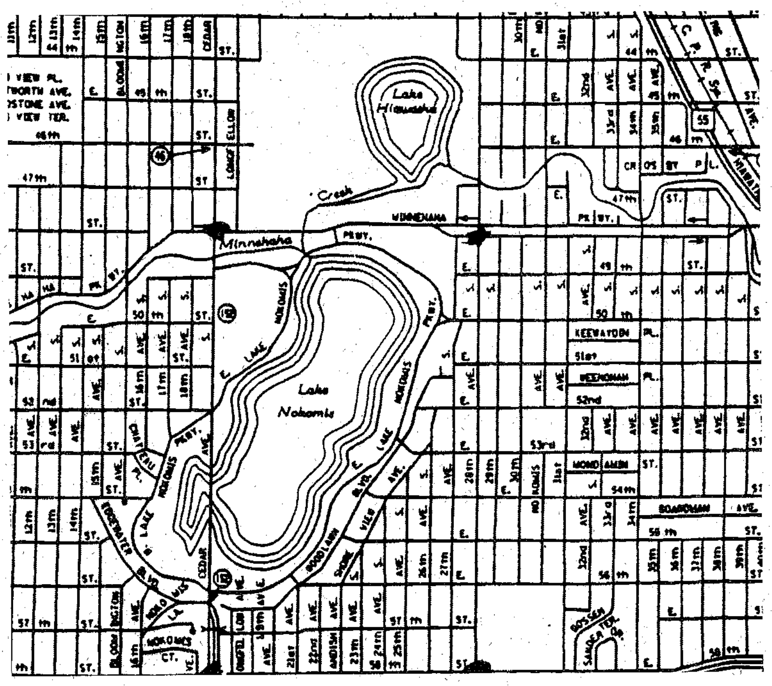
Final Report 1999-14

MINNESOTA DEPARTMENT OF TRANSPORTATION



Human Factors Evaluation of GAINS, A Prototype In-Vehicle Navigation System

Research

42024628

Technical Report Documentation Page

1. Report No. MN/RC - 1999-14	2.	3. Recipient's Accession No.	
4. Title and Subtitle HUMAN FACTORS EVALUATION OF GAINS, A PROTOTYPE NI-VEHICLE NAVIGATION SYSTEM		5. Report Date April 1999 6.	
7. Author(s) Thomas J. Smith Curtis Hammond Michael G. Wade		8. Performing Organization Report No.	
9. Performing Organization Name and Address University of Minnesota Human Factors Research Laboratory, Division of Kinesiology 1901 Fourth Street, S.E. Minneapolis, MN 55414		10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. (C) 74708 TOC # 16	
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard Mail Stop 330 St. Paul, Minnesota 55155		13. Type of Report and Period Covered Final Report 1999 14. Sponsoring Agency Code	

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This project evaluated how driver interaction with an in-vehicle navigation system (IVNS) affects driving performance and safety. Researchers collected measures of simulated driving performance during interaction by 13 different subjects with an IVNS digital map display, using a Honda Acura placed within a fixed-base wrap-around driving simulator. Subjects (Ss) navigated along a maze-like route laid out within a simulated road grid. Dummy Global Positioning System (GPS) coordinates, corresponding to the position of the vehicle in the grid, were transmitted to the IVNS and updated continuously as vehicle position in the simulation environment changed. A digital map of the grid, with an icon representing vehicle representing vehicle position superimposed, was displayed on a laptop computer placed in the Acura. Under the control condition, Ss were not given turn instructions.

Results indicate that for the test relative to the control condition:

- Visual interaction with the IVNS display was greater and task completion times longer.
- More variability in vehicle control was observed for measures of average vehicle speed, peak speed, percent braking time, peak braking pressure, and vehicle heading.

Subjective responses from simulated driving and a separate group of on-road Ss identify both navigation benefits and possible safety problems with the system. It is a reasonable assumption that increased variability in driving performance elevates driving accident risk. Both the simulated driving and subjective response results, therefore, point to possible safety implications in IVNS use for the driving public. The findings suggest that as IVNS use becomes more widespread, both navigation benefits and possible adverse driving safety effects of such systems need to be considered.

