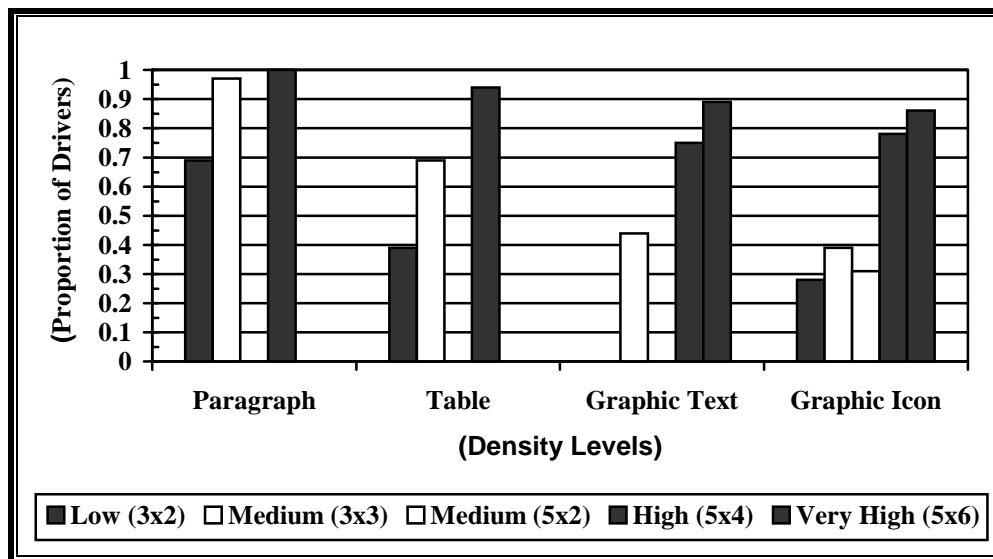


Figure 4.2. Proportion of drivers who exceeded the Red-line Threshold with SP-route tasks.

Note:

- 1) Task did not exist in the low (3x2) density level, graphic text format.
- 2) Task did not exist in the medium (5x2) density level for the paragraph, table, and graphic text formats.
- 3) Task did not exist in the very high (5x6) density level for the paragraph and table formats.
- 4) Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.2. Yellow-line Threshold for SP-route tasks.

	Density Level	Presentation Format			
		Paragraph	Table	Graphic Text	Graphic Icon
Young Drivers	<i>Low (3x2)</i>	0	D	n/a	B
	<i>Medium (3x3)</i>	B	M	M	0
	<i>Medium (5x2)</i>	n/a	n/a	n/a	M
	<i>High (5x4)</i>	12 [#]	D	B	B
	<i>Very High (5x6)</i>	n/a	n/a	7 [#]	B
Middle Age Drivers	<i>Low (3x2)</i>	B	0	n/a	B
	<i>Medium (3x3)</i>	B	D	D	M
	<i>Medium (5x2)</i>	n/a	n/a	n/a	B
	<i>High (5x4)</i>	12 [#]	D	B	D
	<i>Very High (5x6)</i>	n/a	n/a	10 [#]	8 [#]
Older Drivers	<i>Low (3x2)</i>	B	B	n/a	D
	<i>Medium (3x3)</i>	9 [#]	D	D	B
	<i>Medium (5x2)</i>	n/a	n/a	n/a	D
	<i>High (5x4)</i>	12 [#]	12 [#]	7 [#]	B
	<i>Very High (5x6)</i>	n/a	n/a	12 [#]	11 [#]

D– Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), $p < 0.05$.

M– Scanning of mirrors was significantly less than baseline driving, $p < 0.05$.

B– Both driving performance and scanning of mirrors were significantly degraded from baseline driving, $p < 0.05$.

– Data were available for fewer than six drivers.

n/a – Task did not exist in this presentation format.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendix N, Table N.1 for a summary of the Red-line and Yellow-line Thresholds exceeded; Table N.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables N.3 – N.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Tables N.6 – N.9 for the paired T-test results used to determine the Yellow-line Threshold.

4.2.3.3 Route Planning Tasks with Ambiguous Information (SPI Tasks)

As described in Chapter 3, SPI tasks required the driver to first interpret the information presented before using the information to decide how best to accomplish an objective. These tasks involved searching for information, interpreting it, and then using the information to make a route selection decision. All SPI tasks presented the following information:

- Type of road, and
- Description of delays.

Higher density levels of all presentation formats included the above mentioned categories of information and one or more of the following:

- Number of lanes closed,
- Amount of congestion,
- Traffic density, and
- Distance.

The number of categories (2, 3, 4, or 6) that was displayed was used to classify displays into one of four density levels: low, medium, high, and very high, respectively. Depending on the information displayed, SPI tasks were characterized as either 1) SPI-all or 2) SPI-partial tasks. SPI-all tasks did not contain information about distance to destination. SPI-partial tasks presented information about the distance from current location to destination, which was not ambiguous information and consequently did not need to be interpreted. Refer to Chapter 3 for more details on the information displayed in each density level.

As shown in Figure 4.3, SPI-all tasks required a high amount of attention demand. When drivers were provided information on type of roadway and description of delay, more than 45% of drivers exceeded the Red-line Threshold, regardless of presentation format. When additional ambiguous route selection information was added, creating the medium and high density levels, more than 75% of drivers exceeded the Red-line Threshold, regardless of presentation format. Due to the fact that graphic maps always presented distance information, SPI-all tasks were only presented in the table and paragraph formats.

As shown in Figure 4.4 with SPI-partial tasks, when one ambiguous category of information was added to the type of roadway and distance to destination information, typically presented on graphic maps, 39% and 19% of drivers exceeded the Red-line Threshold in the graphic text and graphic icon formats, respectively. In higher density levels, when two or more ambiguous categories were added to the type of roadway and distance to destination information, at least 60% of drivers exceeded the Red-line Threshold in both the graphic text and graphic icon formats. When the same information was presented in the table and paragraph formats, at least 53% of drivers exceeded the Red-line Threshold, regardless of density level.

As shown in Table 4.3, with few exceptions, if six or more drivers completed a task, then driver performance was significantly degraded from baseline driving for all age groups regardless of presentation format or density level.

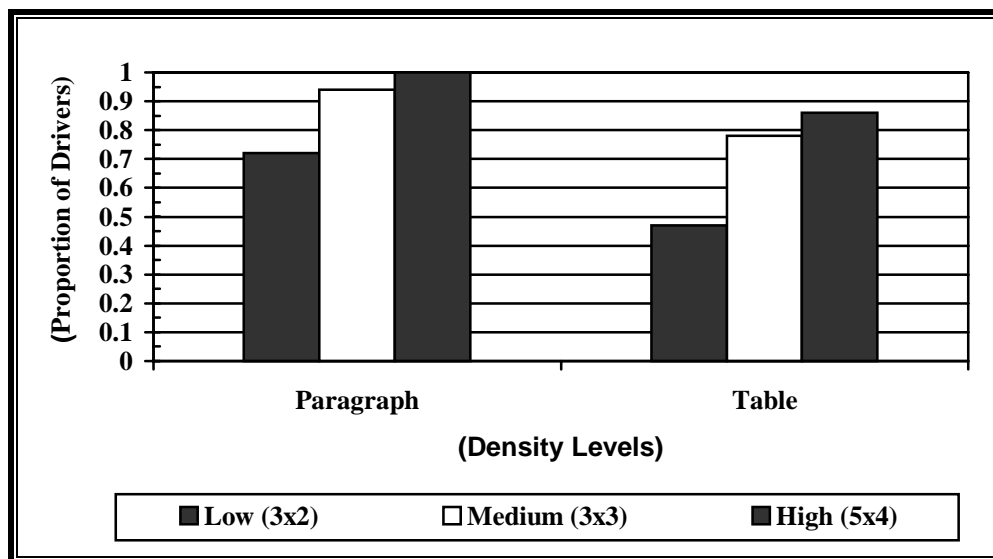


Figure 4.3. Proportion of drivers who exceeded the Red-line Threshold with SPI-all tasks. Note: Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

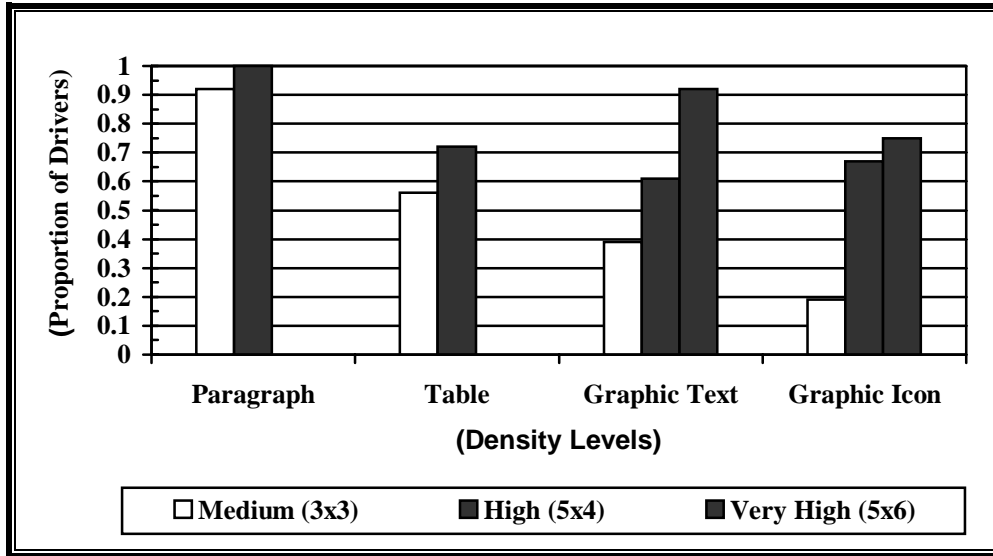


Figure 4.4. Proportion of drivers who exceeded the Red-line Threshold with SPI-partial tasks.

Note:

- 1) Task did not exist in very high (5x6) density level paragraph or table formats.
- 2) Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.3. Yellow-line Threshold for SPI tasks.

		Presentation Format					
		SPI-all		SPI-partial			
		<i>Paragraph</i>	<i>Table</i>	<i>Paragraph</i>	<i>Table</i>	<i>Graphic Text</i>	<i>Graphic Icon</i>
	Density Level						
Young Drivers	<i>Low (3x2)</i>	D	B	n/a	n/a	n/a	n/a
	<i>Medium (3x3)</i>	M	0	D	D	M	0 [#]
	<i>High (5x4)</i>	12 [#]	10 [#]	12 [#]	B	B	D
	<i>Very High (5x6)</i>	n/a	n/a	n/a	n/a	5	D
Middle Age Drivers	<i>Low (3x2)</i>	D	B	n/a	n/a	n/a	n/a
	<i>Medium (3x3)</i>	M	B	B	D	0	D
	<i>High (5x4)</i>	10 [#]	7 [#]	12 [#]	B	B	B
	<i>Very High (5x6)</i>	n/a	n/a	n/a	n/a	6	D
Older Drivers	<i>Low (3x2)</i>	B	D	n/a	n/a	n/a	n/a
	<i>Medium (3x3)</i>	12 [#]	D	B	D	D	D
	<i>High (5x4)</i>	12 [#]	9 [#]	12 [#]	7 [#]	D	D
	<i>Very High (5x6)</i>	n/a	n/a	n/a	n/a	12 [#]	11 [#]

D– Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), p<0.05.

M– Scanning of mirrors was significantly less than baseline driving, p<0.05.

B – Both driving performance and scanning of mirrors were significantly degraded from baseline driving, p<0.05.

– Data were available for fewer than six drivers.

n/a– Task did not exist in this presentation format.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendices O and P, Tables O.1 and P.1 for a summary of the Red-line and Yellow-line Thresholds exceeded; Tables O.2 and P.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables O.3 – O.5 and P.3 – P.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Tables O.6 – O.7 and P.6 – P.9 for the paired T-test results for the Yellow-line Threshold.

4.2.3.4 Determining the Quickest Route (SC-division Tasks, and SC-division & addition Tasks)

As described in Chapter 3, SC-division tasks involved searching for information on a display and then performing computations to determine the quickest route to a destination. Information displayed in the lowest density level SC-division tasks included type of road, distance, and speed limit. In the higher density level SC-division tasks, the route descriptor of toll cost was added. The number of categories of information (3 or 4) that was displayed was used to classify displays into one of two density categories: medium and high, respectively.

SC-division & addition tasks also involved determining the quickest route to the destination. Information presented included type of road, distance, speed limit, and delay in minutes. SC-division tasks were only presented in the 5x4 density level. Refer to Chapter 3 for more details on the information displayed in each density level.

Drivers were instructed during training to determine the quickest route with computations if they felt comfortable diverting the needed attention. Probe questions were asked after the driver stated an answer to determine if a computation had been performed or if the driver had simply performed a logical comparison to determine the quickest route. The results stated below illustrate the attention demand required to determine the quickest route, regardless of whether the driver performed a computation or a logical comparison.

As shown in Figure 4.5, when drivers were presented with the SC-division tasks, a large proportion of drivers exceeded the Red-line Threshold, regardless of presentation format. In the medium density level; where only information on type of road, speed limit, and distance was presented, at least 55% of drivers exceeded the Red-line Threshold. When the additional information of toll cost was also presented in the high density level, at least 80% of drivers exceeded the Red-line Threshold.

All drivers did not successfully complete the secondary task of determining the quickest route. Due to the fact that drivers were not presented a task, the measure of number/proportion of drivers

who unsuccessfully completed the secondary task is by itself not a meaningful measure. However, some might argue that if drivers had allocated more attention to the secondary task, then the Red-line Threshold might have been exceeded. Therefore, Table 4.4 presents the proportion of drivers who exceeded the Red-line Threshold with SC-division tasks based on both the criteria outlined in Chapter 3 and the proportion of drivers who exceeded the Red-line Threshold (taking into consideration whether the task was successfully completed). As shown in Table 4.4, the graphic text format in particular resulted in a relatively large proportion of drivers who completed the task without exceeding the Red-line Threshold, but who stated an incorrect answer (20% of drivers in the 3x3 density level, and 11% of drivers in the 5x4 density level).

Table 4.5 presents the results from the Yellow-line Threshold analysis for SC-division tasks. Results indicate that the driving performance of young and middle age drivers was not significantly different from baseline driving when the SC-division task was presented in the table format, medium density level. However, when this task was presented in either of the other two formats, paragraph or graphic text, the performance of both young and middle age drivers was significantly degraded from baseline driving. The performance of older drivers when completing the medium density level was significantly degraded from baseline driving. In the high density level, regardless of age, if six or more drivers completed the task, then driving was significantly affected.

When SC-division & addition tasks were presented in the table and graphic text formats, at least 83% of all drivers exceeded the Red-line Threshold. Table 4.6 shows the proportion of drivers who exceeded the Red-line Threshold for each of the presentation formats. Table 4.7 shows that the performance of young drivers did not exceed the Yellow-line Threshold when the task was presented in the table format. Yellow-line Threshold data were inconclusive for young drivers in the graphic text format, and were inconclusive for middle age and older drivers in all presentation formats.

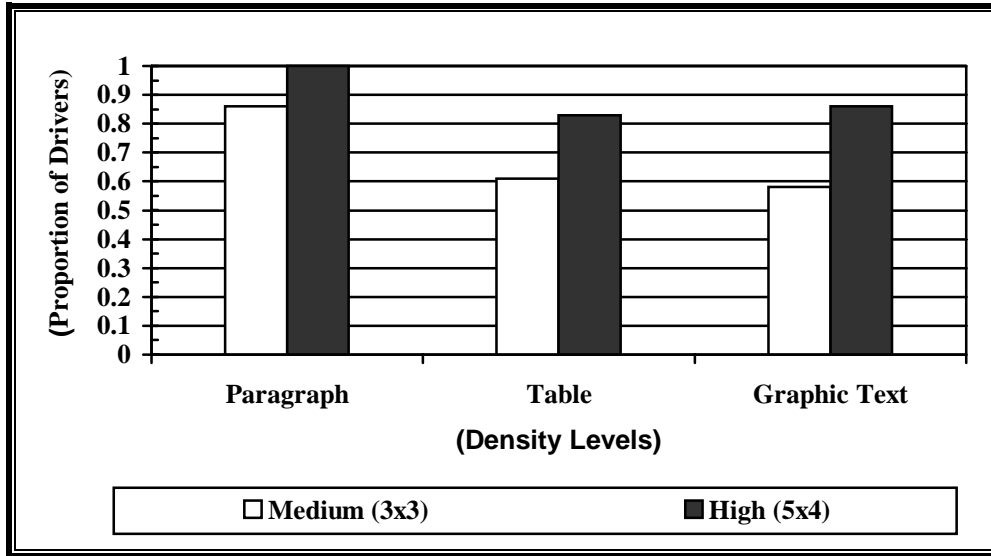


Figure 4.5. Proportion of drivers who exceeded the Red-line Threshold with SC-division tasks. Note: Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.4. Proportion of drivers who exceeded the Red-line Threshold with SC-division tasks.

IVIS Tasks		Proportion of Drivers Exceeding Red-line Threshold							
		Including Computation Errors				Without Including Computation Errors			
Presentation Format	Density Level	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>
Paragraph	<i>Medium (3x3)</i>	0.92	0.91	0.92	0.91	0.92	0.82	0.92	0.89
	<i>High (5x4)</i>	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Table	<i>Medium (3x3)</i>	0.63	0.73	0.75	0.71	0.63	0.73	0.75	0.71
	<i>High (5x4)</i>	0.67	0.83	1.00	0.83	0.67	0.83	1.00	0.83
G. Text	<i>Medium (3x3)</i>	0.50	0.91	1.00	0.80	0.25	0.82	0.75	0.60
	<i>High (5x4)</i>	0.92	1.00	1.00	0.97	0.75	0.83	1.00	0.86

Table 4.5. Yellow-line Threshold for SC-division tasks.

		Presentation Format		
		<i>Paragraph</i>	<i>Table</i>	<i>Graphic Text</i>
Density Level				
Young Drivers	<i>Medium (3x3)</i>	D	0	M
	<i>High (5x4)</i>	9 [#]	B	D
Middle Age Drivers	<i>Medium (3x3)</i>	B	0	D
	<i>High (5x4)</i>	9 [#]	B	D
Older Drivers	<i>Medium (3x3)</i>	D	B	B
	<i>High (5x4)</i>	12 [#]	7 [#]	8 [#]

D – Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), $p < 0.05$.

M – Scanning of mirrors was significantly less than baseline driving, $p < 0.05$.

B – Both driving performance and scanning of mirrors were significantly degraded from baseline driving, $p < 0.05$.

– Data were available for fewer than six drivers.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Table 4.6. Proportion of drivers who exceeded the Red-line Threshold with SC-division & addition.

IVIS Tasks		Proportion of Drivers Exceeding Red-line Threshold							
		Including Computation Errors				Without Including Computation Errors			
Presentation Format	Density Level	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>
Table	<i>High (5x4)</i>	0.92	0.83	1.00	0.92	0.92	0.83	1.00	0.92
G. Text	<i>High (5x4)</i>	0.92	0.92	1.00	0.94	0.92	0.92	1.00	0.94

Table 4.7. Yellow-line Threshold for SC-division & addition tasks.

		Presentation Format	
		<i>Table</i>	<i>Graphic Text</i>
	Density Level		
Young	<i>High (5x4)</i>	4	9 [#]
Middle Age	<i>High (5x4)</i>	9 [#]	8 [#]
Older	<i>High (5x4)</i>	12 [#]	12 [#]

– Data were available from fewer than six drivers.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendix Q, Table Q.1 for a summary of Red-line and Yellow-line Thresholds exceeded; Table Q.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables Q.3 – Q.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Tables Q.6 – Q.8 for the paired T-test results used to determine the Yellow-line Threshold.

4.2.3.5 Determining the Cheapest Route (SC-addition Tasks)

As described in Chapter 3: SC-addition tasks involved searching for information on a display and then performing computations with this information to determine the cheapest route to a destination. SC-addition tasks were presented in the medium and high density levels.

Information displayed in the medium density level included type of road, toll cost #1, and toll cost #2. The 3x3 density level was only presented in the paragraph and table formats. In the high density level, distance to the destination was also presented. This density level was presented in the paragraph, table, and graphic text formats. Refer to Chapter 3 for more details on the information displayed in each density level.

Drivers were instructed during training to determine the cheapest route with computations if they felt comfortable diverting the needed attention to complete the task. Probe questions were asked after the driver had stated an answer to determine if a computation had been performed or if the

driver had simply performed a logical comparison to determine the cheapest route. The results stated below illustrate the attention demand required to determine the cheapest route, regardless of whether the driver performed a computation or a logical comparison.

As shown in Figure 4.6, when drivers were presented with the SC-addition tasks, a large proportion of drivers exceeded the Red-line Threshold, regardless of presentation format. The medium density level was only presented in the table and paragraph formats, and 58% and 86% of drivers exceeded the Red-line Threshold, respectively. When the additional information of distance to the destination was included, at least 75% of drivers exceeded the Red-line Threshold, regardless of the presentation format.

Table 4.8 presents the proportion of drivers who exceeded the Red-line Threshold with SC-addition tasks based on the criteria outlined in Chapter 3 and the proportion of drivers who exceeded the Red-line Threshold (taking into consideration whether or not the task was successfully completed). Unlike the SC-division tasks, no one particular format had a high proportion of drivers who completed the task without exceeding the Red-line Threshold, but who did not successfully determine the correct answer.

Table 4.9 presents the results from the Yellow-line Threshold analysis. Results indicate that if six or more drivers completed the task, then driver performance was found to be significantly degraded from baseline driving regardless of age, presentation format, or density level.

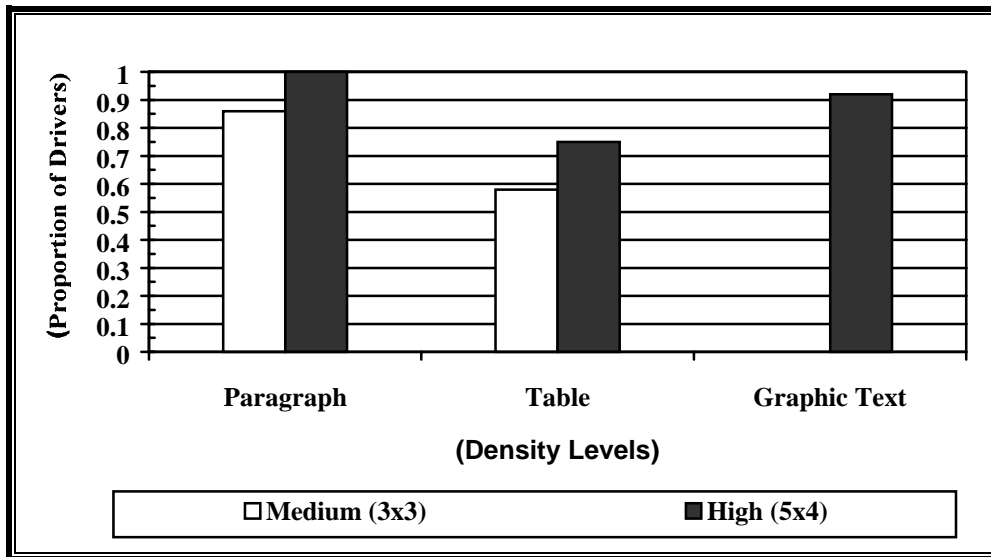


Figure 4.6. Proportion of drivers who exceeded the Red-line Threshold with SC-addition tasks
Note:

- 1) Task did not exist in the medium (3x3) density level graphic text format.
- 2) Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.8. Proportion of drivers who exceeded the Red-line Threshold with SC-addition tasks.

IVIS Tasks		Proportion of Drivers Exceeding Red-line Threshold							
		Including Computation Errors				Without Including Computation Errors			
Presentation Format	Density Level	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>
Paragraph	<i>Medium (3x3)</i>	1.00	0.75	0.92	0.89	0.92	0.75	0.92	0.86
	<i>High (5x4)</i>	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Table	<i>Medium (3x3)</i>	0.33	0.83	0.67	0.61	0.33	0.75	0.67	0.58
	<i>High (5x4)</i>	0.58	0.92	0.83	0.78	0.58	0.92	0.75	0.75
G. Text	<i>High (5x4)</i>	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92

Table 4.9. Yellow-line Threshold for SC-addition tasks.

	Density Level	Presentation Format		
		<i>Paragraph</i>	<i>Table</i>	<i>Graphic Text</i>
Young Drivers	<i>Medium (3x3)</i>	D	D	n/a
	<i>High (5x4)</i>	10 [#]	B	B
Middle Age Drivers	<i>Medium (3x3)</i>	D	B	n/a
	<i>High (5x4)</i>	9 [#]	B	B
Older Drivers	<i>Medium (3x3)</i>	B	B	n/a
	<i>High (5x4)</i>	12 [#]	7 [#]	7 [#]

D – Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), $p < 0.05$.

B – Both driving performance and scanning of mirrors were significantly degraded from baseline driving, $p < 0.05$.

– Data were available for fewer than six drivers.

n/a – Task did not exist in this presentation format.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendix R, Table R.1 for a summary of the Red-line and Yellow-line Thresholds exceeded; Table R.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables R.3 – R.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Tables R.6 – R.8 for the paired T-test results used to determine the Yellow-line Threshold.

4.2.3.6 Route Planning with Computations (SPC Tasks)

As described in Chapter 3, SPC tasks involved searching the IVIS display for information, performing computations to either determine the amount of travel time or the associated toll cost, and then making a decision on what route to select. The information presented allowed drivers to perform a computation if they chose to do so when selecting a route. After a task was completed,

the driver was asked if a computation had been performed. Only if a computation was performed was a task considered to be an SPC task.

The number of categories of information (3 or 4) displayed was used to classify tasks into either the medium or high density levels, respectively. Information presented with SPC tasks included type of road and distance, and either speed limit and/or toll cost information. Refer to Chapter 3 for more details on the information displayed in each density level.

Table 4.10 lists the proportion of drivers who chose not to perform a computation and thus only performed an SP task. Also presented in this table are the proportions of drivers who were determined to have exceeded the Red-line Threshold on SPC tasks. This proportion was based on the total number of drivers who either skipped the task, were not presented the task for safety reasons, or who chose to perform the SPC task; not included in this proportion were drivers who chose to simply perform an SP task. Based on the findings with the SC-addition and SC-division tasks, it was not surprising that a large percentage (at least 73%), of drivers exceeded the Red-line Threshold for the SPC tasks, regardless of presentation format.

Refer to Appendix S Table S.1 for the proportion of all drivers who exceeded the Red-line Thresholds, and Tables S.2 – S.4 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds.

Table 4.10. SPC tasks.

Presentation Format	Density Level	Information Processing		Total Number of Drivers	Chose Not to Perform a Computation	Skipped, Not Presented Task, or Chose to Complete SPC Task	Red-lined on SPC Task
Paragraph	Medium (3x3)	SPC-division	Number	36	13	23	22
			Percentage	100%	36%	64%	96%
	High (5x4)	SPC-addition	Number	36	8	28	28
			Percentage	100%	22%	78%	100%
		SPC-division	Number	36	0	36	36
			Percentage	100%	0%	100%	100%
Table	Medium (3x3)	SPC-division	Number	32	10	22	21
			Percentage	100%	31%	69%	95%
	High (5x4)	SPC-addition	Number	36	17	19	18
			Percentage	100%	47%	53%	95%
		SPC-division	Number	36	5	31	31
			Percentage	100%	14%	86%	100%
Graphic Text	Medium (3x3)	SPC-division	Number	35	24	11	8
			Percentage	100%	69%	31%	73%
	High (5x4)	SPC-addition	Number	36	7	29	24
			Percentage	100%	19%	81%	83%
		SPC-division	Number	36	10	26	26
			Percentage	100%	28%	72%	100%

4.2.3.7 Route Planning with Computations (SPIC Tasks)

As described in Chapter 3, SPIC tasks involved searching the IVIS display for information, interpreting the information, and performing computations to either determine the amount of travel time or the associated toll cost, and then making a decision on what route to select. The information presented allowed drivers to perform a computation if they chose to do so when selecting a route. One category of ambiguous information, type of delay, was also presented. After a task was completed the driver was asked if a computation had been performed if the type of delay information was considered. Only if a computation was performed and the type of delay information considered was a task considered to be an SPIC task.

The SPIC tasks were presented in only the 5x4 density level; information presented included type of road, description of delays, and either two toll costs or distance and speed limit information.

Table 4.11 lists the proportion of drivers who chose not to perform a computation and/or consider type of delay information and thus only performed an SP, SPI, or SPC task. Also presented in this table are the proportions of drivers who were determined to have exceeded the Red-line Threshold on SPIC tasks. This proportion was based on the total number of drivers who either skipped the task, were not presented the task for safety reasons, or who chose to perform the SPIC task; not included in this proportion were drivers who chose to simply perform an SP, SPI, or SPC task. Based on the findings with the SC-addition and SC-division tasks, it was not surprising that a large percentage (at least 95%), of drivers exceeded the Red-line Threshold for the SPIC tasks.

Refer to Appendix T, Table T.1 for the proportion of all drivers who exceeded the Red-line Thresholds, and Tables T.2 – T.4 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds.

Table 4.11. SPIC tasks.

IVIS Task		Drivers				
Presentation Format	Type of Information Processing		Total Number of Drivers	Chose Not to Perform a Computation and/or Interpretation	Skipped, Not Presented Task, or Chose to Complete SPIC Task	Red-lined on SPIC Task
P	SPIC-division	Number	36	6	30	30
		Percentage	100%	17%	83%	100%
	SPIC-addition	Number	36	2	34	34
		Percentage	100%	6%	97%	100%
T	SPIC-division	Number	36	16	20	19
		Percentage	100%	44%	56%	95%
	SPIC-addition	Number	36	17	19	19
		Percentage	100%	47%	53%	100%
GT	SPIC-division	Number	36	19	17	17
		Percentage	100%	53%	47%	100%

4.2.3.8 Scan the IVIS to Find an Item Matching Specified Criteria (Search Tasks)

4.2.3.8.1 Overview

As described in Chapter 3, tasks characterized as Search tasks required the driver to scan the display and locate information that met a predefined parameter. Tasks that required supplemental information processing (planning, interpreting, and/or computing) had different information displayed depending on what type of supplemental information processing was required. Therefore, Search tasks that were created that had similar visual display characteristics as the IVIS displays used for the supplemental information processing tasks. Search tasks were labeled

with the same density level and presentation format as the associated task that required the supplemental information processing. Search tasks were grouped into one of three categories:

- 1) General information,
- 2) Hotel selection information, or
- 3) Route selection information.

4.2.3.8.2 Search Tasks with General Information (S-general Tasks)

Search tasks characterized as searching general information were created in the table and paragraph formats. As shown in Figure 4.7, 17% or less of drivers exceeded the Red-line Threshold in the low, medium, and high density levels in the table format and in the low and medium density levels in the paragraph format. Over 40% of drivers exceeded the threshold in the table format “very high” density level, and over 55% of drivers exceeded the threshold in the paragraph format “high” and “very high” density levels.

Similarly to the SC tasks, there was one correct answer for each secondary task that required the driver to search for specific information on the display. Again, the measure of the number or proportion of drivers who successfully completed the task is not meaningful by itself because not all drivers completed all tasks. Therefore, the proportion of drivers who completed the task without exceeding the Red-line Threshold, but who incorrectly determined the answer for the secondary task, was determined. As shown in Table 4.12, drivers especially had difficulty successfully completing the secondary task of searching for the specified information in the high density level paragraph formats.

As shown in Table 4.13, in the medium, high, and very high density levels, in both the table and paragraph formats, if six or more drivers completed the task, then driver performance was significantly degraded from baseline driving. In the low density level paragraph format the performance of both young and older drivers was found to be significantly degraded from baseline driving; results were inconclusive for middle age drivers. In the low density level table format, the performance of older drivers was not significantly degraded from baseline driving; results were inconclusive for young and middle age drivers.

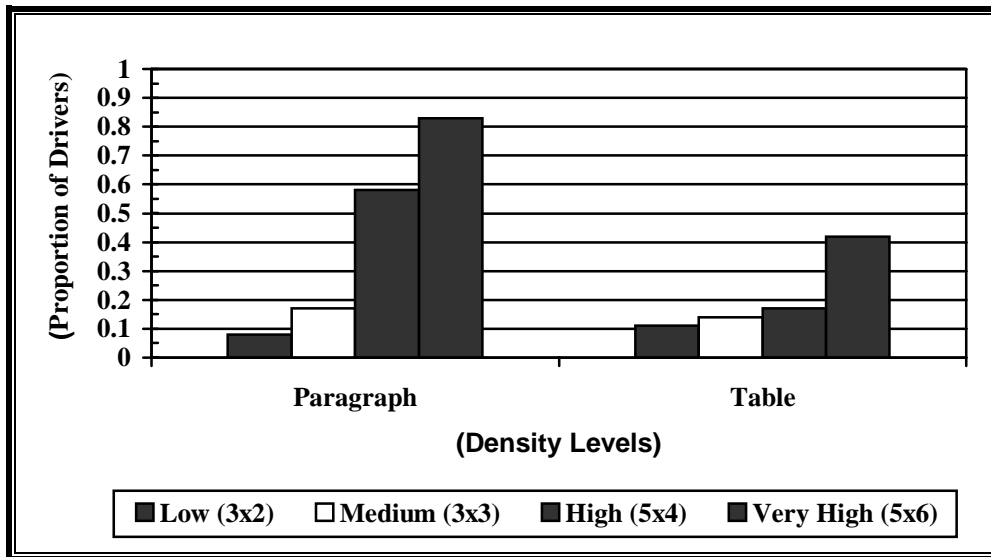


Figure 4.7. Proportion of drivers who exceeded the Red-line Threshold with S-general tasks.
Note: Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.12. S-general tasks successfully completed.

IVIS Tasks		Proportion of Drivers Exceeding Red-line Threshold							
		Including Searching Errors				Without Including Searching Errors			
Presentation Format	Density Level	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>
Paragraph	<i>Low (3x2)</i>	0.00	0.08	0.17	0.08	0.00	0.08	0.17	0.08
	<i>Medium (3x3)</i>	0.00	0.17	0.33	0.17	0.00	0.17	0.33	0.17
	<i>High (5x4)</i>	0.75	0.58	0.83	0.72	0.50	0.42	0.83	0.58
	<i>Very High (5x6)</i>	0.75	0.75	1.00	0.83	0.75	0.75	1.00	0.83
Table	<i>Low (3x2)</i>	0.00	0.00	0.33	0.11	0.00	0.00	0.33	0.11
	<i>Medium (3x3)</i>	0.08	0.17	0.50	0.25	0.00	0.08	0.33	0.14
	<i>High (5x4)</i>	0.08	0.08	0.33	0.17	0.08	0.08	0.33	0.17
	<i>Very High (5x6)</i>	0.08	0.33	0.83	0.42	0.08	0.33	0.83	0.42

Table 4.13. Yellow-line Threshold for S-general tasks

		Presentation Format	
		<i>Paragraph</i>	<i>Table</i>
Density Level			
Young Drivers	<i>Low (3x2)</i>	D	0 [#]
	<i>Medium (3x3)</i>	D	M
	<i>High (5x4)</i>	D	D
	<i>Very High (5x6)</i>	6	M
Middle Age Drivers	<i>Low (3x2)</i>	0 [#]	0 [#]
	<i>Medium (3x3)</i>	B	B
	<i>High (5x4)</i>	B	M
	<i>Very High (5x6)</i>	D	M
Older Drivers	<i>Low (3x2)</i>	B	1
	<i>Medium (3x3)</i>	B	D
	<i>High (5x4)</i>	8 [#]	M
	<i>Very High (5x6)</i>	12 [#]	9 [#]

D– Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), $p < 0.05$.

M– Scanning of mirrors was significantly less than baseline driving, $p < 0.05$.

B – Both driving performance and scanning of mirrors were significantly degraded from baseline driving, $p < 0.05$.

– Data were available for fewer than six drivers.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendix U, Table U.1 for a summary of Red-line and Yellow-line Thresholds exceeded; Table U.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables U.3 – U.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Tables U.6 – U.7 for the paired T-test results used to determine the Yellow-line Threshold.

4.2.3.8.3 Search tasks with Hotel Selection Information (S-HP Tasks)

Search tasks created with displays similar to the SP-hotel tasks were presented in the graphic text and graphic icon formats. As shown in Figure 4.8, less than 15% of drivers exceeded the Red-line Threshold in the graphic text format's low, medium, and high density levels. However, more than 40% of drivers exceeded the Red-line Threshold in the graphic text's very high density level. In the graphic icon format, less than 15% of drivers exceeded the Red-line Threshold in the low density level, more than 20% of drivers exceeded the threshold in the medium density level, and over 30% exceeded the threshold in the high and very high density levels. As shown in Table 4.14, most drivers who completed the task without exceeding the Red-line Threshold were able to successfully identify the specified information that they were searching for on the display.

As shown in Table 4.15, Yellow-line Threshold results were inconclusive for young and middle age drivers in the low density level. However, in all other density levels, in both the graphic text and graphic icon formats, the performance of young and middle age drivers was found to be significantly degraded from baseline driving. The performance of older drivers' was found to be significantly degraded from baseline driving in all density levels in both formats.

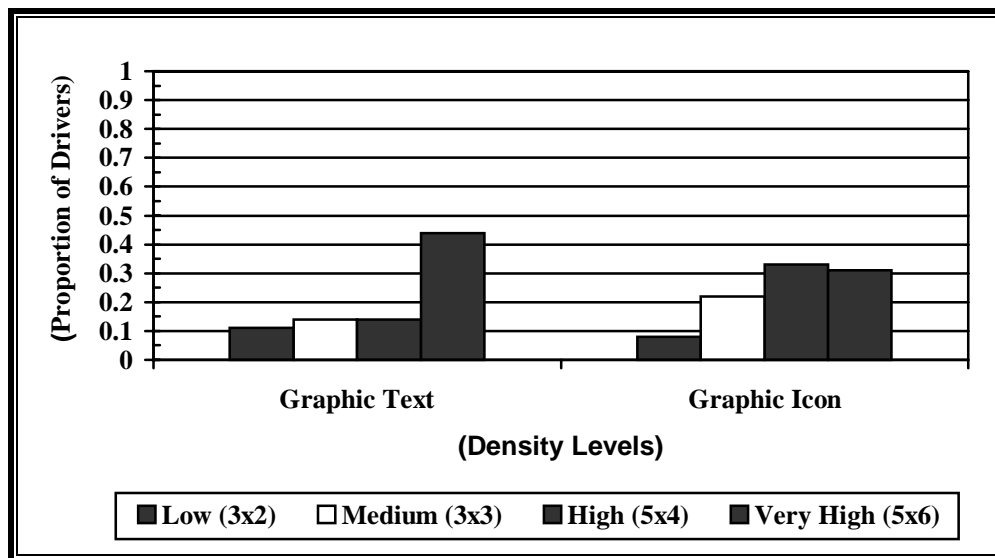


Figure 4.8. Proportion of drivers who exceeded the Red-line Threshold with S-HP tasks. Note: Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.14. S-HP tasks successfully completed.

IVIS Tasks		Proportion of Drivers Exceeding Red-line Threshold							
		Including Searching Errors				Without Including Searching Errors			
Presentation Format	Density Level	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>
G. Text	<i>Low (3x2)</i>	0.00	0.08	0.25	0.11	0.00	0.08	0.25	0.11
	<i>Medium (3x3)</i>	0.00	0.00	0.42	0.14	0.00	0.00	0.42	0.14
	<i>High (5x4)</i>	0.17	0.08	0.33	0.19	0.17	0.00	0.25	0.14
	<i>Very High (5x6)</i>	0.08	0.42	0.83	0.44	0.08	0.42	0.83	0.44
G. Icon	<i>Low (3x2)</i>	0.00	0.00	0.25	0.08	0.00	0.00	0.25	0.08
	<i>Medium (3x3)</i>	0.08	0.17	0.42	0.22	0.08	0.17	0.42	0.22
	<i>High (5x4)</i>	0.08	0.25	0.75	0.36	0.08	0.25	0.67	0.33
	<i>Very High (5x6)</i>	0.00	0.08	0.83	0.31	0.00	0.08	0.83	0.31

Table 4.15. Yellow-Line Threshold for S-HP tasks

		Presentation Format	
		Graphic Text	Graphic Icon
		Density Level	
Young Drivers	<i>Medium (3x3)</i>	0 [#]	0 [#]
	<i>Medium (3x4)</i>	B	M
	<i>High (5x5)</i>	D	D
	<i>Very High (5x7)</i>	D	M
Middle Age Drivers	<i>Medium (3x3)</i>	0 [#]	0 [#]
	<i>Medium (3x4)</i>	D	M
	<i>High (5x5)</i>	B	M
	<i>Very High (5x7)</i>	D	B
Older Drivers	<i>Medium (3x3)</i>	D	D
	<i>Medium (3x4)</i>	D	B
	<i>High (5x5)</i>	D	B
	<i>Very High (5x7)</i>	9 [#]	9 [#]

D – Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), $p < 0.05$.