17. Document Analysis/Descriptors In-vehicle navigation In-vehicle information systems Intelligent transportation systems	Driving performance Driving safety Driving simulators	18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	197	

Human Factors Evaluation of GAINS, A Prototype In-Vehicle Navigation System

Final Report

Prepared by:

Thomas J. Smith
Curtis Hammond

Human Factors Research Laboratory
Division of Kinesiology
University of Minnesota

141 Mariucci Arena
1901 Fourth Street S.E.
Minneapolis, MN 55414

April 1999

Published by

Minnesota Department of Transportation
Office of Research Administration
200 Ford Building Mail Stop 330
117 University Avenue
St. Paul Minnesota 55155

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of the following people whose contributions were instrumental to completion of the project.

Mn/DOT Personnel
Farideh Amiri, Intern Traffic Engineer
Jay Koski, Research Project Coordinator
Ben Osemenam, Program Development Engineer
Ia Xiong, Intern Traffic Engineer

Etak, Inc. Personnel
Jeff Lange, Product Manager, Intelligent Transportation Systems
David Michmerhuizen, Software Engineer
Lawrence Sweeney, Vice President, Advanced Development Center

University of Minnesota Division of Kinesiology Personnel
Paul Cassidy, Graduate Research Assistant
Michael Wade, Professor and Director

University of Minnesota Human Factors Research Laboratory Personnel
Peter Easterlund, Systems Programmer
Peter Hancock, Director
James Klinge, Systems Analyst/Programmer
Michelle Pieper, Laboratory Administrator
Steve Scallen, Director of Research

Funding Acknowledgment

This project was conducted with funding provided by the Minnesota Department of Transportation (Mn/DOT) Guidestar Office. Minnesota Guidestar's mission is to provide leadership and coordination for an Intelligent Transportation System (ITS) program that provides the greatest benefits to travelers in Minnesota.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

Page

TABLES

List of Tables

TABLE OF CONTENTS (continued)

Page

FIGURES

List of Figures

TABLE OF CONTENTS (continued)

Page

FIGURES (continued)

List of Figures (continued)

TABLE OF CONTENTS (continued)

APPENDICES

ABBREVIATIONS, ACRONYMS AND DEFINITIONS

3D	three-dimensional
ANOVA	analysis of variance
ANSI	American National Standards Institute
control condition	researcher provided turning instructions at each intersection for simulated driving Ss
CTS	University of Minnesota Center for Transportation Studies
deg	degree
df	degrees of freedom
DOT	Department of Transportation
E-W	east-west
Excel	Microsoft spreadsheet program
F / F crit	F value / critical F value for $p<.05$.
ft	feet/foot
GAINS	GUIDESTAR Advanced In-Vehicle Navigation System
GPS	global positioning system
GUIDESTAR	Mn/DOT office with the mission of providing leadership and coordination for an ITS program that provides the greatest benefits to travelers in Minnesota
HF; HF/E	human factors; human factors/ergonomics
HFRL	University of Minnesota Division of Kinesiology Human Factors Research Laboratory
HFS	Human Factors Society
hr	hour
hz	hertz
ID	identification
in	inch
ITS	Intelligent Transportation System
IVNS	in-vehicle navigation system
km	kilometers
kph	kilometers per hour
Linux	operating system for PC - alternative system to Windows 95

m	meters
MAX	maximum
mi	miles
MIN	minimum
min	minutes
mm	millimeters
Mn/DOT	State of Minnesota Department of Transportation
mph	miles per hour
MS	mean sum of squares
N	number of subjects
N-S	north-south
NAD27	GPS coordinate reference system used by Skymap
no.	number
p	probability
PC	IBM-compatible personal computer
RS232	standard PC serial communications port
S, Ss	subject, subjects
SD	standard deviation
sec	seconds
SGI	Silicon Graphics Inc.
Skymap	Windows 95 compatible proprietary software developed by Etak, Inc. containing navigation, map database, and points-of-interest database files, and used to generate GAINS digital map display
SS	sum of squares
t	t statistic
test condition	researcher did not provide turning instructions at each intersection for simulated driving Ss
UM	University of Minnesota
V	volts
VDT	visual display terminal
WGS-84	GPS coordinate reference system used by GAINS Sony GPS receiver

EXECUTIVE SUMMARY

This Mn/DOT and CTS sponsored study evaluated a prototype in-vehicle navigation system termed GAINS, consisting of a digital map software system, digital map databases of areas of Minnesota, a GPS signal receiver, a remote control, and IBM-compatible notebook and laptop PCs running Windows 95 on which the digital map software and databases were installed.