M– Scanning of mirrors was significantly less than baseline driving, $p < 0.05$.

B – Both driving performance and scanning of mirrors were significantly degraded from baseline driving, $p < 0.05$.

– Data were available for fewer than six drivers.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendix V, Table V.1 for a summary of Red-line and Yellow-line Thresholds exceeded; Table V.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables V.3 – V.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Tables V.6 – V.7 for the paired T-test results used to determine the Yellow-line Threshold.

4.2.3.8.4 Search Tasks with Route Selection Information (S-RP, S-RPI, and S-compute Tasks)

Route selection Search tasks were presented in the table, graphic text, and graphic icon formats to represent the different type of information/icons presented in the IVIS tasks that required the additional information processing of planning, interpreting, and/or computing. Refer to Chapter 3 for more information on information displayed in each IVIS task.

Table Format

As shown in Figure 4.9, when route selection information was presented in table format in the low and medium density levels, less than 15% of drivers exceeded the Red-line Threshold; 28% of drivers exceeded the threshold in the high density level. As shown in Table 4.16, most drivers who completed the task and who did not exceed the Red-line Threshold were successfully able to identify the correct information they were searching for on the display. As shown in Table 4.17, the performance of young drivers was not significantly different from baseline driving when the Search task with route selection information was presented in the low (3x2) density level. However, the performance of both middle age and older drivers was significantly degraded from baseline driving in the low density level. Driver performance, regardless of age, was significantly degraded from baseline driving in the medium and high density levels.

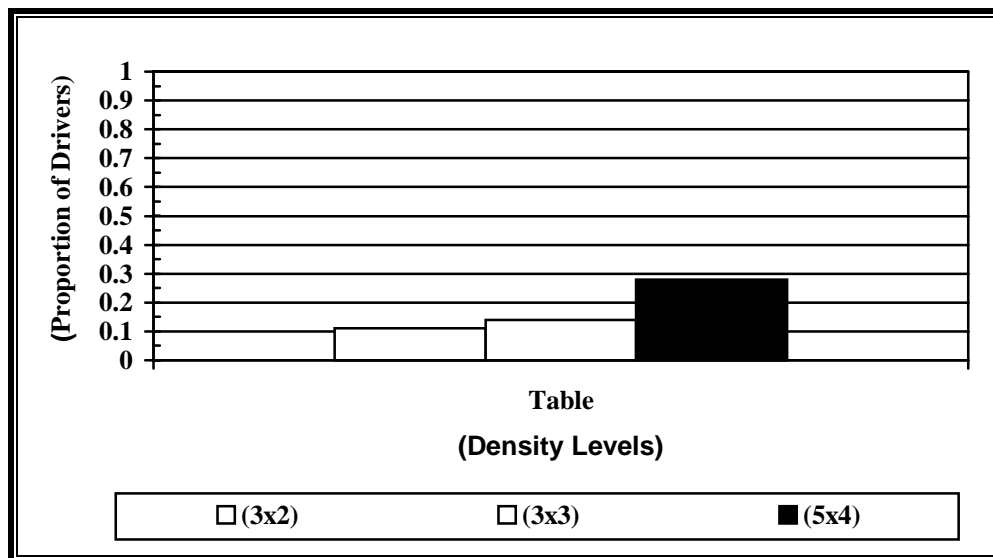


Figure 4.9. Proportion of drivers who exceeded the Red-line Threshold with route selection Search tasks, table format.

Note: Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.16. Route selection Search tasks successfully completed in the table format.

IVIS Tasks		Proportion of Drivers Exceeding Red-line Threshold							
		Including Searching Errors				Without Including Searching Errors			
Presentation Format	Density Level	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>
Table	<i>Low (3x2)</i>	0.00	0.17	0.17	0.11	0.00	0.17	0.17	0.11
	<i>Medium (3x3)</i>	0.08	0.08	0.25	0.14	0.08	0.08	0.25	0.14
	<i>High (5x4)</i>	0.08	0.17	0.67	0.31	0.08	0.08	0.67	0.28

Table 4.17. Yellow-line Threshold for route selection Search tasks, table format.

	Density Level	Table Format
Young Drivers	<i>Low (3x2)</i>	0
	<i>Medium (3x3)</i>	B
	<i>High (5x4)</i>	M
Middle Age Drivers	<i>Low (3x2)</i>	M
	<i>Medium (3x3)</i>	M
	<i>High (5x4)</i>	M
Older Drivers	<i>Low (3x2)</i>	D
	<i>Medium (3x3)</i>	D
	<i>High (5x4)</i>	B

D– Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), $p < 0.05$.

M– Scanning of mirrors was significantly less than baseline driving, $p < 0.05$.

B– Both driving performance and scanning of mirrors were significantly degraded from baseline driving, $p < 0.05$.

()– The presence of a number indicates:

- 1) Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
- 2) The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendix W, Table W.1 for a summary of Red-line and Yellow-line Thresholds exceeded; Table W.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables W.3 – W.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Table W.6 for the paired T-test results used to determine the Yellow-line Threshold.

4.2.3.8.5 Graphic Text and Graphic Icon Formats

As shown in Figure 4.10, 17% of drivers exceeded the Red-line Threshold when they searched for information on a graphic map with three possible routes to a destination, low (3x2) density level, and 28% of drivers exceeded the Red-line Threshold when they searched for information on a graphic map with five possible routes to a destination, medium (5x2) density level. As shown in Table 4.18, when either three or five routes to a destination were presented on a graphic map (the 3x2 and 5x2 density levels), driver performance, regardless of age, was significantly degraded from baseline driving.

As shown in Figures 4.11 – 4.13, when the additional route information used in the S-RP and S-RPI tasks in the medium density level was added to the graphic map, less than 15% of drivers exceeded the Red-line Threshold in both the graphic text and graphic icon formats. When the additional route descriptors used in the high density level were added, 11% of drivers exceeded the Red-line Threshold in the S-RP graphic text format. In all the other Search tasks presented in the high density level, 19% or more of drivers exceeded the Red-line Threshold. In addition, as shown in Table 4.18, drivers had difficulty searching for and correctly identifying information when presented in the very high density level.

As shown in Table 4.19, with few exception, regardless of age and presentation format, driver performance was found to be significantly degraded from baseline driving when additional route descriptors were added in the high and very high density levels.

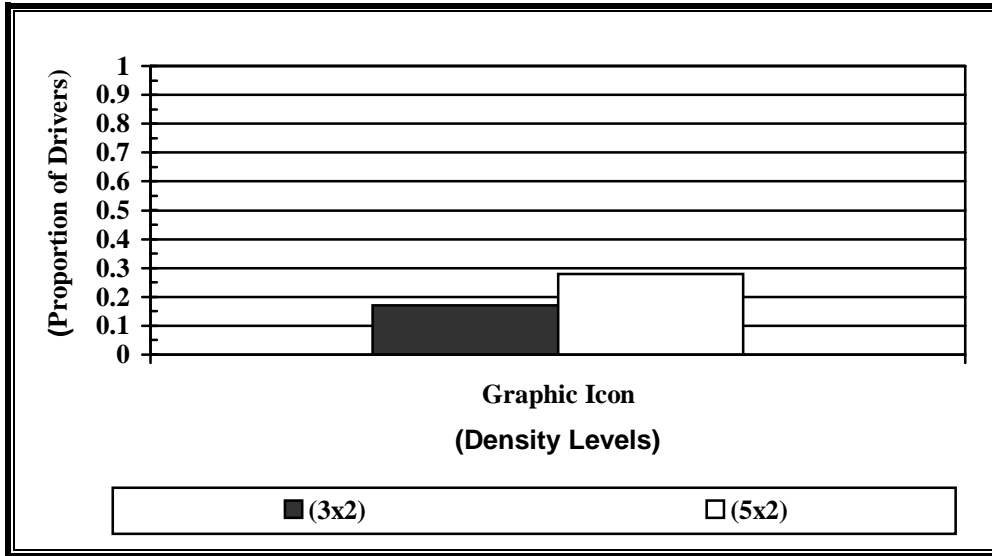


Figure 4.10. Proportion of drivers who exceeded the Red-line Threshold with route selection Search tasks, graphic map format.

Note: Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

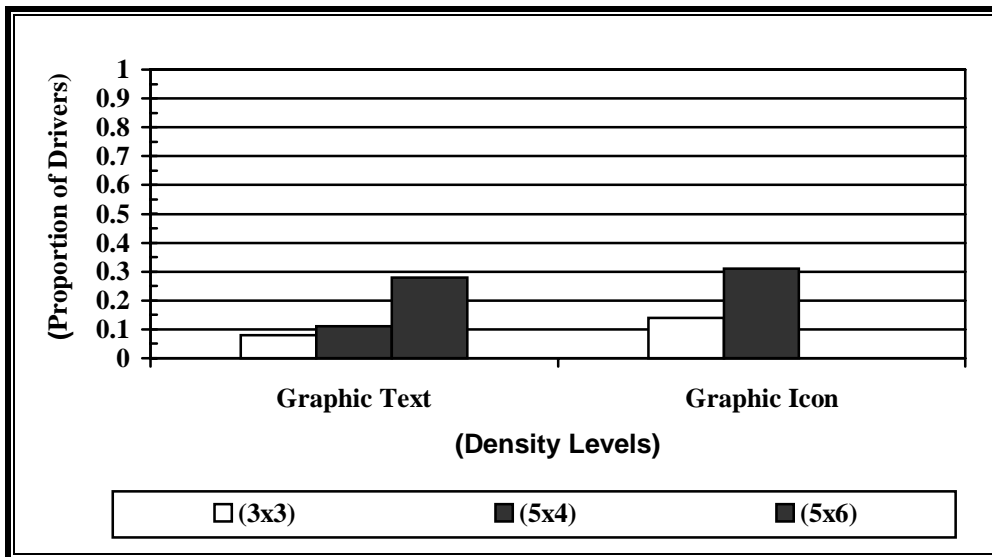


Figure 4.11. Proportion of drivers who exceeded the Red-line Threshold with S-RP tasks.

Note:

- 1) Task did not exist for the graphic icon, 5x6 density level
- 2) Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

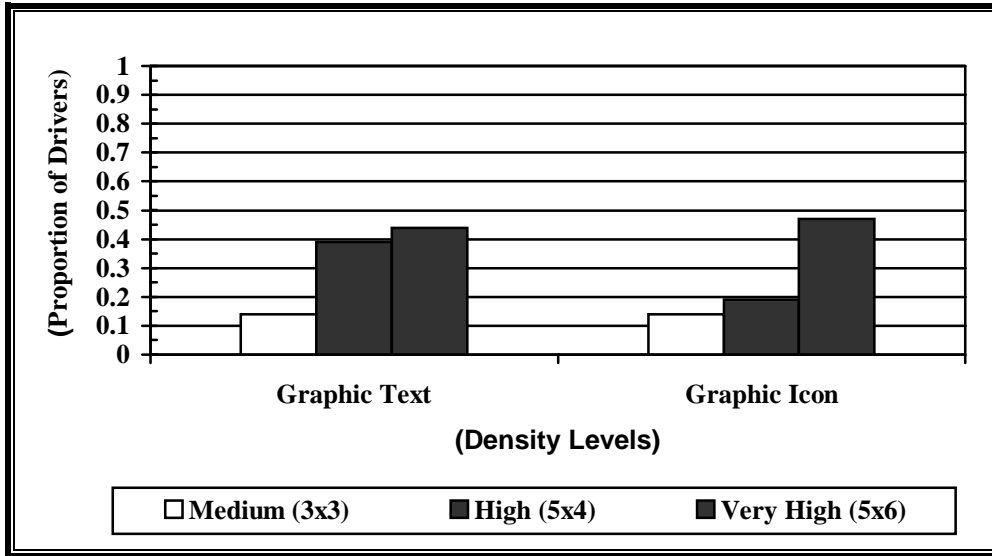


Figure 4.12. Proportion of drivers who exceeded the Red-line Threshold with S-RPI tasks.
 Note: Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

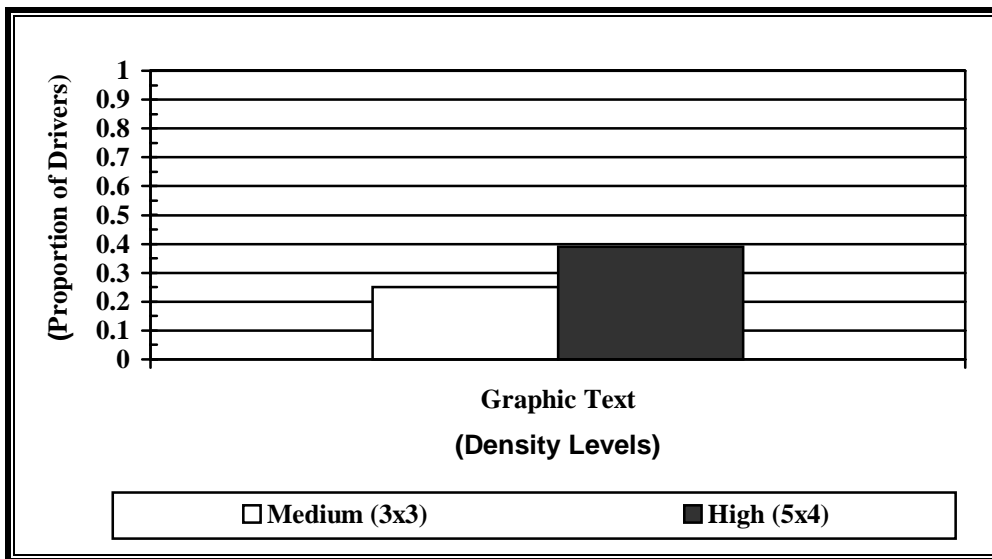


Figure 4.13. Proportion of drivers who exceeded the Red-line Threshold with S-compute tasks.
 Note: Bar graphs correspond to the ordering, left to right, of descriptors in the legend.

Table 4.18. Route selection Search tasks successfully completed in the graphic map formats.

IVIS Tasks			Proportion of Drivers Exceeding Red-line Threshold							
			Including Searching Errors				Without Including Searching Errors			
Info. Processing	Presentation Format	Density Level	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>	<i>Young</i>	<i>Middle Age</i>	<i>Older</i>	<i>All Drivers</i>
S-RP	G. Text	<i>Medium (3x3)</i>	0.00	0.08	0.17	0.08	0.00	0.08	0.17	0.08
		<i>High (5x4)</i>	0.08	0.08	0.17	0.11	0.08	0.08	0.17	0.11
		<i>Very High (5x6)</i>	0.08	0.25	0.50	0.28	0.08	0.25	0.50	0.28
	G. Icon	<i>Low (3x2)</i>	0.08	0.00	0.42	0.17	0.08	0.00	0.42	0.17
		<i>Medium (3x3)</i>	0.00	0.08	0.42	0.17	0.00	0.00	0.42	0.14
		<i>Medium (5x2)</i>	0.17	0.17	0.50	0.28	0.17	0.17	0.50	0.28
		<i>High (5x4)</i>	0.08	0.25	0.58	0.31	0.08	0.25	0.58	0.31
S-RPI	G. Text	<i>Medium (3x3)</i>	0.00	0.00	0.25	0.08	0.00	0.00	0.25	0.08
		<i>High (5x4)</i>	0.00	0.25	0.17	0.14	0.00	0.25	0.17	0.14
		<i>Very High (5x6)</i>	0.50	0.75	0.58	0.61	0.17	0.42	0.58	0.39
	G. Icon	<i>Medium (3x3)</i>	0.00	0.08	0.33	0.14	0.00	0.08	0.33	0.14
		<i>High (5x4)</i>	0.00	0.17	0.58	0.25	0.00	0.17	0.42	0.19
		<i>Very High (5x6)</i>	0.25	0.33	0.83	0.47	0.25	0.33	0.83	0.47
S-compute	G. Text	<i>Medium (3x3)</i>	0.08	0.25	0.42	0.25	0.08	0.25	0.42	0.25
		<i>High (5x4)</i>	0.42	0.25	0.75	0.47	0.33	0.25	0.58	0.39

Table 4.19. Yellow-line Threshold for route selection Search tasks in the graphic map formats.

IVIS Task		Presentation Format					
		Young Drivers		Middle Age Drivers		Older Drivers	
Type of Info. Processing	Density Level	Graphic Text	Graphic Icon	Graphic Text	Graphic Icon	Graphic Text	Graphic Icon
SP	<i>Low (3x2)</i>	n/a	B	n/a	B	n/a	B
SP	<i>Medium (3x3)</i>	0 [#]	0 [#]	0	M	D	B
SPI	<i>Medium (3x3)</i>	0 [#]	D	0	0	1	B
SC	<i>Medium (3x3)</i>	D	n/a	B	n/a	B	n/a
SP	<i>Medium (5x2)</i>	n/a	D	n/a	M	n/a	D
SP	<i>High (5x4)</i>	B	B	B	B	B	D
SPI	<i>High (5x4)</i>	B	B	M	B	B	B
SC	<i>High (5x4)</i>	D	n/a	0	n/a	D	n/a
SP	<i>Very High (5x6)</i>	M	n/a	M	n/a	D	n/a
SPI	<i>Very High (5x6)</i>	B	M	B	B	D	9 [#]

D – Driving performance affected (max. steering velocity significantly greater than and/or min. speed significantly less than baseline driving), p<0.05.

M – Scanning of mirrors was significantly less than baseline driving, p<0.05.

B – Both driving performance and scanning of mirrors were significantly degraded from baseline driving, p<0.05.

– Data were available for fewer than six drivers.

n/a – Task did not exist in this presentation format.

() – The presence of a number indicates:

1. Driving performance and scanning of mirrors were not significantly different from baseline driving for the drivers who completed the task, and
2. The number of drivers out of twelve who either skipped the task or were not presented the task for safety reasons.

Refer to Appendix X for route selection Search tasks, graphic map formats: Table X.1 for a summary of Red-line and Yellow-line Thresholds exceeded; Table X.2 for the proportion of all drivers who exceeded the Red-line Thresholds; Tables X.3 – X.5 for the proportion of young, middle age, and older drivers who exceeded the Red-line Thresholds; and Tables X.6 and X.7 for the paired T-test results used to determine the Yellow-line Threshold.

4.3 COMPARATIVE ANALYSIS OF ATTENTION DEMANDS FOR IVIS TASKS

This section presents the findings revealed from an investigation of the attention demand required of IVIS tasks. The effects of type of information processing, presentation format, density, and age were studied. Past research has not found a significant effect of gender on driving performance with the exception of risk perception (Farber, Blanco, Foley, Curry, Greenberg, and Serafin, 2000; T. Dingus, personal communication, July 1999). Consequently, the effects of gender were not investigated in this research study.

The attention demands of IVISs were compared using the Red-line Threshold. An analysis of variance was performed to determine the significant effects. The results, presented in the following sections, are organized by density level. Not all tasks were presented in each density level; therefore, the density levels were analyzed separately. Refer to Chapter 3 for more information on both the Red-line Threshold and the tasks presented in each density level.

Within each density level, the effect of presentation format was studied. Because not all tasks were presented in each presentation format, tasks were grouped together based on common presentation formats. Separate ANOVAs were performed on the following three groups:

- 1) Route selection tasks that did not require computations,
- 2) Route selection tasks that did require computations, and
- 3) Hotel selection tasks.

Within each density level, the effect of type of information processing and age was also studied with ANOVAs. Not all types of information processing were presented in each presentation format at each density level. Results from the low density level are presented first, followed by the medium density level, and then the high density level.

4.3.1 LOW DENSITY LEVEL

Tasks presented in the different presentation formats at the low density level are listed in Table 4.20. Several ANOVAs were performed. The first group of ANOVAs determined the effect of presentation format on driving performance. The second group of ANOVAs determined the effects of type of information processing and age; separate analyses were performed for each presentation format.

Table 4.20. Types of information processing tasks presented in each of the presentation formats at the low density level.

Information Processing	Presentation Format		
	Paragraph	Table	Graphic Icon
S-General	X	X	
S-HP			X
S-route		X	X
SP-hotel	X	X	X
SP-route	X	X	X

4.3.1.1 Analysis for the Effects of Presentation Format

4.3.1.1.1 Overview

Analyses were performed to determine the effects of presentation format on the proportion of drivers who exceeded the Red-line Threshold. Two analyses were performed; one for route selection tasks, and another for hotel selection tasks. Analyses for the route selection tasks are presented first, followed by the hotel selection tasks.

4.3.1.1.2 Route Selection

For the route selection tasks, not all tasks were presented in each presentation format. Therefore, only those tasks that were presented in the three presentation formats of paragraph, table, and graphic icon were analyzed. There were two Search tasks presented in the table format: S-general and S-route. To determine the effect of presentation format across type of information processing, these tasks were combined and labeled as Search tasks. Analysis supported the belief that these two Search tasks were similar [$F(1,26) = 0.01, p=0.91$].

Data analysis revealed significant main effects of presentation format [$F(2, 190) = 5.10, p < 0.01$] and type of information processing [$F(1, 190) = 53.67, p < 0.01$]; a significant interaction between presentation format and type of information processing [$F(2, 190) = 10.16, p < 0.01$]; and a significant interaction between presentation format and age [$F(4, 190) = 4.06, p < 0.01$].

The interactive effect of type of information processing and presentation format is illustrated in Figure 4.14. Post hoc analysis revealed that the attention demand required to simply extract information from a display was not significantly different with the different presentation formats. However, the SP-route task presented in the paragraph format had significantly more “red-lines” than both the table ($p < 0.01$) and graphic icon ($p < 0.01$) formats. These findings indicate that at this low density of information presentation, no presentation format was more difficult than another in terms of extracting information. However, when additional information processing was required after the information was extracted, the paragraph format required a higher attention demand than the other presentation formats to complete the task.

The interactive affect of age and presentation format is illustrated in Figure 4.15. Post hoc analysis revealed that young drivers were affected by presentation format, a significantly higher proportion of young drivers exceeded the Red-line Threshold in the paragraph format than the table format ($p = 0.02$). Middle age drivers were also affect by presentation format; they had significantly more “red-lines” in the paragraph format than the graphic text format ($p = 0.02$). However, presentation format did not significantly affect older drivers ($p > 0.05$).

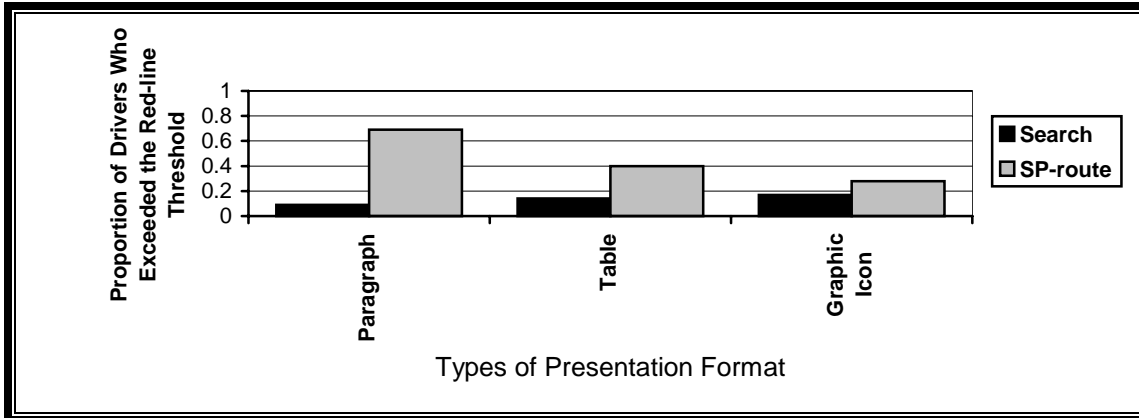


Figure 4.14. Proportion of drivers who exceeded the Red-line Threshold when presented with Search tasks and SP-route tasks in each of the presentation formats, at the low density level.

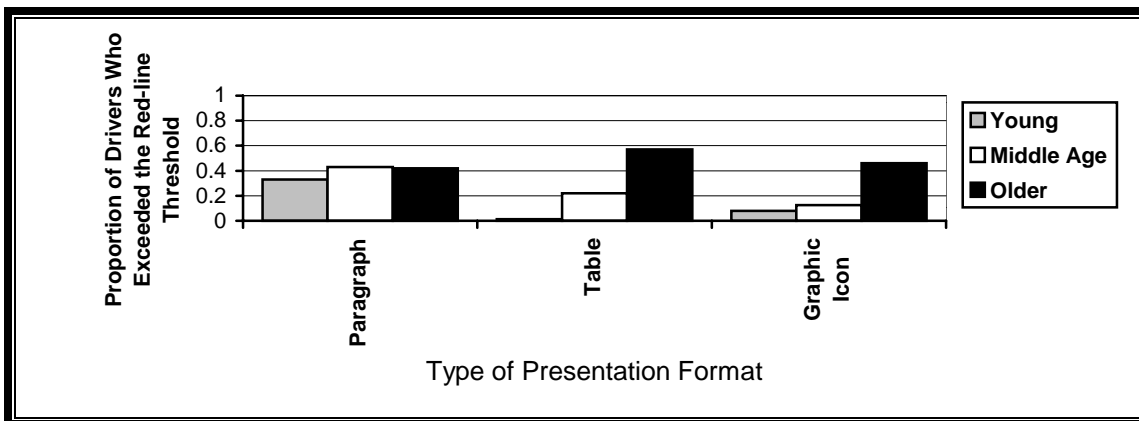


Figure 4.15. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold on each presentation format, at the low density level.

4.3.1.1.3 Hotel Selection

The analysis of SP-hotel tasks revealed that there was no effect of presentation format on the proportion of drivers who “red-lined” [$F(3, 76) = 0.47, p=0.71$]. It is important to note that both the graphic text and graphic icon formats, as mentioned in Chapter 3, each had one additional category of information for drivers to consider than either the table or paragraph formats. Both graphic text and graphic icon formats had the additional category of “type of road” due to the fact that the information was presented on a graphic map.

4.3.1.2 Analysis for Effects of Type of Information Processing and Age

4.3.1.2.1 Overview

The effect of type of information processing was analyzed on each presentation format separately. Not all tasks were presented in each format; therefore, separate analysis of each presentation format allowed for the comparison of all tasks within a presentation format. Results of the paragraph format are presented first, followed by the table format, and then the graphic icon format.

4.3.1.2.2 Paragraph Format

The analysis of the paragraph format revealed that there were main effects for both age [$F(2, 94) = 6.03, p < 0.01$] and type of information processing [$F(3, 94) = 23.00, p < 0.01$]. As shown in Figure 4.16, both the S-general and SP-hotel tasks had a significantly lower proportion of drivers who exceeded the Red-line Threshold than all other tasks. There was no significant difference between S-general and SP-hotel tasks ($p = 0.28$).

As shown in Figure 4.17, it was also revealed that young drivers had significantly fewer “red-lines” than older drivers ($p < 0.01$), whereas middle age drivers were not significantly different than either young ($p = 0.31$) or older drivers ($p = 0.15$).

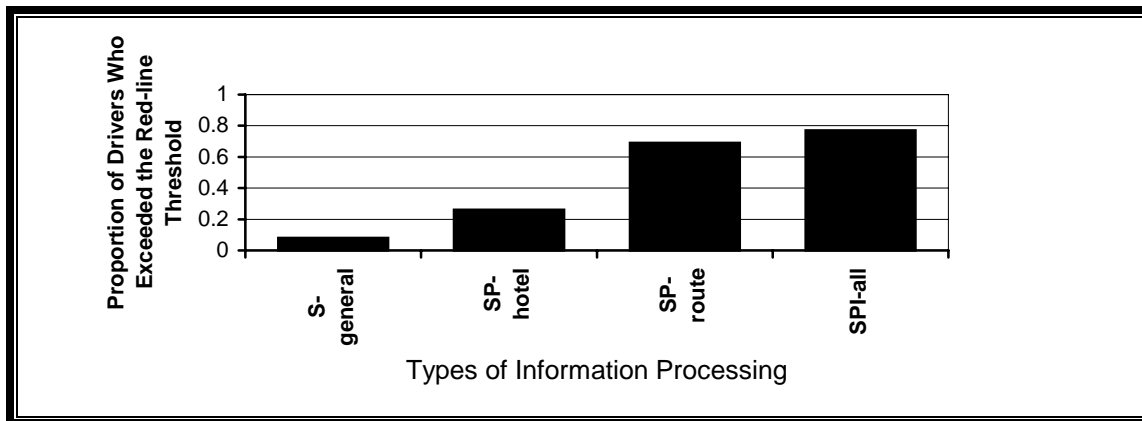


Figure 4.16. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the paragraph format, at the low density level.

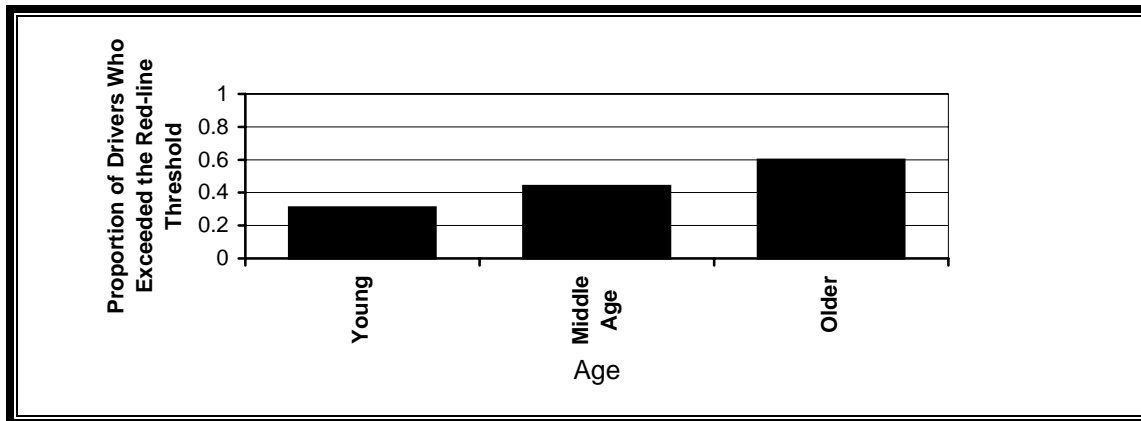


Figure 4.17. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the paragraph format, at the low density level.

4.3.1.2.3 Table Format

The analysis of the table format revealed that there were main effects for both age [$F(2, 115) = 24.26, p < 0.01$] and type of information processing [$F(3, 115) = 9.31, p < 0.01$], as well as a significant interaction between age and type of information processing [$F(6, 115) = 3.07, p < 0.01$]. As shown in Figure 4.18, young drivers did not have any “red-lines” on S-general, SP-hotel, and SP-route tasks, but 50% of young drivers exceeded the Red-line Threshold with the SPI-all task. Middle age drivers did not have significantly different proportions of “red-lines” on any task ($p > 0.05$). Older drivers had significantly more “red-lines” with SP-route tasks than with Search tasks.

Post hoc analysis also revealed that there was no significant difference between young and middle age drivers on any task ($p > 0.05$). However, older drivers had significantly more ($p < 0.05$) “red-lines” than young and middle age drivers on both SP-hotel and SP-route tasks.

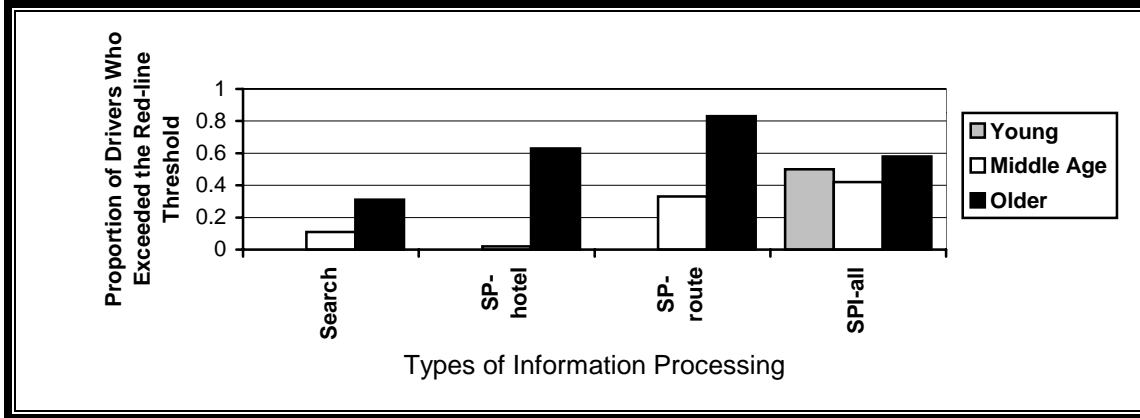


Figure 4.18. Proportion of drivers who exceeded the Red-line Threshold with the table format, at the low density level.

4.3.1.2.4 Graphic Icon Format

Analysis of the graphic icon format revealed that there was no significant difference between the different types of information processing [$F(1, 33) = 1.6, p=0.21$]. However, there was a significant main effect of age [$F(2, 33) = 7.3, p<0.01$]. As shown in Figure 4.19, older drivers had significantly more “red-lines” than both young ($p<0.01$) and middle age ($p<0.01$) drivers.

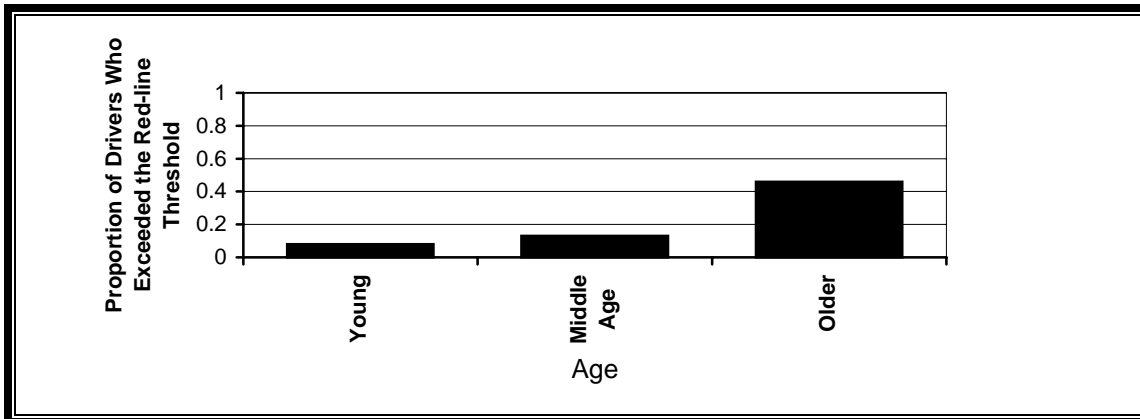


Figure 4.19. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold in the graphic icon format, at the low density level.

4.3.2 MEDIUM DENSITY LEVEL

Tasks that were presented in the different presentation formats at the medium density level are listed in Table 4.21. Several ANOVAs were performed. The first group of ANOVAs determined the effect of presentation format on driving performance. The second group of ANOVAs determined the effects of type of information processing and age; separate analyses were performed for each presentation format.

Table 4.21. Types of information processing tasks presented in each of the presentation formats at the medium density level.

Information Processing	Presentation Format			
	Paragraph	Table	Graphic Text	Graphic Icon
S-general	X	X		
S-HP			X	X
S-route		X	X	X
S-compute			X	
SP-hotel	X	X	X	X
SP-route	X	X	X	X
SPI-partial	X	X	X	X
SPI-all	X	X		
SC-addition	X	X		
SC-division	X	X	X	

4.3.2.1 Analysis for the Effects of Presentation Format

4.3.2.1.1 Overview

Analyses were performed to determine the effects of presentation format on the proportion of drivers who exceeded the Red-line Threshold. Route selection tasks and hotel selection tasks were analyzed separately. Results from the route selection analyses are presented first.

4.3.2.1.2 Route Selection

For the route selection tasks, not all tasks were presented in each presentation format. Therefore, to determine the effects of presentation format, two analyses were performed. The first analysis was performed on tasks that were presented in all four presentation formats: paragraph, table,

graphic text, and graphic icon. The route selection tasks that were presented in all four presentation formats involved searching and/or planning, but did not involve computations: Search, SP-route, and SPI-partial tasks. The SC-division tasks involved computations and were only presented in the paragraph, table, and graphic text formats; therefore, a separate data analysis was performed to determine effects of presentation format for these tasks.

There were two Search tasks presented in the table, graphic text, and graphic icon formats that represented visual displays used for route selection planning tasks. To determine the effect of presentation format across type of information processing, these tasks were combined and labeled Search tasks. Results from separate analyses of each pair of Search tasks supported the belief that the attention demand required to extract information from the visual display was similar for each pair of Search tasks. Analysis found no significance difference between the task presented in the table format [$F(1, 28) = 0.20, p=0.66$], the graphic text format [$F(1, 29) = 0.04, p=0.84$], or the graphic icon format [$F(1, 30) = 0.01, p = 0.94$].

Data analysis for Search, SP-route, and SPI-partial tasks presented in the paragraph, table, graphic text, and graphic icon formats revealed significant main effects for both presentation format [$F(3, 447) = 32.95, p < 0.01$] and age [$F(2, 447) = 36.84, p < 0.01$]; a significant interaction between presentation format and type of information processing [$F(6, 447) = 7.12, p < 0.01$]; and a significant interaction between presentation format and age [$F(6, 447) = 2.36, p = 0.03$].

The interactive effect of type of information processing and presentation format is illustrated in Figure 4.20. Post hoc analysis revealed that presentation format affected the proportion of “red-lines” for both SP-route and SPI-partial tasks. With both of these tasks, the paragraph format had significantly more ($p<0.05$) “red-lines” than all other presentation formats, whereas the table format had significantly more than the graphic icon format ($p<0.05$), and the graphic text format was not significantly different ($p>0.05$) from either the table or the graphic icon formats. However, presentation format did not affect the proportion of “red-lines” with Search tasks ($P>0.05$).

The interactive effect of age and presentation format is illustrated in Figure 4.21. Post hoc analysis revealed that presentation format affected all age groups. With young drivers, the paragraph format had significantly more “red-lines” than all other formats, whereas the table format had significantly more “red-lines” than the graphic text ($p=0.03$) and graphic icon ($p<0.01$) formats, and there was no significant difference between the graphic text and graphic icon formats ($p=0.99$). With middle age drivers, the paragraph format had significantly more “red-lines” than the graphic text ($p=0.02$) and graphic icon ($p<0.01$) formats. The proportion of older drivers who exceeded the Red-line Threshold was not affected by presentation format, with the exception that the paragraph format had significantly more “red-lines” than the graphic text format ($p=0.01$).

Analysis of the SC-division tasks presented in the paragraph, table, and graphic text formats also revealed a significant main effect of presentation format [$F(2, 153) = 2.17, p<0.01$], and a significant interaction between age and presentation format [$F(2, 153) = 2.17, p<0.01$]. As shown in Figure 4.22, post hoc analysis revealed that presentation format did not significantly affect the proportion of middle age or older drivers who exceeded the Red-line Threshold for the SC-division task. However, significantly fewer young drivers had “red-lines” with the graphic text format than with the paragraph format.