The evaluation comprised three phases: (1) collection of subjective responses from users of the system regarding the utility, usability, appeal, and shortcomings of the system; (2) objective analysis of effects of visual interaction with the system on a series of dependent measures of simulated driving performance; and (3) HF/E analysis of the legibility of the system display.

Subjective responses from both the on-road and simulated driving respondents address both strengths and shortcomings of the system. Strengths cited include map accuracy, navigation benefit, and ease of understanding, learning, reading, and using the system. Conversely, difficulty in using the system, unclear instructions, inaccurate and incomplete map, poor display legibility, confusion in relating left-right movements of the vehicle icon on the display with left-right vehicle turn directions, and adverse driving effects of looking at the display, are among the shortcomings cited.

The sometimes contradictory mix of subjective responses regarding both positive and negative attributes of GAINS indicates a wide range of individual differences in relation to the degree to which respondents were able to effectively interact with and thereby derive benefit from GAINS. This implies that a wide range of individual differences may exist in customer acceptance of IVNS technology generally.

During simulation testing, Ss were required to navigate from a start to an end point in a simulated driving environment. At each intersection, instructions regarding which way to turn at successive intersections were either provided (control condition) or not provided (test condition). Dependent measures of driver control of vehicle speed, braking and trajectory were collected. Simulation testing required development and implementation of an innovative methodology, in which a dummy data stream of GPS coordinates was transmitted to GAINS, such that the digital map display indicated and updated vehicle position in real time as Ss traversed the simulated driving environment.

During simulation testing, visual interaction with the GAINS digital map for navigation was more frequent under the test condition compared with the control condition. This suggests that differences in visual interaction with the map between the control and test conditions contributed to differences observed in dependent measures of simulated driving performance between the two conditions.

For 6 dependent measures of simulated driving performance---unfiltered and filtered measures of overall vehicle speed, peak vehicle speed, percent braking time, number of braking adjustments, and vehicle heading error---simulated driving under the test condition displays greater variability in performance than that under the control condition.

Route trajectories for different simulated driving Ss under the test condition indicate distinct differences in navigation strategies between those who found the end point successfully and those who did not. These findings suggest a range of individual differences in user ability to effectively interact with IVNS technology for navigation purposes, which in turn may result in individual differences in customer appeal of such systems.

Various factors limit the generalizability of the results. These include lack of representative sample population, small number of on-road and simulated driving Ss, possible bias in responses from on-road driving Ss, presence of small feedback delay between steering wheel movements and update of visual display during simulation testing, and the prototype nature of the system evaluated.

Two sets of findings point to possible adverse effects of IVNS technology on driving safety. First, 4 study participants reported that visual interaction with the GAINS display adversely affected their driving. Second, the more variable level of simulated driving performance observed under the test condition implies less consistent control of the vehicle by the driver during visual interaction with the digital map. This in turn may expose the vehicle and the driver to an elevated level of accident risk, in the sense that more pronounced fluctuations in vehicle speed, braking, and/or heading may elevate the risk of such incidents as collisions or departure from the roadway.

However, participant responses indicate that GAINS definitely aided navigation and gave some Ss a comforting sense of situational awareness regarding vehicle position relative to the surroundings. The challenge for IVNS technology therefore is reduce possible adverse effects of driver interaction with such systems on driving safety, while improving system design and documenting possible driving benefits of such systems.

To improve the system, participants in the study offer a number of suggestions: (1) improve system usability and capabilities of system; (2) improve presentation and scope of map perspective; (3) improve map accuracy; (4) improve system instructions; (5) provide directional indicators (N,S,E,W) on map; and (6) place display closer to driver's line of sight.

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1. INTRODUCTION

As part of its 1995-1997 work plan, the State of Minnesota Department of Transportation (Mn/DOT) GUIDESTAR office (charged with the mission of providing leadership and coordination for an Intelligent Transportation System (ITS) program that provides the greatest benefits to travelers in Minnesota) entered into an agreement with Etak, Inc. to evaluate a prototype in-vehicle navigation system (IVNS) designed for installation on IBM-compatible personal computer (PCs). Mn/DOT and the University of Minnesota (UM) Center for Transportation Studies (CTS) subsequently contracted with the UM Division of Kinesiology Human Factors Research Laboratory (HFRL) to conduct a human factors/ergonomic (HF/E) research evaluation of the system. GUIDESTAR places emphasis on incorporating HF/E analysis as part of overall system evaluation. This final report outlines the background to the project, describes research methods and results, and discusses conclusions supported by the findings.

The report is divided into five chapters. Chapter 1 deals with the project introduction and background. Chapter 2 describes methods and results for on-road evaluation of system use by means of a subjective response survey questionnaire (Tasks 1 and 2 of project work plan). Chapter 3 describes methods and results for evaluation of the effects of driver interaction with the system on driving performance under simulated driving conditions (Tasks 3, 4, 5, 7, and 8 of project work plan). Chapter 4 describes methods and results for a static HF/E evaluation of system design (Task 6 of project work plan). Chapter 5 discusses implications and conclusions of the study.

Two interim reports describing progress in completing Task 1 [1] and Tasks 3, 4, and 5 [2] of the project work plan have been submitted to Mn/DOT. Some findings from the project have been described in a conference presentation [3].

In-vehicle navigation systems are designed to provide information on traffic, transit, and other driving conditions of interest to travelers wishing to avoid congestion and to reach their destinations without excessive delay under prevailing conditions. As the name implies, such systems prompt travelers to find and use acceptable routes which are likely to take them from the origin to the destination of their journeys smoothly and effectively. However, uncertainties remain about potential HF/E issues and problems pertaining to usability, utility, reliability, and effectiveness of these systems. Questions pertaining to possible safety liability issues associated with permitting drivers to use such systems during vehicle operation also remain unresolved.

The research described in this report addresses these questions through a combination of subjective response, driving simulator, and static HF/E analyses by evaluating software and hardware interface design features, in-vehicle placement of system, content and relevance of information presented, safety implications, and user acceptance. Findings from the analyses may point to possible design improvements to the system that can be targeted for later implementation.

1.2. BACKGROUND

To introduce and describe the background for the project, subsections below summarize the: (1) system description; (2) research objectives and work plan; (3) HF/E issues associated with use of IVNS technology; and (4) personnel and planning activities associated with the project.

1.2.1. System Description

The IVNS system evaluated by this project comprises: (1) proprietary software and map databases developed by Etak, Inc. (a digital map company subsidiary of Sony, Inc., based in Menlo Park, CA) that are used to provide computer digital map displays of a number of areas in the U.S., including a 41-county area of southern Minnesota that includes the Twin Cities metropolitan area; (2) PCs on which the Etak software and databases are installed; and (3) a global positioning system (GPS) with computer interface. The present project represents just one of a number of ITS projects involving collaboration between Etak and Departments of Transportation (DOTs) in various states.

Originally, it was envisioned that system hardware for this project would be provided by Delco. Plans subsequently were revised to install the Etak software on IBM-compatible PCs for evaluation purposes. Further, the system configuration evaluated here is a prototype, not intended for commercial distribution. Consequently, this report refers to the system as the 'GUIDESTAR Prototype In-Vehicle Navigation System.' The acronym GAINS (GUIDESTAR Advanced In-Vehicle Navigation System) is used to refer to the system.

Etak software and map databases provide real-time, turn-by-turn map navigation and points-of-interest display capabilities, based on GPS input that is used to relate, update, and display the geographic position of the vehicle carrying the GPS with coordinates on the digital map display. Installation of the system (from CD-ROMs provided by Etak) on the PC of choice generates a digital map directory called Skymap containing navigation, map database, and points-of-interest database files. Skymap must be installed on a PC running Microsoft Windows 95.

For the GAINS project, Etak software and databases were installed on two Toshiba Libretto 30 notebook PCs with 6-inch displays, and two laptop PCs (Compaq and Toshiba) with 11-inch displays. All PC models run the Windows 95 operating system. Two Libretto 30 PCs were provided for project use by Etak, one for installation in a Mn/DOT fleet vehicle, and one for use by the UM team. The Libretto 30 currently is unavailable in the U.S. and is configured with the Japanese language. One Compaq laptop was provided by Mn/DOT for use during the on-road evaluation (Chap. 2). A second Toshiba Satellite 205CDS laptop PC was provided by HFRL for use during the simulation testing phase of the project (Chap. 3).