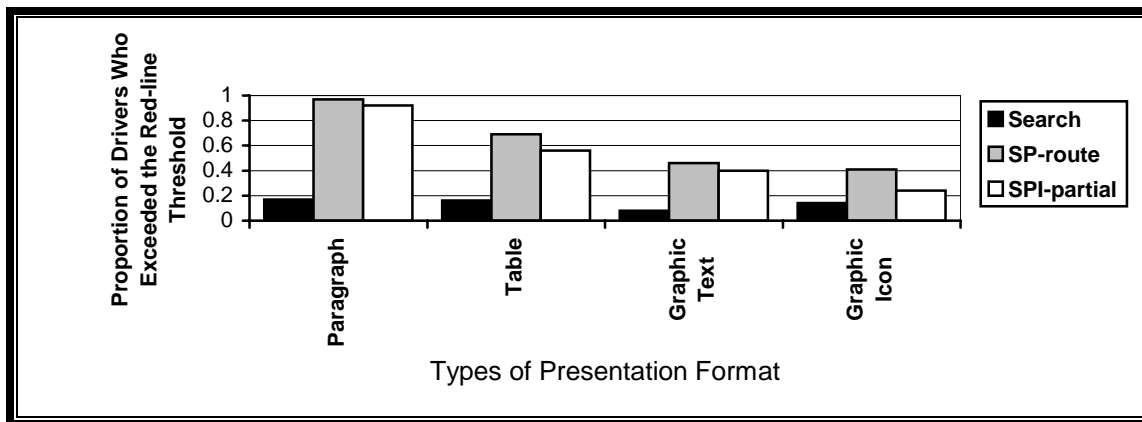


Figure 4.20. Proportion of drivers who exceeded the Red-line Threshold when presented with Search, SP-route, and SPI-partial tasks in different presentation formats, at the medium density level.

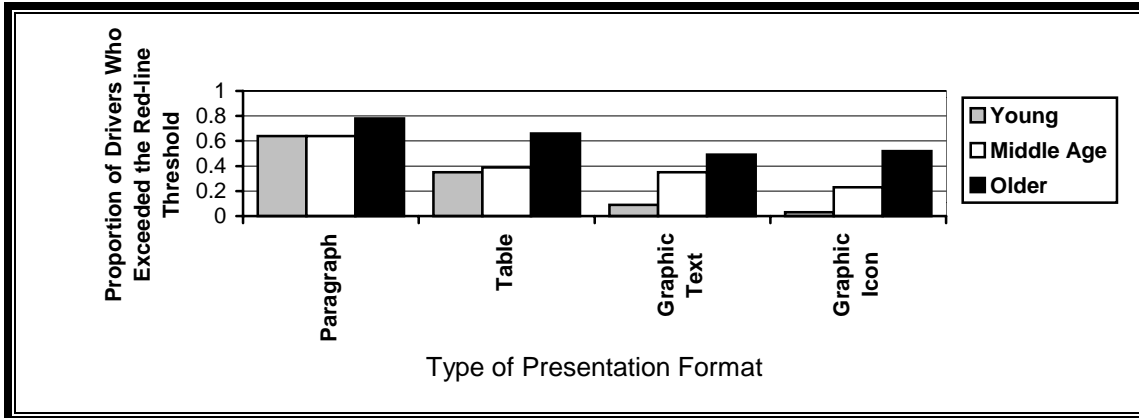


Figure 4.21. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold on Search, SP-route, and SPI-partial tasks in different presentation formats, at the medium density level.

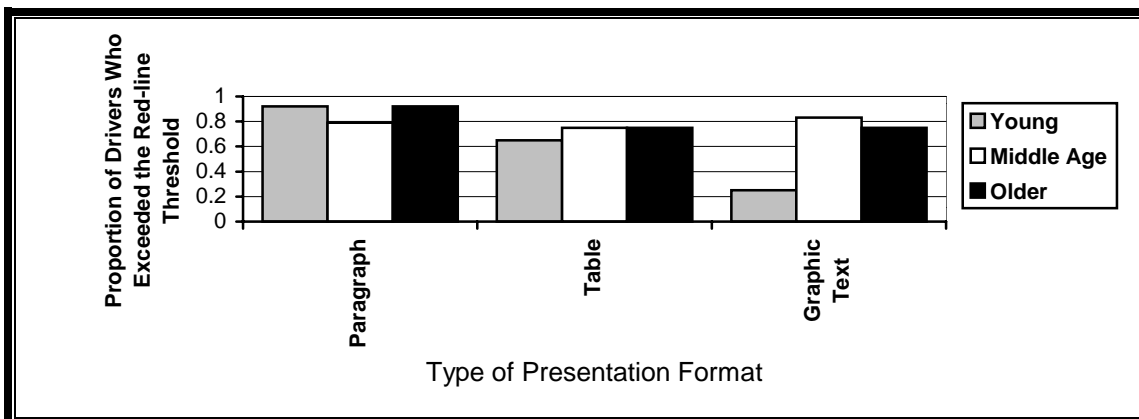


Figure 4.22. Proportion of drivers who exceeded the Red-line Threshold when presented with the SC-division task in different presentation formats, at the medium density level.

4.3.2.1.3 Hotel Selection

The analysis of SP-hotel tasks revealed that presentation format did not have a significant effect on the proportion of drivers who “red-lined.” The main effect of presentation format was $[F(3, 84) = 0.83, p=0.48]$. It is important to note that both the graphic text and graphic icon formats as mentioned in Chapter 3, each had one additional category of information for drivers to consider than either the table or paragraph formats. Both graphic text and graphic icon formats had the additional category of “type of road” due to the fact that the information was presented on a graphic map.

4.3.2.2 Analysis for Effects of Type of Information Processing and Age

4.3.2.2.1 Overview

The effect of type of information processing was then analyzed on each presentation format separately. Not all tasks were presented in each format; therefore, a separate analysis of each presentation format allowed for comparison of all tasks within a presentation format. Results of the paragraph format are presented first, followed by the table format, the graphic text format, and then the graphic icon format.

4.3.2.2.2 Paragraph Format

Analysis of the paragraph format revealed that there were significant main effects for both types of information processing [$F(6, 196) = 37.94, p < 0.01$] and age [$F(2, 196) = 7.09, p < 0.01$]. As shown in Figure 4.23, the analysis of the paragraph format revealed that there was no significant difference between the S-general task and the SP-hotel task ($p = 0.20$); however, all other tasks had a significantly higher proportion of drivers who “red-lined” ($p < 0.05$) than either the S-general or SP-hotel tasks.

Figure 4.24 illustrates the main effect of age in the paragraph format. Post hoc analysis revealed that young and middle age drivers were not significantly different ($p = 0.81$); however, older drivers had significantly more “red-lines” than either young ($p < 0.01$) or middle age ($p < 0.01$) drivers.

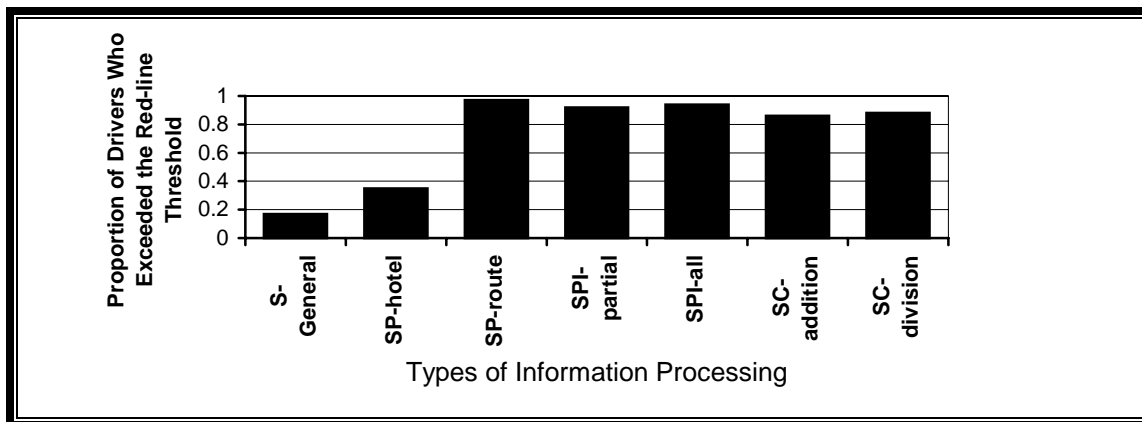


Figure 4.23. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the paragraph format, at the medium density level.

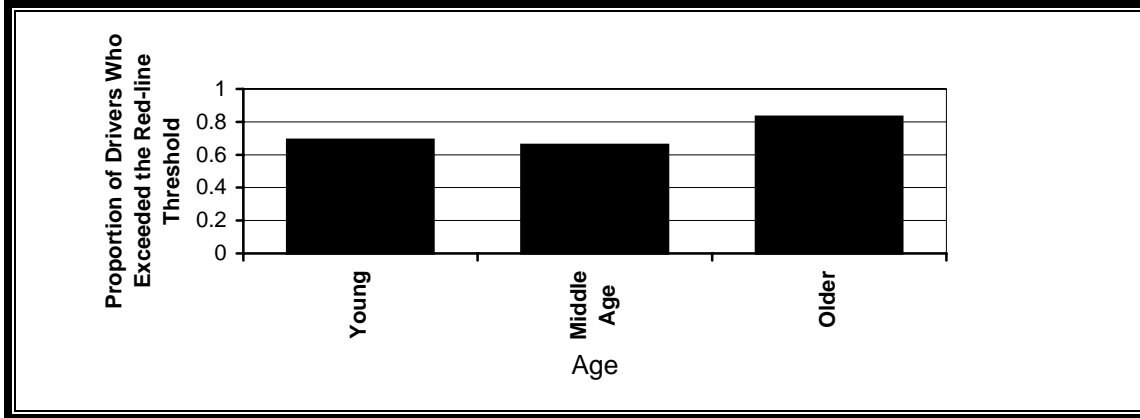


Figure 4.24. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the paragraph format, at the medium density level.

4.3.2.2.3 Table Format

The analysis of the table format revealed that there were main effects for both type of information processing [$F(6, 221) = 14.99, p < 0.01$] and age [$F(2, 221) = 9.13, p < 0.01$]. As shown in Figure 4.25, Search tasks had significantly fewer “red-lines” than all other tasks, with the exception of the SP-hotel task ($p = 0.64$). SP-route, SPI-all, and tasks that required computations were not significantly different ($p > 0.05$).

Figure 4.26 illustrates the main effect of age in the table format. Post hoc analysis revealed that older drivers had significantly more “red-lines” than both young ($p < 0.01$) and middle age ($p = 0.01$) drivers.

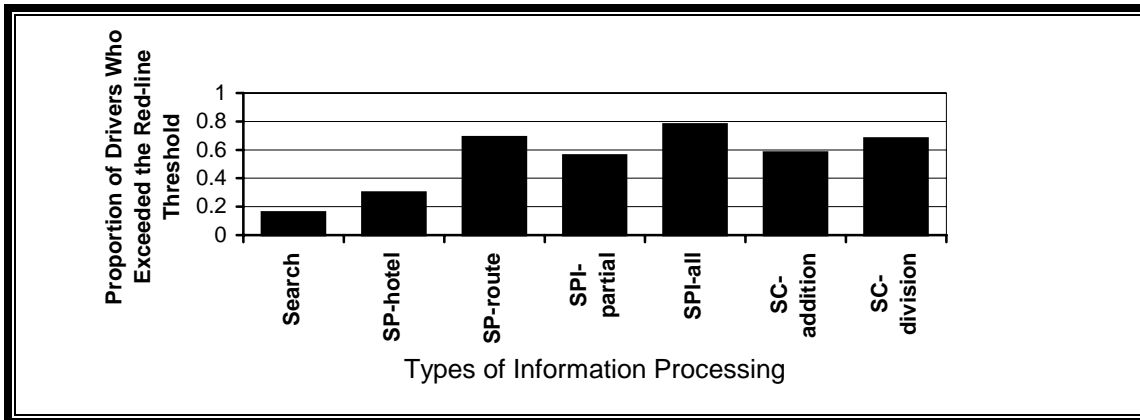


Figure 4.25. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the table format, at the medium density level.

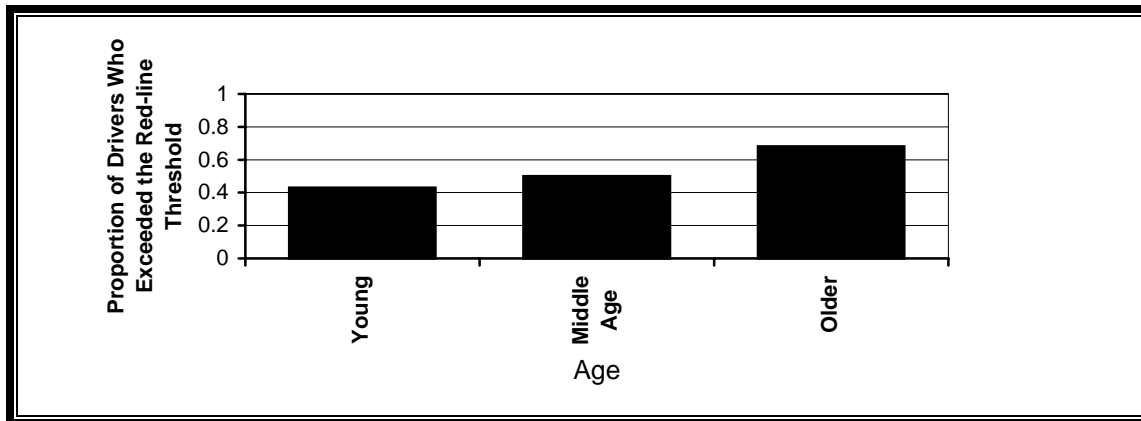


Figure 4.26. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the table format, at the medium density level.

4.3.2.2.4 Graphic Text Format

The analysis of the graphic text format revealed that there was a main effect for both type of information processing [$F(7, 214) = 10.06, p < 0.01$] and age [$F(2, 214) = 22.74, p < 0.01$]. As shown in Figure 4.27, tasks that simply required the extraction of information from the display had fewer “red-lines” than the corresponding task that required not only extraction, but also supplemental information processing (with the exception of the SP-hotel task). Also, tasks that only involved searching were not significantly different from one another ($p > 0.05$). S-RP tasks had significantly fewer “red-lines” than SP-route tasks ($p < 0.01$), while S-RPI had significantly fewer “red-lines” than SPI-partial ($p = 0.01$), and S-C tasks had significantly fewer “red-lines” than SC-division tasks ($p < 0.01$). However, S-HP was not significantly different from SP-hotel ($p = 0.99$).

Tasks that required route planning or computations were not significantly different: SP-route, SPI-partial, and SC-division tasks ($p > 0.05$). However, the SP-hotel had significantly fewer “red-lines” than both the SP-route ($P = 0.03$) and SC-division tasks ($p < 0.01$). There was no significant difference between the SP-hotel and SPI-partial tasks ($p = 0.18$).

Figure 4.28 illustrates the main effect of age in the graphic text format. Post hoc analysis revealed that young drivers had a significantly lower proportion of “red-lines” than both middle age ($p < 0.01$) and older ($p < 0.01$) drivers. Middle age drivers had significantly fewer “red-lines” than older drivers ($p = 0.02$).

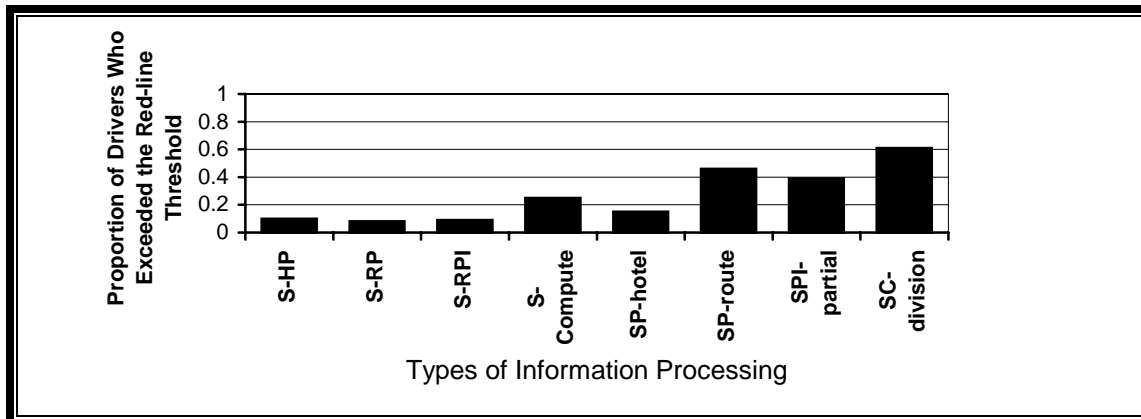


Figure 4.27. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the graphic text format, at the medium density level.

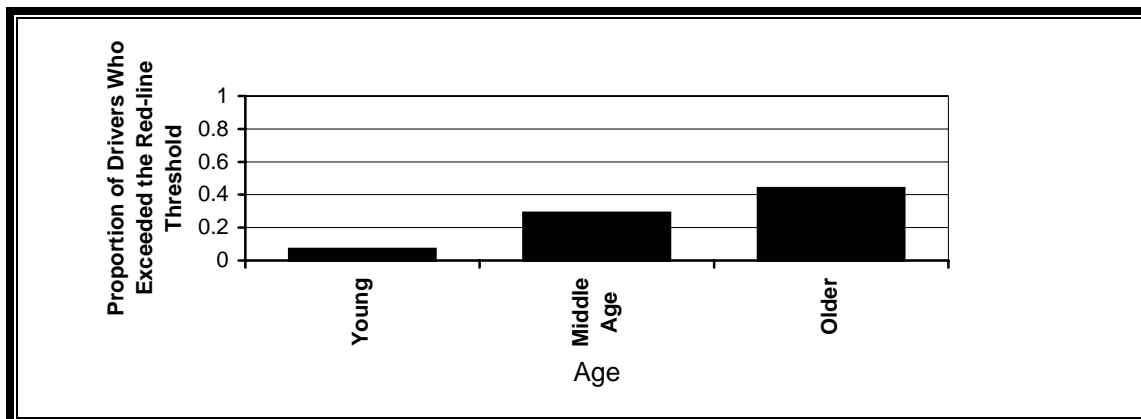


Figure 4.28. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the graphic text format, at the medium density level.

4.3.2.2.5 Graphic Icon Format

The analysis of the graphic icon format revealed main effects for both type of information processing [$F(5, 140) = 4.01, p < 0.01$] and age [$F(2, 140) = 27.62, p < 0.01$]. As shown in Figure 4.29, tasks that required only the extraction of information from the screen did not necessarily have fewer “red-lines” than tasks that also required supplemental information processing. However, the tasks that required only the extraction of information were not significantly different from one another ($p > 0.05$). The S-RP task had significantly fewer “red-lines” than the SP-route task ($p = 0.02$), but the S-RPI task was not significantly different from the SPI-partial task ($p = 0.84$), and the S-HP task was not significantly different from the SP-hotel task ($p = 0.88$). There was also no significant difference between the tasks that involved route planning; SP-route

and SPI-partial tasks ($p=0.33$). However, the SP-hotel task had significantly fewer “red-lines” than the SP-route task ($p<0.05$).

Figure 4.30 illustrates the main effect of age in the graphic icon format. Post hoc analysis revealed that older drivers had significantly more “red-lines” than young ($p<0.01$) and middle age ($p<0.01$) drivers. There was no significant difference between young and middle age drivers ($p=0.16$).

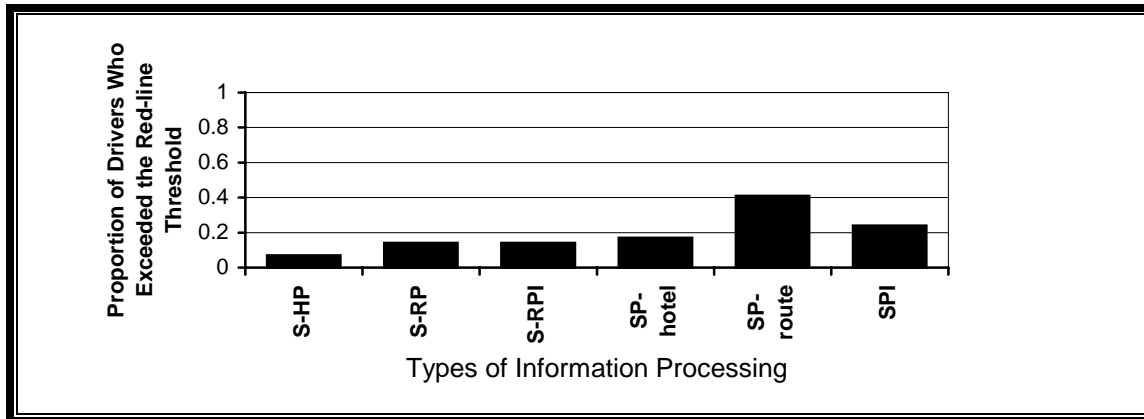


Figure 4.29. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the graphic icon format, at the medium density level.