During system operation, GPS input is sampled at a rate of 1 hertz (hz), and vehicle position is indicated and updated on the map display in real time using a special icon. In addition, a trip file for the trip, containing successive entries for each GPS record sampled, is generated automatically and saved in Skymap, using a proprietary formatting protocol developed by Etak. A trip file can be retrieved at a later time and used to replay the trajectory of a vehicle on the digital map for that particular trip.

1.2.2. Research Objectives, Work Plan and Contract

The overall objective of the study is to carry out a HF/E analysis of use of GAINS for navigation purposes. This analysis addressed the following types of questions about the system.

- Is the system easy to operate and use?
- Can the map display and navigation aids be perceived and easily understood by the driver? Is the navigation assistance helpful? Annoying? Distracting?
- What factors influence the legibility and understandability of information displayed by the system?
- Under what on-road conditions do drivers employ GAINS?

- Does map and navigation information presented by GAINS conform to HF/E guidelines for computer information displays?
- Does GAINS divert the driver's attention away from the driving task so as to compromise driving safety? In particular, does driver interaction with the system during driving activity interfere with: (1) braking performance? (2) lane position control? and/or (3) speed control?

A total of 9 project tasks are specified in the project work plan, which address three major research phases: (1) use of a survey questionnaire to collect subjective responses from Mn/DOT employees about on-road use of the GAINS unit placed in Mn/DOT fleet vehicles (Chap. 2); (2) collection of driving performance measures from subjects (Ss) under simulated driving conditions, with the unit installed in the vehicle used for analysis of simulated driving performance in the HFRL wrap-around driving simulator (Chap. 3); and (3) static HF/E analysis of system design features, to assess their conformance with recommended HF/E design guidelines and standards for visual displays (Chap. 4).

Findings collected from these analyses form the basis for a series of conclusions discussed in Chapter 5 pertaining to utility, usability, design features, and driving performance and safety implications of GAINS.

1.2.3. Human Factors Issues Associated With Use Of In-Vehicle Navigation Systems

The growing number of IVNS projects, vendors, and units in operation has prompted scrutiny by professionals in the human factors (HF) and transportation safety communities regarding the possible influence of such systems on driving performance and safety. As with many other technological innovations, IVNS technology has been introduced and implemented without a thorough understanding of its potential human and societal implications. However, a variety of HF/E research studies including this one have been initiated or completed in an effort to broaden this understanding. For example, the current GAINS project has evolved from a previous Mn/DOT-HFRL collaborative research project dealing with GENESIS, another in-vehicle information system [4,5].

The two HFRL final reports on GENESIS previously submitted to Mn/DOT [4,5] contain an extensive series of HF/E references on in-vehicle information systems, user interface design, message formatting, and multitasking impacts on driving safety. In addition, the GAINS project work plan contains a series of HF/E references on IVNS research, retrieved by the Mn/DOT Library staff using the following key words: Etak Navigation Systems, Etak/Delco Navigation Systems, In-Vehicle Navigation Systems, and TravTek.

For purposes of this report, a selective survey of some recent HF/E research studies on in-vehicle information systems was carried out, supporting the following conclusions.

- HF/E design deficiencies with legibility and formatting of messages displayed by the GENESIS system were documented in previous Mn/DOT-HFRL research, related to the experimental nature of the system, and easily remedied [4].
- Initial results from field studies of TravTek (an advanced traveler information and traffic management system) indicate that the system: (1) saves trip planning time but not travel time; (2) reduces the number of wrong turns during a trip with use of the route map; (3) receives positive ratings from drivers for route guidance use; and (4) is perceived by drivers as having time saving and driving safety benefits [6,7].
- Further results from TravTek research indicate that: (1) with experience in using TravTek, drivers become familiar with the system and develop strategies for its efficient and safe use; (2) relative to younger drivers, drivers over age 65 have more difficulty driving and concurrently using the system to navigate---older drivers drive more slowly and cautiously, yet still make more safety-related driving errors, than younger drivers while using the system; and (3) older drivers benefit substantially from a well-designed IVNS driver interface [8].
- Findings from a driving reaction time study of 5 different in-vehicle route guidance systems (paper map; head-down turn-by-turn display; head-down electronic route map display; head-up turn-by-turn display; an audio guidance system), using a fixed-base, high fidelity driving simulator, indicate that: (1) drivers respond fastest using audio guidance and slowest using the paper map; (2) reaction times with use of the head-up turn-by-turn display are faster than those with use of the head-down turn-by-turn display; and (3) performance with the head-down electronic map was better than that with the head-down turn-by-turn display [9].

CHAPTER 2

ON-ROAD EVALUATION OF GAINS

2.1. INTRODUCTION

For on-road evaluation of GAINS (project work plan Tasks 1 and 2), a Subjective Response Survey Questionnaire was developed to elicit driver opinions about using GAINS for navigation purposes during on-road driving activity. Appendix A contains a copy of the final version of the questionnaire. Sections below summarize the purpose and objectives of the subjective response survey, methods used to develop the questionnaire and to select Ss, implementation of the survey process, and results of the survey.

2.2. PURPOSE AND OBJECTIVES OF SURVEY QUESTIONNAIRE

The survey questionnaire is designed to secure subjective driver opinions on the utility and usability of the GAINS prototype related to different driving conditions, ease of use, desirability of functions, safety implications, and recommendations for possible improvements to system interface design features and in-vehicle placement. The purpose in collecting questionnaire responses is to provide information on positive features, possible benefits, negative features, and possible problems related to system use by actual drivers during driving performance under operational driving conditions. This subjective response information, which profiles real-world experience with the system, complements objective driving performance data collected under simulated driving conditions (project work plan Tasks 3, 4, 5, and 7). There is ample scientific precedent for using a subjective response survey to collect information about driver opinions about and experiences with in-vehicle information systems under operational driving conditions [6-8].

2.3. METHOD

2.3.1. Questionnaire Development

Questions in the survey questionnaire developed for the project (Appendix A) request user responses in 3 categories: (1) information about the user (Questions 1-11); (2) user opinions about

GAINS (Questions 12-23), in which users are asked to respond to a series of statements about the system with a 5-choice scale that ranges from 'Strongly Disagree' to Strongly Agree'; and (3) narrative responses (Questions 24-28) regarding problems, likes, and dislikes with the system. The questionnaire is designed to be short, so that it can be completed in less than 5 minutes (min).

Development of the 5-choice questions was guided by similar questions employed in: (1) a 30-page survey questionnaire developed for user evaluation of the TravTek system [6-8]; and (2) a standard evaluation form for onboard vehicle information systems developed for internal use by Nissan Research and Development Corp., and translated from Japanese. Copies of the TravTek and Nissan instruments were furnished to the UM team by Amy Polk (Polk, personal communication).

Once a draft version of the survey questionnaire had been developed, it was reviewed by Mn/DOT and Etak representatives, and by a survey specialist at the UM Center for Survey Research. The final version of the questionnaire (Appendix A) incorporates changes and improvements recommended by these various parties.

2.3.2. Subjects

By agreement with Mn/DOT, it was determined that Mn/DOT employees using Mn/DOT fleet vehicles would represent an accessible and acceptable sample population for the survey. Accordingly, GAINS was installed in two PCs (a Libretto notebook and a Compaq laptop) which then were emplaced in two Mn/DOT fleet vehicles. A public notice was issued to Mn/DOT employees announcing availability of the system, encouraging use of fleet vehicles containing the system, and completion of survey questionnaires.

2.3.3. Implementation of Survey Process

A rack mount for holding a Toshiba Libretto 30 notebook PC was installed by Mn/DOT in a 1993 Chevrolet Lumina Mn/DOT fleet vehicle in early July, 1997. A set of instructions for using GAINS and the Libretto 30 were compiled by Mn/DOT and also installed in the Lumina on laminated sheets. A similar set of instructions for using GAINS with a Compaq laptop PC also were developed.

To increase opportunities on the part of Mn/DOT employees for interaction with GAINS and for returning completed survey questionnaires, Mn/DOT configured a Mn/DOT Plymouth fleet van with a rack mount for holding a Compaq laptop PC on which GAINS also was installed. The van was made available for use in August, 1997.

Arrangements were made with the Supervisor of the Mn/DOT transportation garage to oversee day to day usage of the system. This involved: (1) distributing a survey questionnaire to each Mn/DOT employee intending to use GAINS at the outset of their trip; (2) warning each user that the system should not be actuated until the vehicle had left the garage, so that the GPS could acquire the satellite signal; (3) collecting completed questionnaires from each employee using a GAINS vehicle at the end of their trip; and (4) ensuring that the system was powered down at the end of the workday, after the fleet vehicle had been returned to the garage.