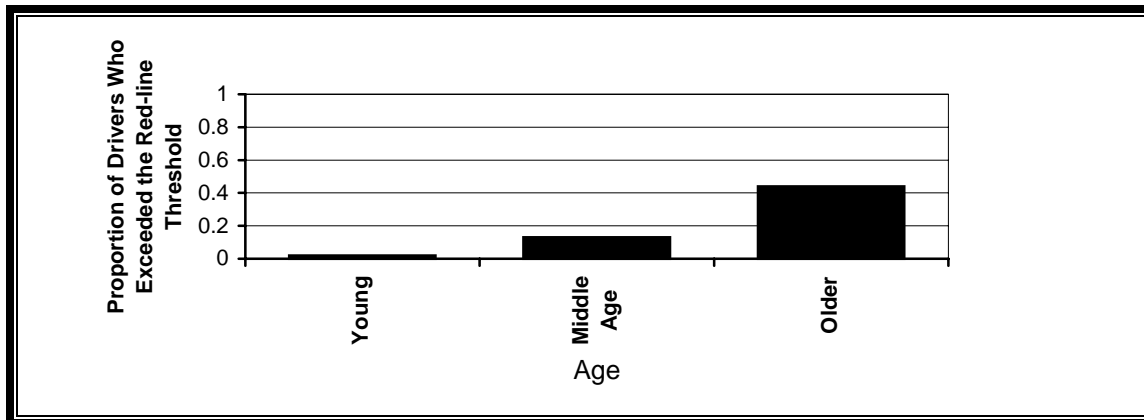


Figure 4.30. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the graphic icon format, at the medium density level.

4.3.3 HIGH DENSITY LEVEL

Tasks that were presented in the different presentation formats at the high density level are listed in Table 4.22. Several ANOVAs were performed. The first group of ANOVAs determined the effect of presentation format on driving performance. The second group of ANOVAs determined the effect of type of information processing and age; separate analyses were performed for each presentation format.

Table 4.22. Types of information processing tasks presented in each of the presentation formats at the high density level.

Information Processing	Presentation Format			
	Paragraph	Table	Graphic Text	Graphic Icon
S-general	X	X		
S-HP			X	X
S-route		X	X	X
S-compute			X	X
SP-hotel	X	X	X	X
SP-route	X	X	X	X
SPI-partial	X	X	X	X
SPI-all	X	X		
SC-addition	X	X		
SC-division	X	X	X	

4.3.3.1 Analysis for the Effects of Presentation Format

4.3.3.1.1 Overview

Analyses were performed to determine the effects of presentation format on the proportion of drivers who exceeded the Red-line Threshold. Route selection tasks and hotel selection tasks were analyzed separately. Results for route selection analyses are presented first.

4.3.3.1.2 Route Selection Tasks

With the route selection tasks, not all tasks were presented in each presentation format.

Therefore, to determine the effects of presentation format, two analyses were performed. The first analysis was performed on tasks that were presented in all four presentation formats:

paragraph, table, graphic text, and graphic icon. The route selection tasks that were presented in

all four presentation formats involved searching and/or planning, but not computations: Search, SP-route, and SPI-partial tasks. The SC-division and SC-addition tasks involved a computation and were therefore only presented in the paragraph, table, and graphic text formats; a separate data analysis was performed on these tasks.

There were two Search tasks presented in the table, graphic text, and graphic icon formats that represented visual displays used for route selection tasks. Each format was analyzed separately and the results from each of these analyses supported the belief that the attention demand required to extract information from the visual display was not different for each pair of tasks. Analysis found no significant difference between the tasks presented in the table format [$F(1,28) = 2.41$, $p=0.13$], the graphic text format [$F(1, 33) = 0.2$, $p=0.66$]; or the graphic icon format [$F(1, 32) = 1.93$, $p = 0.17$]. Therefore, the Search tasks within each presentation format were grouped together under the category of Search task.

Data analysis for Search, SP-route, and SPI-partial tasks presented in the paragraph, table, graphic text, and graphic icon formats revealed a significant main effect for presentation format [$F(3, 462) = 21.93$, $p<0.01$]. As shown in Figure 4.31, data analysis revealed that the paragraph format had significantly more ($p<0.01$) “red-lines” than the table, graphic text, and graphic icon formats, and that the table format had significantly more “red-lines” than the graphic text format ($p=0.01$).

Data analysis for the tasks that required computations, SC-division and SC-addition, revealed a significant main effect of presentation format [$F(2, 165) = 10.2$, $p<0.01$]. As shown in Figure 4.32, post hoc analysis revealed that the paragraph format had significantly more “red-lines” than both the table ($p< 0.01$) and graphic text ($p<0.05$) formats.

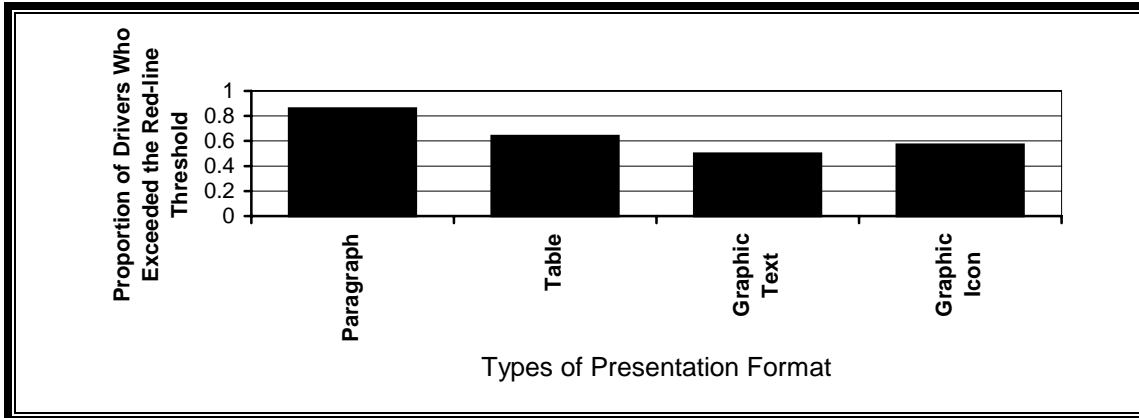


Figure 4.31. Proportion of drivers who exceeded the Red-line Threshold when presented with Search, SP-route, and SPI-partial tasks in different presentation formats, at the high density level.

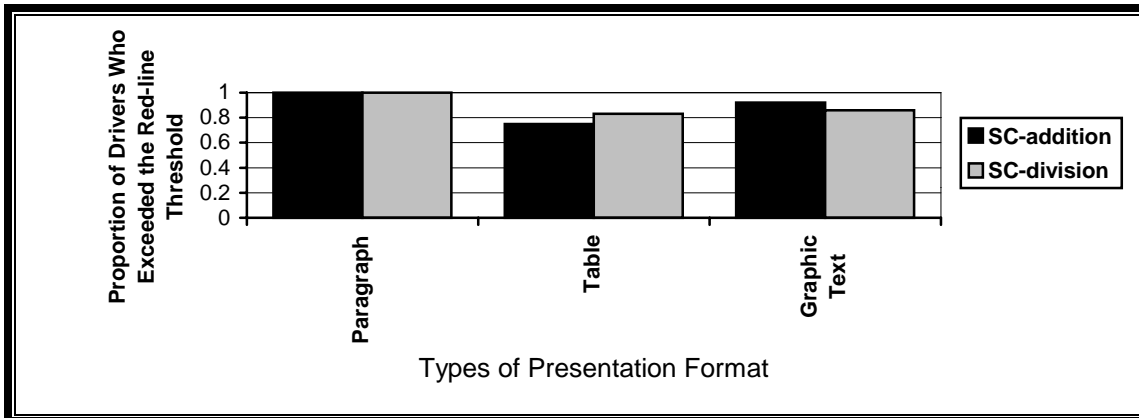


Figure 4.32. Proportion of drivers who exceeded the Red-line Threshold when presented with computation tasks in different presentation formats, at the 5x4 density level.

4.3.3.1.3 Hotel Selection

Analysis of SP-hotel tasks revealed that there was a significant main effect for presentation format [$F(3, 98) = 8.24, p < 0.01$], and a significant interaction between presentation format and age [$F(6, 98) = 2.2, p < 0.05$]. As shown in Figure 4.33, post hoc analysis revealed that presentation format did not affect the proportion of middle age or older drivers who exceeded the Red-line Threshold. However, with young drivers, the proportion who exceeded the Red-line Threshold with the paragraph format was significantly greater than for the graphic icon format.

It is important to note that both the graphic text and graphic icon formats, as mentioned in Chapter 3, each had one additional category of information for drivers to consider than either the

table or paragraph formats. Both graphic text and graphic icon formats had the additional category of “type of road” due to the fact that the information was located on a graphic map.

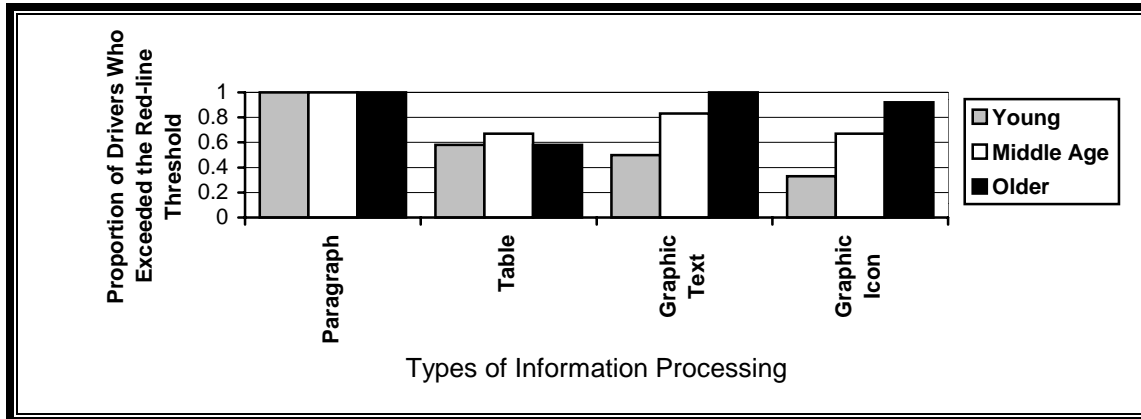


Figure 4.33. Proportion of drivers who exceeded the Red-line Threshold when presented with SP-hotel tasks in each of the presentation formats, at the high density level

4.3.3.2 Analysis for Effects of Type of Information Processing and Age

4.3.3.2.1 Overview

The effect of type of information processing was analyzed on each presentation format separately. Not all tasks were presented in each format; therefore, separate analysis of each presentation format allowed for comparison of all tasks within a presentation format. Results of the paragraph format are presented first, followed by the table format, graphic text, and graphic icon formats.

4.3.3.2.2 Paragraph Format

The analysis of the paragraph format revealed that there was a main effect of type of information processing [$F(6,198) = 27.2, p < 0.01$], and a significant interaction between age and type of information processing [$F(12,198) = 2.54, p < 0.01$]. As shown in Figure 4.34, the proportion of drivers who exceeded the Red-line Threshold was significantly less for S-general tasks than for all other tasks for young ($p < 0.01$) and middle age ($p < 0.01$) drivers; no other tasks for either age group were significantly different from one another ($p > 0.05$). With older drivers, there was no significant difference between any of the tasks ($p > 0.05$). The proportion of older drivers who exceeded the Red-line Threshold when performing an S-general task was significantly larger than for either young ($p < 0.01$) or middle age ($p < 0.01$) drivers.

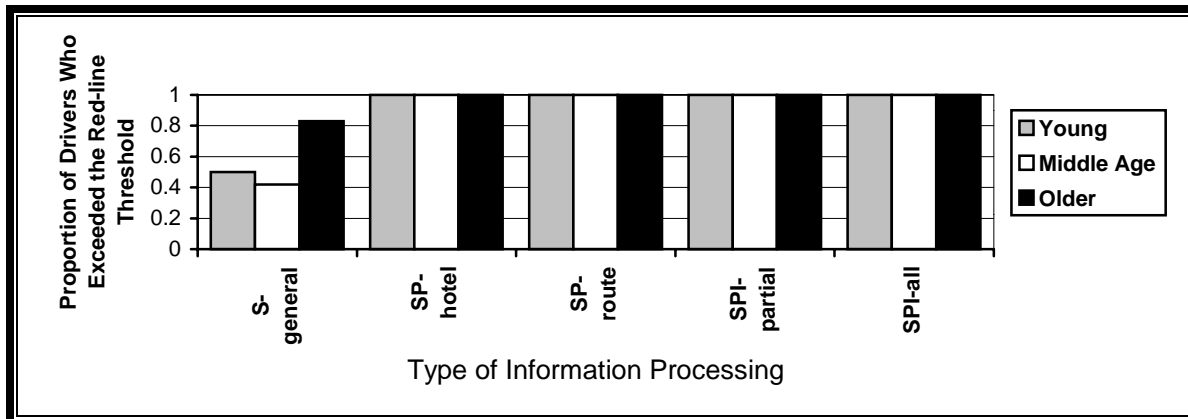


Figure 4.34. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the paragraph format, at the high density level.

4.3.3.2.3 Table Format

Analysis of the table format revealed that there were main effects for both age [$F(2, 229) = 9.62$, $p < 0.01$] and type of information processing [$F(6, 229) = 22.67$, $p < 0.01$]. There was also a significant interaction between age and type of information processing [$F(12, 229) = 2.08$, $p = 0.02$]. As shown in Figure 4.35, with both young and middle age drivers, the Search task had significantly fewer ($p < 0.05$) “red-lines” than all other tasks; all other tasks were not significantly different ($p > 0.05$) from one another. With older drivers, there was no significant difference between the different tasks ($p > 0.05$). The Search task was the only task in which age had an effect on the proportion of “red-lines;” older drivers had significantly more “red-lines” than young ($p < 0.01$) and middle age ($p < 0.01$) drivers. With all other tasks, there was no significant difference between the different age groups ($p > 0.05$).

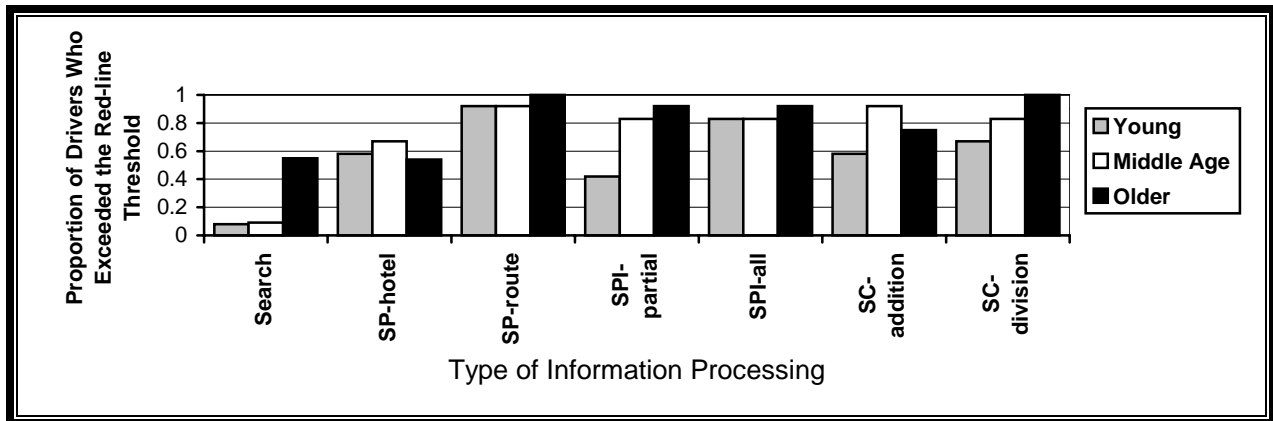


Figure 4.35. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the table format, at the high density level.

4.3.3.2.4 Graphic Text Format

Analysis of the graphic text format in the high density level revealed a significant main effect for both type of information processing [$F(8, 260) = 28.06, p < 0.01$] and age [$F(2, 260) = 10.61, p < 0.01$]. As shown in Figure 4.36, all tasks that simply required the extraction of information from a visual display required less attention demand than tasks that also required additional information processing: S-RP was significantly less than SP-route ($p < 0.01$), S-RPI was significantly less than SPI-partial ($p < 0.01$), and S-compute was significantly less than both SC-division ($p < 0.01$) and SC-addition ($p < 0.01$).

Tasks that required planning or computing were not significantly different ($p > 0.05$) from one another. As shown in Figure 4.37, post hoc analysis revealed that older drivers had significantly more “red-lines” than either young ($p < 0.01$) or middle age ($p < 0.01$) drivers.

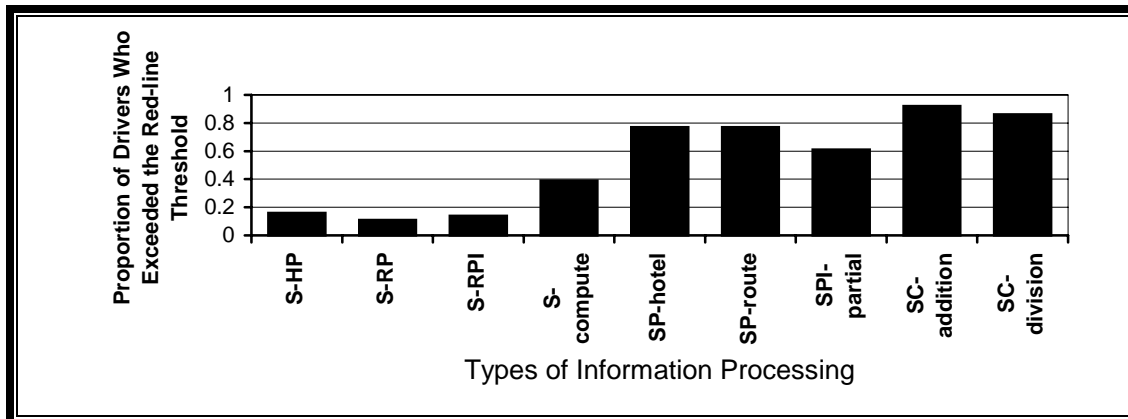


Figure 4.36. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the graphic text format, at the high density level.

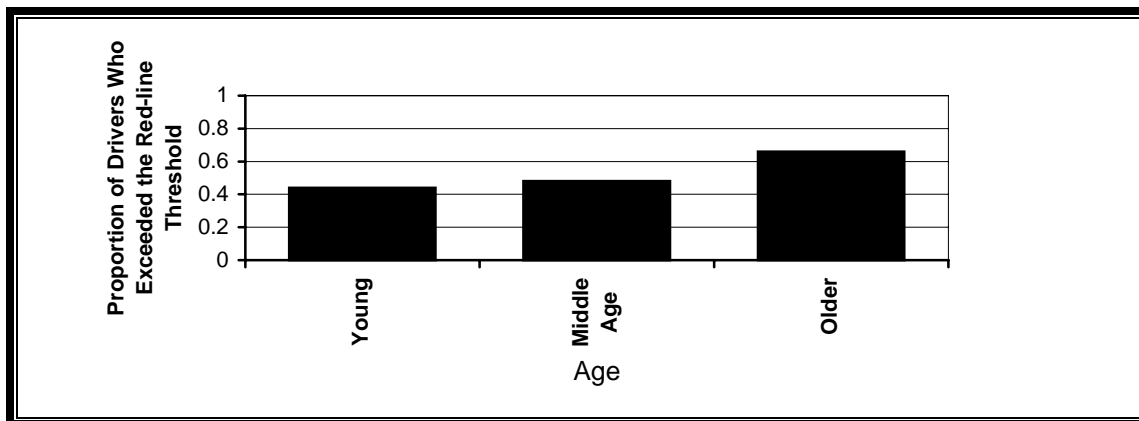


Figure 4.37. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the graphic text format, at the high density level.

4.3.3.2.5 Graphic Icon Format

Analysis of the graphic icon format of the high density level revealed main effects for age [$F(2, 161) = 29.5, p < 0.01$] and type of information processing [$F(5, 161) = 12.53, p < 0.01$]. As shown in Figure 4.38, post hoc analysis of the graphic icon format revealed that tasks that required only the extraction of information had significantly fewer “red-lines” than the tasks that also involved planning ($p < 0.05$): the S-RP task had significantly fewer “red-lines” than the SP-route task ($p < 0.01$), the S-RPI task had significantly fewer “red-lines” less than the SPI-partial task ($p < 0.01$), and the S-PH task had significantly fewer “red-lines” than the SP-hotel task ($p = 0.03$). Tasks that involved planning were not significantly different from one another: SP-hotel, SP-route, and SPI-partial tasks ($p > 0.05$).

As shown in Figure 4.39, post hoc analysis revealed that young drivers had fewer “red-lines” than both middle age ($p < 0.01$) and older ($p < 0.01$) drivers, and middle age drivers had significantly fewer “red-lines” than older drivers ($p < 0.01$).

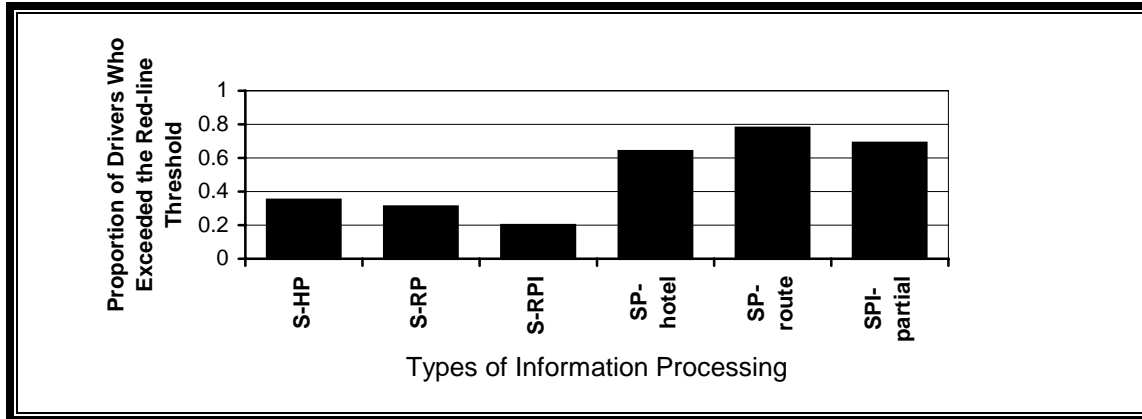


Figure 4.38. Proportion of drivers who exceeded the Red-line Threshold with each type of information processing in the graphic icon format, at the high density level.

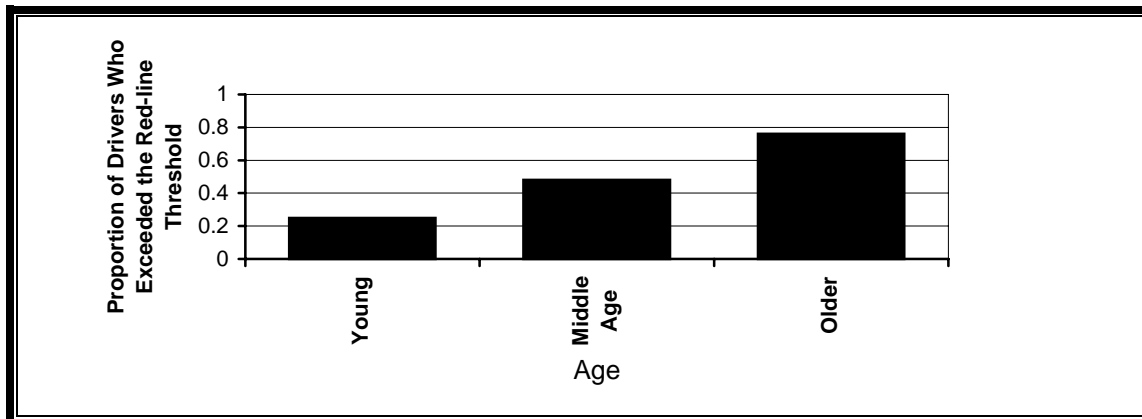


Figure 4.39. Proportion of young, middle age, and older drivers who exceeded the Red-line Threshold with the graphic icon format, at the high density level.

CHAPTER 5: DISCUSSION AND FUTURE RESEARCH

5.1 OVERVIEW

The results from this study support previous research by confirming that IVISs have the potential to negatively affect driver safety. However, previous research also indicate that IVISs can be beneficial when designed appropriately; careful assessment of the capabilities and limitations of the intended user groups needs to be included in design efforts. The pertinent findings related to the objectives of this study are discussed in this chapter in the context of design solutions for IVISs. Findings related to developing the method for evaluating driving performance are discussed first. Next, the results found from using this method to investigate the effects of age, presentation format, and processing information are discussed.

5.2 OBJECTIVE: TO DEVELOP A METHOD FOR EVALUATING DRIVING PERFORMANCE WITH REGARD TO SAFETY

To be proactive and determine IVISs that pose a safety risk prior to mass market distribution, composite measures utilizing several measures of workload and situation awareness were developed. The method built upon the technique used in the TravTek Camera Car Study (Dingus *et al.*, 1995) in which driver errors were analyzed to perform safety-related system comparisons.

Two composite measures were developed. The Yellow-line Threshold, indicated that driver performance had been degraded during IVIS task completion. Driver performance was significantly degraded from baseline driving, but did not necessarily exceed a safety threshold. However, the Red-line Threshold was composed of a group of surrogate safety measures that indicated if driver performance exceeded values that had been determined in previous research or by expert opinion to indicate driver performance had been substantially affected. The following two sections discuss the Red-line and Yellow-line Threshold measures, and their benefits and limitations for IVIS design.

5.2.1 RED-LINE THRESHOLD MEASURE

Developing the Red-line Threshold composite measure accomplished the objective of providing data on the proportion of drivers who exceeded a safety threshold for each of the different IVIS tasks. The measures used to determine the Red-line Threshold were:

- 1) Task skipped by driver,
- 2) Task not presented to driver because of safety concerns,
- 3) Nine or more eye glances to the IVIS display,
- 4) Single eye glance longer than 2.5 seconds to the IVIS display,
- 5) Lane deviation, and
- 6) IVIS task completion time greater than 20 seconds.

5.2.1.1 Benefits for IVIS Design

The Red-line Threshold measure allowed for an assessment of driving performance. Data collected on a variety of driver performance measures have, in the past, been commonly presented in descriptive form. While mean and standard deviation values provide insight into the attention demand required of IVIS, a composite measure provides additional insight not available with these individual measures. The composite measure, Red-line Threshold, developed in this study allows for a determination of the proportion of drivers who would be adversely affected if a particular system had mass market distribution. A similar technique to the Red-line Threshold is used by Human Factors experts when designing other consumer products (for example, designing the ergonomics of a chair to accommodate the 95th percentile male and the 5th percentile female.) This is not to say that a composite measure, such as the Red-line Threshold, is a better measure than the descriptive measures of mean and standard deviation, but rather that both types of measures provide useful and unique insights for the design process.

The driving performance of different drivers will be affected differently when performing IVIS tasks. The Red-line Threshold, which combines several measures of situation awareness and mental workloads, provides a method for determining whether each driver exceeded one or more safety parameters. For example, some drivers maintained adequate speeds and lane tracking while completing a task; however, the eye glance data indicate that they had poor situation awareness. Other drivers appeared to have adequate situation awareness based on eye glance

data; however, their speed maintenance and/or lane tracking data indicate that the attention demand required to complete the IVIS task intruded upon the primary task of driving. Knowledge of the proportion of drivers who exceeded this composite measure will both 1) allow for a comparison of IVISs, and 2) aid in assessing the impact and determination of the appropriate implementation strategy, such as training, guarding, or warnings, for a particular IVIS.

5.2.1.2 Limitations

Tables located in Appendices M-X provide a further breakdown of the data that allows for modifications of the Red-line Threshold. For example, if an individual believes the threshold for IVIS task completion time should be 13 seconds versus 20 seconds, then the Red-line Threshold can be modified using the data in Appendices M-X. This modification provides an estimate of the proportion of drivers who exceeded the Red-line Threshold based on a value of 13 seconds for IVIS task completion. The results are only an estimate because driver performance is not known for drivers who were not presented the task. The performance of some drivers was assumed to be below the Red-line Threshold, based on the criteria stated above, and because of this assumption, these drivers were not presented with a task. Therefore, if the Red-line Threshold is modified, then the wording of the results needs to reflect that “at least X drivers” exceeded the Red-line Threshold.

5.2.2 YELLOW-LINE THRESHOLD MEASURE

The Yellow-line Threshold provides a different evaluation than the Red-line measure. The Red-line Threshold indicate if driver performance exceeded specified values, whereas the Yellow-line Threshold compared each individual driver’s performance during IVIS task completion with his/her normal driving performance (baseline driving). Driver performance for each age group during IVIS task completion was compared with baseline driving to determine if driver performance was significantly degraded. Several measures were collected and analyzed to determine the Yellow-line Threshold. However, only three measures were found to be sensitive to changes in driving performance:

- 1) Minimum speed,
- 2) Peak steering wheel angular velocity, and
- 3) Number of eye glances to mirror locations.

5.2.2.1 Benefits for IVIS Design

The Yellow-line Threshold provides an indicator that driver performance was affected during IVIS tasks. With this measure, there is no question that driver performance was significantly degraded from baseline driving; however, the magnitude of the change in driver performance is not discernible with this measure. For this reason, the Yellow-line and Red-line Thresholds complement one another. The Yellow-line Threshold indicates that driver performance was significantly degraded from normal baseline driving, and the Red-line Threshold indicates when driver performance exceeded safety parameters.

5.2.2.2 Limitations

Results obtained from the Yellow-line Threshold measure needed to be interpreted in conjunction with the results from the Red-line Threshold. Results may indicate that a Yellow-line Threshold had not been exceeded, and that driving was not affected; however, there may have been drivers who either chose to skip the task because they felt the task was too difficult to complete, or who were not presented the task because of safety considerations. When either of these instances occurred, the results simply indicate that driving was not affected for the drivers who completed the IVIS task and thus are not necessarily representative of the entire driver population. The same is true with the interpretation of results when some drivers were not presented a task because the task was assumed to be below the Red-line Threshold.

5.3 OBJECTIVE: TO INVESTIGATE DRIVER PERFORMANCE DURING IVIS TASKS THAT REQUIRED ADDITIONAL PROCESSING OF INFORMATION AFTER THE EXTRACTION OF INFORMATION FROM THE DISPLAY

IVISs have been the subject of much research that has facilitated the creation of guidelines. However, a need was identified for data on tasks that required supplemental information processing. From epidemiological studies performed on cellular telephones, findings indicate that cellular phone usage while driving increased the probability of an accident (Redelmeir and Tibshirani, 1997). Depending on the cellular phone conversation, supplemental information processing may take place. There was concern that a similar increase in accidents might result if drivers performed IVIS tasks that required supplemental information processing. There is no doubt that there are benefits to providing drivers with the information presented on the IVIS in this study. However, the information portrayal method needs to be studied to determine the optimal method of presentation such that the benefits outweigh the negative impact of IVIS implementation.

In the following sections, possible design solutions and future research ideas for tasks that involve supplemental information processing are discussed based on the findings from this study. This discussion is divided into two sections:

- 1) Characteristics of the intended driver and vehicle, and
- 2) Characteristics of the IVIS task.

5.3.1 CHARACTERISTICS OF THE INTENDED DRIVER AND VEHICLE

One of the first steps in any design process is to perform a needs analysis and determine the capabilities and limitations of potential users. IVISs have a potential to impact many applications. Consequently, drivers of all ages, including 1) typical commuter driver, 2) professional commercial driver (such as taxi driver, delivery truck driver, or bus driver), and 3) special vehicle operators (such as ambulance drivers or police officers), may find using an IVIS to be beneficial while driving. Therefore, the design process of IVISs should involve a careful

evaluation of the needs, capabilities, and limitations of different types of drivers. First, the limitations of this study with regard to characteristics of the intended driver and vehicle are presented followed by a discussion of the possible design ramifications and areas of future research.

5.3.1.1 Limitations

This study provides designers with data comparable to a scenario in which an individual buys a new IVIS, discusses how to use the system with a knowledgeable salesperson, spends an hour becoming familiar with the new system, and then starts using the system while driving on highways. The effect of age was investigated; however, the effects of driver type, training, and different types of vehicles were not investigated. Therefore, the results from this study provide insight into the general driving public. Findings are not necessarily generalizable to drivers with specialized training and experience.

There are several commercial and public service applications for IVISs. Some special vehicle operators already receive special driver training that emphasizes the importance of maintaining situation awareness and aims to improve driving performance under all types of driving conditions. Other commercial drivers are on the road for many hours a day due to the nature of their jobs, and therefore have considerably more driving experience than a typical commuter. Thus, the results from this study, like many from previous studies, may not adequately portray the results that IVISs would have on the driving performance of commercial vehicle and special vehicle drivers. The vehicle type was limited to a four-door passenger sedan.

5.3.1.2 Ramifications for IVIS Design

IVISs need to be carefully designed because there is a potential for these systems to draw upon the limited resources of the driver that the system was originally designed to augment. In the design process an important consideration for designers is the age range of the intended IVIS. The findings from this study indicate that the performance of older drivers was significantly more affected than young drivers when using an IVIS. It is important to note that the performance of older drivers was not only significantly more affected on tasks that required supplemental information processing, but that performance was also more affected on tasks that simply required

the driver to extract information from the visual display. From the results, it is apparent that designers must recognize that as drivers age, they have a significantly harder time performing tasks in all presentation formats, even when selecting a route at the low density level when only the road type and distance information were presented for three possible routes.

The aging process causes changes in the visual system that decrease the ability of individuals to extract visual information from their environment. Other changes also occur with the auditory system that affect the extraction and processing of auditory information and with the muscular and nervous systems that affect reaction times. The exact changes that occur are not important for interpreting the results from this study. What is important to note is that as a user grows older, his or her needs, limitations, and capabilities can change due to biological changes occurring within the body. Another potential explanation for the observed driving performance of older drivers is these individuals are more cautious; they are the survivors of their generation. Higher risk takers from their generation are now fewer in number. Older individuals have a different attitude toward speed/accuracy tradeoff; they tend to go for accuracy whereas younger individuals tend to go for speed of task completion.

If a designer is to create a system that can be used by the entire population, then to maintain safety in the user's environment, the system should be designed such that the system is either:

- 1) Flexible, and can be modified/preset based on a specific operator's ability, or
- 2) If only one setting is possible, designed such that the limitations of all potential operators are considered.

If the IVIS has the functionality to be set at different operating levels based on driver abilities then other issues, outside the scope of this paper, would need to be addressed, such as:

- 1) Who determines what training and evaluation is needed for drivers as they perform IVIS tasks?
- 2) Who performs the training and evaluation?

The biological/medical conditions that contribute to the difficulties that older drivers experience can occur in individuals of any age. Older individuals simply have a higher occurrence of these

medical conditions. Likewise, not all older drivers have these medical problems, so age alone should not be used as a selection criteria; instead, age should be an indicator for caution and prudent judgment.

In addition to biological changes, another possible explanation for the performance of older drivers being more affected than younger drivers, is the issue of skill transferability. Younger individuals in today's society are more likely to be familiar with computer interfaces than older individuals. Therefore, unless older individuals have had the same extensive exposure in their later years, this lack of familiarity can contribute to the fact that the computer interface in the vehicle required more attention demand of older drivers to complete the task than of younger drivers.

5.3.1.3 Future Research

With regard to training, if drivers received intense training and evaluation prior to using the IVIS on public roadways, would drivers be able to perform in-vehicle tasks that required supplemental information processing while maintaining safe vehicle operations? Research performed in the aviation industry, particularly by military applications, indicates that this might be the case (Gugerty and Tirre, 1997; Vidulich, McCoy, and Crabtree 1995).

As mentioned previously, many of the IVISs currently under development have very practical applications for professional drivers, such as commercial vehicle operators of heavy trucks and light trucks, bus drivers, taxi drivers, and emergency vehicle operators. For the general driving population, the current driving system does not compare to the intense training and preparation that military pilots undergo as they learn to use their avionic systems and fly their planes in combat. However, if research is performed that indicates that an intensive training and evaluation program allows for safe use of IVISs, then it is conceivable that professional drivers could undergo a rigorous training program and evaluation before being allowed to use advanced IVISs on public roadways. If the use of IVISs will increase the efficiency, effectiveness, productivity, and/or quality of service provided by professional drivers, then employers will be apt to provide both training and evaluation with appropriate external oversight.

5.3.2 CHARACTERISTICS OF THE IVIS TASK

The main focus of this study was to research the effects of supplemental information processing. IVISs that allow the driver to select alternative routes and perform other tasks that require planning and decision-making, and thus require supplemental information processing, would obviously be very beneficial and desired by drivers while in the vehicle. Possible design solutions and areas of future work are discussed in this section. First, however, limitations of this study with regard to the type of IVIS task presented are discussed.

5.3.2.1 Limitations

This study was designed to study the effects of supplemental information processing after the extraction of information from a visual display. However, there were three limitations with regard to information processing. Each limitation is discussed below:

- 1) Presentation of information auditorily,
- 2) Presentation of information via several visual screens as opposed to one, and
- 3) The issue that drivers did not make decisions they would follow through with action.

Information to complete the route planning and hotel selection tasks could be presented both visually and/or auditorily. In this study, information was only presented visually. In another study, Biever (in progress) examined the effect of presenting information auditorily which then required supplemental information processing. Drivers in this study were representative of the general driving population and drove a four-door sedan as the study vehicle. The results from Biever's study were not available at the time this document was written.

The results from the current study provide insight into IVIS designs that present all the information on one screen for a particular task. Results are not necessarily generalizable to tasks that require the user to advance through more than one screen of information to complete a task.

The IVIS tasks that required the driver to select a route or a hotel did not have a correct answer. The driver could provide any answer, and consequently it is unknown to what degree the driver considered his or her answer to be the best one possible. During training, drivers were instructed

to only state an answer if they felt confident that they were making the best possible decision. The drivers were instructed to either make a decision they were comfortable acting on, or to say “skip” if they would want to pull over to the shoulder, stop the vehicle, and look at the information in more detail. Drivers were given these instructions, but the degree to which they were followed is not possible to ascertain. Therefore, the results from this study should be used to exclude tasks from further consideration due to high attention demands. Ideally, another study that had the driver act on his/her decisions, such as selecting an alternate route to a destination, could be performed to validate the results of the tasks that this study indicate had a low attention demand.

5.3.2.2 Ramifications for IVIS Design

As expected, tasks that needed supplemental information processing required more attention demand than tasks that required searching for specific information. For many of the tasks that required supplemental information processing, there was a high proportion of drivers, from all age groups, who exceeded the Red-line Threshold. This study does not indicate that designers should completely eliminate tasks that required supplemental information processing. However, this study does indicate that careful assessment needs to be performed to avoid the potentially high attention demands of tasks that require supplemental information processing.

As mentioned in an earlier section, Redelmeirer and Tibshirani (1997) collected accident data that indicated that if a driver used a cellular phone while driving, he/she was four times as likely to have an accident than if no cellular phone was used. One rationalization for this safety concern with cellular phones is that the person with whom the driver is having a conversation is not in the vehicle and is not aware of the driving environment. The driver is not in control of the information inputs and consequently, the information received from the person with whom the driver is having a conversation can create a dangerous situation when the road being traveled upon also requires a high attention demand. There might be some belief that the IVIS would not have the same effect of diverting too much attention away from the primary task of driving the vehicle. The rationale for this belief is that drivers are better able to control the amount of attention diverted to the IVIS task than with a cellular phone. However, as the findings from this study show, this is not the case. IVIS tasks can cause a driver to divert too much attention away

from the primary task of driving to the point that driving performance exceeds safety parameters established from past research and expert opinion.