Arrangements also were made with the Mn/DOT technical liaison for the GAINS project to meet at the garage on approximately a weekly basis to collect completed surveys, to transfer trip files generated during the week to a backup computer, and to discuss and address any problems with the survey process that may have occurred.

From July through October, 1997, hardware and software problems with GAINS, coupled with periodic lack of availability of the Plymouth van and Lumina fleet vehicles for maintenance and other reasons, resulted in a loss of approximately 6 weeks of survey questionnaire data collection time for both vehicles combined. The pattern of use of these vehicles indicates that Mn/DOT employees generally preferred to make use of GAINS for extended trips outside of the Twin Cities area typically lasting more than one day, presumably because interaction with GAINS benefitted navigation through unfamiliar territory on such trips. As a consequence, only about one completed survey questionnaire per week for each GAINS vehicle was returned. These factors may have contributed, in part, to the relatively low number of completed questionnaires that ultimately were retrieved (below).

2.3.4. In-Vehicle Placement and Viewing Conditions for GAINS Digital Map Display

With the GAINS PCs mounted on the rack mounts in the Plymouth van and Lumina, viewing conditions for the digital map display were as follows: (1) distance from driver eye position to the center of the display was approximately 0.6 meters (m) (2 feet (ft)); (2) center of display was positioned approximately 15 degree (deg) below eye level of the driver; and (3) legibility of the digital map was influenced by time of day, location of vehicle (in sun or shadow), sun conditions, and orientation of vehicle with respect to sun. Dimensions cited in Points 1 and 2 varied somewhat in relation to driver height and head position.

A series of 7 photographs are presented in Appendix B to illustrate various features of in-vehicle placement and viewing conditions for the GAINS digital map display. All photographs illustrate the Libretto 30 PC installed on its stand in the Lumina. The photographs were taken in a Mn/DOT parking lot outside the Mn/DOT Ford building in St. Paul, MN on Nov. 6, 1997 between 8:45 and 9:00 AM on a sunny day. At this date and time at the latitude of St. Paul, the sun was still relatively low in the southeastern sky. The driver shown is Farideh Amiri, Mn/DOT technical liaison for the project at the time (Acknowledgments).

Photographs B-1 and B-2 show the Libretto from viewing perspectives of the passenger seat (Photograph B-1) and over the drivers left shoulder (Photograph B-2). The photographs illustrate placement of the computer and computer mount, the display, the remote control (situated below the computer in Photograph B-1), the GPS receiver (on the dash), and instructions for system use (pages hanging from the computer). During actual system operation, the GPS receiver is mounted on the inside of the windshield on the right side using a suction mount.

Photograph B-3 shows a close-up of the GAINS display from the driver's perspective. Photographs B-4 through B-7 show how the visibility and legibility of the GAINS digital map display varies under sunny conditions in relation to vehicle location (in shade or sun), as well as orientation with respect to the sun. For Photograph B-4, the vehicle was facing west in the shade, with the sun behind and to the left of the vehicle. For Photograph B-5, the vehicle remained in the shade but was facing east, with the sun in front and to the right. For Photograph B-6, the vehicle was in the sun facing northwest, with the sun behind. For Photograph B-7, the vehicle was in the sun facing southeast directly into the sun.

The scanning process that produced the photographs in Appendix B resulted in an appreciable loss of resolution from the original photographs. Nevertheless, the last 4 photographs in Appendix B support the following observations: (1) features of the GAINS display generally are more legible with the vehicle in the shade than in the sun (compare Photographs B-4 and B-5 with Photographs B-6 and B-7); and (2) with the vehicle facing into the sun, glare from the dash may interfere with viewing of the display (compare glare reflection off dash in Photograph B-7 with lack of similar glare in preceding 3 photographs).

2.3.5. On-Road Initialization and Use of GAINS

As a prototype, the system required more computer familiarity on the part of the user for on-road initialization and use than might be the case for a system fully integrated into the vehicle. For example, the remote can be used to actuate system functions during on-road use, but availability of the keyboard (Appendix B, Photograph B-1) may tempt some users to interact with the keyboard (a keyboard typically would not be included with a fully integrated system). Actuation of some functions (such as Points of Interest or Address Location) requires a series of steps, whereas a single control might be used for such functions with a fully integrated system. With the Libretto 30, Windows 95 operating system text information is displayed in Japanese, not English. If the GPS receiver loses contact with the GPS satellite (i.e., vehicle enters underground garage or tunnel), the system must be restarted---this process might be made automatic with a fully integrated system. System initialization after the GPS receiver acquires the satellite signal involves a 2-min delay that may be confusing to the user. If the system stops working or locks up, the user is required to carry out a series of steps using the keyboard to reboot the system---for a fully integrated system the re-initialization process might be simplified.