The high proportion of drivers who exceeded the Red-line Threshold while completing IVIS tasks requiring supplemental information processing is cause for concern when designing IVISs. However, findings suggest that both young and middle age drivers have the potential for performing tasks that require a limited amount of supplemental information processing. As expected, the more information presented, the higher the proportion of drivers who exceeded the Red-line Threshold. Depending on the age of the driver (young or middle age) and the information displayed, two categories of information may be considered for presentation. However, with older drivers, a high percentage (at least 50%) exceeded the Red-line Threshold when only two categories of information were presented.

A relatively low proportion of young and middle age drivers exceeded the Red-line Threshold compared to older drivers for tasks requiring planning and/or interpreting, such as selecting a route or hotel. However, if a task required a computation, at least 25% of drivers from each age group exceeded the Red-line Threshold. In addition, if drivers had the choice to perform a computation and then use this newly acquired information when selecting a route, many chose not to perform a computation. Almost all drivers who chose to perform a computation and then use the computed information to select a route exceeded the Red-line Threshold. These findings with computation tasks are not surprising based on documented human and machine capabilities and limitations (McCormick, 1985). The data collected on the attention demands required of drivers to complete computation tasks reinforced the expert opinion that the IVIS should perform these tasks.

Findings from this study appeared to indicate that young and middle age driver performance would not be degraded while performing tasks that only required the extraction of information from a visual display. However, when determining information to be presented to drivers, designers should understand the intended purpose of the system and the potential misuses of the system. For example, if the information displayed is only intended for the driver to search and the designer has displayed the appropriate amount of information that has been shown can be

searched safely, then a problem occurs if the driver also performs supplemental information processing using the displayed information. If the driver does choose to perform supplemental information processing, such as route planning or hotel selection, then a potentially higher proportion of drivers, as the findings indicate, will exceed the Red-line Threshold.

The same is true when displaying numeric values such as distance, speed limit, and costs. With current technology, it is hard to imagine that designers would not have a computer perform computations. However, designers need to identify potential computations that drivers might try to perform from displayed information and then create a system that automatically computes these values. For example, a designer should recognize the potential for a driver performing a computation to determine the quickest route when an IVIS presents more than one route and provides the route descriptors of distance and speed limit. Findings from this study indicate that a large proportion of drivers will exceed the Red-line Threshold if they attempt to determine the quickest route. Therefore, a solution might be to present an estimated time of travel for each route in lieu of speed limit, or if a driver requests information on the speed limits, the time of travel could be presented along with the speed limit.

The information presented to drivers in this study was used because it was believed that drivers would want this information when selecting a route or a hotel. The safest solution would be to have a lock-out function that only presented this type of information when the vehicle was stopped (for example, parked on the shoulder). However, especially for commercial drivers and specialty vehicle operators, it would be desirable to present information for decision-making purposes as the vehicle is moving.

Therefore, another design possibility for consideration is the presentation of small amounts of information serially. Findings from this study indicate that when selecting a route, if more than three categories for three possible routes are presented to young drivers and more than two categories are presented to middle age drivers, then a high proportion will exceed the Red-line Threshold. Another related finding was that the hotel selection task frequently required less attention demand than the route planning tasks. One possible explanation for this is that the categories of information in the hotel selection task facilitated the decision-making process by

making it easier for drivers to exclude one or more of the presented options and all the associated information from further decision-making. Whereas, with the route planning tasks, options might not have been as easily excluded from further consideration based on one category of information, more categories of information were considered and compared between options.

A possible example of the decision-making process for selecting a hotel is as follows: if three hotels are presented, a driver might scan for the cheapest hotel. Once the least expensive hotel is located, the driver might check the other categories of information to make sure that he/she is within proper limits (for example, distance to travel or quality rating of the hotel). As another example, perhaps the driver prefers to stay at Comfort Inns. The driver therefore searches the available options, locates a Comfort Inn, and then verifies the distance and cost to ensure that they are within acceptable limits.

IVISs that provide information in small amounts, allowing drivers to eliminate options from further consideration, may result in an acceptable attention demand. If the small amount of information presented results in a decision that leads to a new screen with additional information (the old information replaced with new information vs. increasing the total amount of information), then the interaction with the manual and speech demands needs to be researched. Working memory load would also need to be minimized, if not eliminated, as a driver advanced from one screen to the next in the IVIS to complete a task.

Another issue to consider when attempting to minimize the attention demand of tasks requiring supplemental information processing is the selection of the best presentation format(s) to portray the information on the visual display. When selecting a route, the paragraph format required a higher attention demand than any of the other presentation formats, regardless of the density level. When only type of roadway and distance were presented, there was no significant difference between the table format and the graphic map format. However, when an additional route descriptor was added (for example, delay in minutes), then the graphic map format required less attention demand than the table format. This finding supports the IVIS guideline that states that the graphic portrayal of information should be utilized when possible (Campbell, 1998).

It was not surprising that the paragraph format had the highest attention demand; however, with the potential for email systems and other similar systems to be available in vehicles, it was desired to make the attention demand of text presentations available to designers. Findings from this study indicate that a high proportion of drivers from all age groups will exceed the Red-line Threshold when presented with tasks requiring supplemental information processing when information is presented in paragraph format, even when only 3 lines of text are presented.

5.3.2.3 Future Research

Results from this study indicate that young and middle age drivers have the potential to be able to perform tasks requiring supplemental information processing when a limited amount of information is displayed. To assess the feasibility of presenting several categories of information to drivers for route planning, hotel selection, or similar tasks, additional research should be performed with small amounts of information presented serially to the driver while the vehicle is in motion. In addition, if information is presented serially, then the combined attention demand of visual extraction of information, supplemental information processing, and either manual or voice demands needs to be assessed.

CHAPTER 6: CONCLUSIONS

The three objectives set forth at the beginning of this research project were accomplished.

- 1) Tasks were created and presented to drivers of different ages to assess the effect of different types of tasks, density levels, and presentation formats on driver performance.
- 2) A method for evaluating driving performance to assess safety criteria was developed.
- 3) Descriptive data were collected and used in the development of the IVIS model (Hankey, Dingus, Hanowski, Wierwille, and Andrews, 2000).

A method was created establishing Red-line and Yellow-line Thresholds, which, if exceeded, provided evidence of decreased driver performance in regard to safety. The Red-line and Yellow-line Thresholds created in this research effort can be used by both designers of IVISs and individuals advocating for legislative intervention on policies pertaining to the use of IVISs.

These thresholds provide:

- Face valid indication of driver performance degradation,
- Assessment based upon safety parameters established by previous research and expert opinion, and
- The proportion of drivers whose driver performance is substantially affected when completing different IVIS tasks

This research provides insight into tasks resulting in decreased situation awareness. Tasks requiring supplemental information processing had a high attention demand when compared with tasks that only required the scanning and extraction of information from a visual display. The ramifications of this discovery are important with regard to creating and maintaining safe roadways. Based on the findings from this research, design guidelines are listed below.

DESIGN GUIDELINES

The results from this IVIS research suggest the following for visual information presentation to drivers while a vehicle is in motion:

- Consider how the driver will use this information before considering the visual characteristics of the information presented:
 - What types of decisions will be made?

- What decision-making process will be performed by the driver when using the displayed information (e.g. Will all information for all options be compared? Will the driver exclude options from further consideration based on one or more categories of information?).
- Design the information presentation to:
 - Minimize the attention demand required for decision-making
 - Facilitate the driver in making quick and accurate decisions
 - Allow for easy elimination of potential options
 - Allow for easy pause and restart of the decision-making task
- Structure the information presentation to facilitate decision-making. Tasks that allow for quick option elimination require less attention demand.
 - Identify potential options meeting driver specifications
 - Identify and display criteria desired by the driver for decision-making
 - Identify the relative importance, determined by the driver, of the different criteria and then use this ranking to determine the sequence of information portrayal
 - Provide accurate and specific details for criteria identified as being important, by the driver, for decision-making
 - Avoid the presentation of information not valued by the driver for decision-making
 - Allow for easy identification/removal of information presented that is determined not pertinent for decision-making
- Develop an IVIS to assist with decision-making by avoiding displays with a high density level and tasks that require calculations.
 - Preset system to display information with specifications based on driver preferences/needs
 - Minimize the number of potential options displayed
 - Allow the driver to limit the amount of information to be presented during decision-making tasks
 - Design the system to perform calculations desired by the driver for decision-making
 - Avoid displaying information that could be used by drivers to perform calculations, such as determining the quickest route from speed and distance information, unless the IVIS also provides the information obtained from performing the calculation

- Avoid the presentation of information in a format or density level that requires a high attention demand. The proportion of drivers who exceeded the Red-line Threshold was dependent on the presentation format of the displayed information.
 - Avoid using the paragraph format to present information to drivers
 - Utilize the graphic icon format, when possible, for route planning tasks instead of either the table or graphic text formats
- Consider the information processing capabilities of various driver age groups.
 - Avoid presenting information in the graphic icon format above the medium density level to young drivers. Information presented to young drivers in either the table or graphic text formats should not exceed the low density level
 - Present information to middle age drivers in the graphic icon format and do not exceed the low density level
 - Use caution when presenting information for decision-making tasks to older drivers. Older drivers are burdened by the attention demand required for decision-making elicited by visually displayed information regardless of the density level or presentation format
- Avoid the use of warnings, such as those printed on consumer devices, as the primary intervention in creating safe IVISs. Drivers did not appear to be aware of the decrease in their situation awareness while performing IVIS tasks. Many drivers repeatedly exceeded the Red-line Thresholds, indicating that they either:
 - Had poor ability in assessing their situation awareness,
 - Were not aware of the ramification that their driving performance had on their ability to safely respond to events in their surroundings, and/or
 - Had a false sense of security due to the in-vehicle experimenter being present to monitor and/or intervene when necessary

Generally speaking designers should avoid using technology for technology sake. IVISs should be utilized when there is an opportunity to provide drivers with information in a more efficient and effective manner than conventional means allow, thereby, improving safety when compared to decision-making processes using current, non-technology methods.

REFERENCES

- Anderson, J. (1990). Cognitive psychology and its implications. New York: W.H. Freeman and Company.
- Anton, T. (1989). Occupational safety and health management. New York: McGraw-Hill, Inc.
- Bhise, V.D., Forbes, L.M., and Farber, E.I. (1986). Driver behavioral data and considerations in evaluating in-vehicle controls and displays. Presented at the Transportation Research Board 65th Annual Meeting. Washington, D.C.
- Biever, W. (in progress). Auditory based supplemental information processing demand effects on driving performance. Unpublished master's thesis. Virginia Tech, Blacksburg, VA.
- Boff, K. and Lincoln, J. (1988). Engineering Data Compendium: Human Perception and Performance, Volume II. Harry G. Armstrong Medical Research Laboratory, Wright Patterson Air Force Base, Ohio.
- Brown, C. (1988). Human-computer interface design. Norwood, NJ: Ablex Publishing Corporation.
- Campbell, J., Carney, C., and Kantowitz, B. (1998). Development of human factors guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO) (Tech. Report). Washington, D.C.: Federal Highway Administration.
- Carpenter, J.T., Fleishchman, R.N., Dingus, T.A. Szczublewski, F.E., Krage M.K., Means, L.G. (1991). Human factors engineering the TravTek driver interface," In the Conference Record of Papers at the 2nd Vehicle Navigation and Information Systems Conference.
- Committee on Public Works and Transportation, U.S. House of Representatives (1989). The status of the nation's highways and bridges: Conditions and performance (Committee Print 101-2). Washington, DC: U.S. Printing Office.

Dingus, T. (1997). Presentation at the FHWA ITS RCE Advisory Board Meeting, Spring 1997. Blacksburg, VA: Best Western Red Lion Inn.

Dingus, T., McGehee, D., Hulse, M., Jahns, S., Manakkal, N., Mollenhauer, M., and Fleischman, R. (1995). Travtek evaluation task c₃ – camera car study. (Tech. Report). Washington, D.C.: Federal Highway Administration.

Eggemeier, F. T. and Wilson, G. F. (1991). Subjective and performance-based assessment of workload in multitask environments. In D. L. Damos (Ed.), Multiple task performance (pp. 217-278). London: Taylor and Francis.

Endsley, M. (1995a). Measurement of situation awareness in dynamic systems. Human Factors, 37(1), 65-84.

Endsley, M. (1995b). Toward a theory of situation awareness in dynamic systems. Human Factors, 37(1), 85-104.

Endsley, M. (1995c). Theoretical underpinnings of situation awareness: A critical review. In Proceedings of an International Conference: Experimental Analysis and Measurement of Situation Awareness (pp. 17-24). Daytona, Florida: U.S. Federal Aviation Administration, U.S. Nuclear Regulatory Commission.

Farber, E., Blanco, M., Foley, J., Curry, R., Greenberg, J., and Serafin, C. (2000) Surrogate measures of visual demand while driving. Proceedings of the IEA 2000/HFES 2000 Congress. (pp. 3.274-3.277). San Diego, CA: Human Factors Society.

Gugerty, L. and Tirre, W. (11/10/1997). Individual Differences in Situation Awareness [On-line]. Available: <http://www.sa.galaxyscientific.com/lee/SACHAP.html>

Hankey, J., Dingus, T., Hanowski, R., Wierwille, W., and Andrews, C. (2000). In-vehicle information systems behavioral model and design support. (Technical Report Contract No. DTFH61-96-C-00071) Washington D.C.: Federal Highway Administration.

Hanowski, R., Bitter, A., Knipling, R., Byrne, E., and Parasuraman, R. (1995). Analysis of older-driver safety interventions: A human factors taxonomic approach. Proceedings of the 1995 Annual Meeting of ITS America (pp. 955-965). Fairfax, VA: Caset Associates, Ltd.

Hanowski, R., Dingus, T., Gallagher, J., Kieliszewski, C., and Neale, V. (1999). Driver response to in-vehicle warnings. Transportation Human Factors, 1(1), 91-106.

Hart, S.G. and Staveland L.E. (1988). Development of NASA-TLX results of empirical and theoretical research. In P.A. Hancock and N. Meshkati (Eds.), Human Mental Workload, (pp. 139-183). North-Holland Elsevier.

IVHS America. (1992). Strategic plan for intelligent vehicle-highway systems in the United States (Report no. IVHS-AMER-92-3). Washington, DC.

Jones, P. F. (1978). Four principles of man-computer dialog. IEEE Transactions on Professional Communication, PC-21, 154-159.

Kurokawa, K. and Wierwille, W. (1990). Development of an evaluation program for automotive instrument panel design. (Technical Report ISE 90-04) Blacksburg, VA: Vehicle Analysis and Simulation Laboratory, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University.

Lee, J., Morgan, J., Wheeler, W., Hulse, M., and Dingus, T. (1997). Development of Human Factors Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO): Description of ATIS/CVO Functions (Technical Report DTFH61-92-C-00102) Washington D.C.: Federal Highway Administration.

McCormick, E.J. (1985). Human Factors Engineering. New York: McGraw-Hill, pp. 20-21.

Miller G. A. (1956). The magical number seven plus or minus two. Some limits on our capacity for processing information. Psychological Review, 63, 81-97.

Miller, R. (1971). Development of a taxonomy of human performance: Design of a systems task vocabulary (Tech. Report AIR-72/6/2053-3/71-TRII). Silver Spring, MD: American Institutes for Research.

Miller, R. (1974). A method for determining task strategies (Technical Report AFHRL-TR-74-26). Washington, D.C.: American Institute for Research.

Monty, R.W. (1984). Eye movements and driver performance with electronic automotive displays. Unpublished master's thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Moeur, R.C. (2/1/98). Manual of traffic signs. [On-line]. Available:
<http://members.aol.com/rcmoeur/signman.html>

National Highway Traffic Safety Administration. (2001). Traffic Safety Facts – 2000 (On-line). Available: WWW URL: <http://www.nhtsa.dot.gov/>.

National Safety Council (1994). Accident facts 1994. Chicago: National Safety Council.

Pritchett, A.R., Hansman, R.J., and Johnson, E.N. (1995). Use of testable responses for performance based measurement of situation awareness. In Proceedings of an International Conference: Experimental Analysis and Measurement of Situation Awareness (pp. 75-81). Daytona, Florida: U.S. Federal Aviation Administration, U.S. Nuclear Regulatory Commission.

Rasmussen, J. (1986). Information processing and human-machine interaction: An approach to cognitive engineering. New York: North Holland.

Redelmeirer, D. and Tibshirani, R. (1997). Association between cellular-telephone calls and motor vehicle collisions. The New England Journal of Medicine, 336 (7), 453-458.

Reid, G.B. and Nygren, T.E. (1988). The subjective workload assessment technique: a scaling procedure for measuring workload. In P.A. Hancock and N. Meshkati (Eds.), Human Mental Workload, (pp. 185-218). North-Holland Elsevier.

SAE Standard for Navigation and Route Guidance Function Accessibility While Driving (SAE 2364) – Committee Draft. Nov. 23, 1998.

Salvendy, G. (1997). Handbook of Human Factors and Ergonomics. New York: John Wiley and Sons, Inc.

Shneiderman, B. (1992). Designing the user interface: Strategies for effective human computer interaction, 2nd edition. Reading, MA: Addison-Wesley Publishing Company.

Stamatiadis, N., Taylor, W.C., and McKelvey, F.X. (1990). Accidents of elderly drivers and intersection traffic control devices. Journal of Advanced Transportation, 24, 99-112.

Stern, J., Wang, L., and Schroeder, D. (1995). Physiological measurement techniques: What the heart and eye can tell us about aspects of situational awareness. In Proceedings of an International Conference: Experimental Analysis and Measurement of Situation Awareness (pp. 155-162). Daytona, Florida: U.S. Federal Aviation Administration, U.S. Nuclear Regulatory Commission.

Stewart, T.F.M. (1976). Displays and the software interface. Applied Ergonomics, 7, 137-146.

Treat, J., Tumbas, N., McDonald, S., Shinar, D., Hume, R., Mayer, R., Stansifer, R., and Castellan, N. (1979). The study of the causes of traffic accidents, final report, volume 1: Causal

factor tabulations and assessments (Tech. Report Contract No. DOT HS-034-3-535). United States Department of Transportation, National Traffic Safety Administration, Washington, D.C.

Tullis, T.S. (1990). The formatting of alphanumeric displays: A review and analysis. In M. Venturino (Ed.), Selected readings in human factors (pp. 371-396). Santa Monica, CA: Human Factors Society.

Vidulich, M.A., McCoy A.L., and Crabtree, M.S. (1995). Situation Awareness: Limitations and Enhancement in the Aviation Environment. In AGARD Conference Proceedings 575. (pp.18.1-18.5). Brussels, Belgium: Aerospace Medical Panel Symposium.

Wierwille, W. and Casali, J. (1983). A validated rating scale for global mental workload measurement applications. In Proceedings of the Human Factors Society – 27th Annual Meeting. (pp. 129-133). Norfolk, Virginia: Human Factors Society.

Wierwille, W. and Eggemeier, T. (1993). Recommendations for mental workload measurement in a test and evaluation environment. Human Factors, 35(2), 263-281.

Wierwille, W. and Gutman J. C. (1978). Comparison of primary and secondary task measurements as a function of simulated vehicle dynamics and driving conditions. Human Factors, 20, 233-244.

Wierwille, W., Dingus, T., Neale, V., and Gallagher, J. (1996). Program plan for development of an in-vehicle information system behavioral model (IVIS/BM). (Tech. Report). Blacksburg, Virginia: Virginia Tech Transportation Institute, Virginia Polytechnic and State University.

Wilson, G. (1995). Psychophysiological assessment of situational awareness. In Proceedings of an International Conference: Experimental Analysis and Measurement of Situation Awareness (pp. 141-145). Daytona, Florida: U.S. Federal Aviation Administration, U.S. Nuclear Regulatory Commission.

Zwahlen, H., Adams, C., and DeBald, D. (1988). Safety Aspects of CRT Touch Panel Controls in Automobiles. In Vision in Vehicles II, Proceedings of the Second International Conference on Vision in Vehicles (pp.335-344). Nottingham, U.K.: Applied Vision Association in conjunction with the Ergonomics Society and the Association of Optometrists.