The difficulties that some of these operations pose for some users is made clear by some of the negative narrative responses cited in Tables 2-1 through 2-6 (Sections 2.4.1 and 2.4.2 below). It is reasonable to suggest that many of these difficulties would be obviated with a fully integrated system.

2.4. SURVEY QUESTIONNAIRE RESULTS

Completed GAINS Project survey questionnaires were collected from Mn/DOT employee respondents over approximately a 4-month period, from July 2, 1997 through Nov. 7, 1997. Over this period, a total of 19 completed questionnaires were collected. This low number is likely attributable, at lease in part, to factors summarized above related to periodic problems with GAINS software and hardware, occasional lack of availability of the fleet vehicles, and the pattern of use of the system for primarily longer-duration trips. Because of missing responses for some questions, some results below are based on N<19 responses.

Among the 19 respondents, 14 (74 pct) are males and 5 (26 pct) are females. Mean age for respondents is 38.7 years, with an age range of 25-47 years (N=18). Fifteen questionnaires were completed by drivers, 4 by passengers.

2.4.1. Responses to Forced Choice Questions Dealing With GAINS Attributes and Usability

Question 12 through 23 in the survey questionnaire (Appendix A) solicit respondent opinions about GAINS using a forced choice scale, with a response of '1' denoting that the respondent strongly disagrees, and that of '5 denoting that the respondent strongly agrees, with the question. Each question solicits respondent opinion about an attribute or usability feature of GAINS. Table 2-1 tabulates individual results for each question. Figures 2-1 through 2-12 are histograms showing the distribution of responses for questions in the series.

The distribution of responses for Questions 12-23 (Figures 2-1 through 2-12) suggest that for all 12 questions responses are mixed, with responses in the full range of '1' to '5' provided for 10 of the 12 questions.

Figures 2-1, 2-2, 2-3, 2-5, and 2-11 illustrate the distribution of responses to five questions that directly address the usability and utility of GAINS. Figure 2-1 shows that most respondents agree with the statement that GAINS is easy to understand (Question 12). Figure 2-4 shows that most respondents disagree with the statement that GAINS interfered with their driving (Question 15). Responses are more mixed to questions dealing with how easy the system is to learn (Figure 2-2; Question 13), whether the system helped in navigation (Figure 2-3; Question 14), and how useful the system is (Figure 2-11; Question 22).

Statistics summarizing responses to the GAINS Project survey questionnaire are in Figures 2-13 and 2-14. Figure 2-13 shows mean and modal data for responses to Questions 12-23 in the survey questionnaire plus two additional questions dealing with computer usage and gender of respondents. Responses to Question 9 dealing with computer usage indicate that 18 of 19 respondents used a computer on a daily basis, with 1 respondent reporting usage 2-3 times a week. These data suggest that any difficulties or concerns that respondents may have had in interacting with and using GAINS likely are not attributable to a general lack of familiarity with computers. Nevertheless, narrative responses to Questions 24 and 27 (Section 2.4.2) indicate that for some users, interaction with the operating features of GAINS hardware and software posed difficulties.

The statistics for Questions 12-23 in Figure 2-13 indicate that results for essentially all of these questions are mixed. In terms of the modal data, Question 21 (dealing with ease of use of the remote control) yielded the most positive responses, and Question 16 (suggesting that the system interfered with driving) yielded the most negative responses. Across Questions 12-23, mean response levels range from 2.4 to 3.8 and appear to be clustered at or near a response level of 3, a neutral response on the forced choice scale of 1 to 5.

Figure 2-14 shows cumulative statistics for responses to Questions 12-23 in the GAINS Project survey questionnaire. Across all 12 questions combined, the most frequent response is '4' (agree), followed in descending order of frequency by responses of '3' (neutral), '2' (disagree), '1' (strongly disagree), and '5' (strongly agree).

The summary statistics reported in Figures 2-13 and 2-14, and distributions for responses to individual Questions 12 through 23 reported in Figures 2-1 through 2-12, indicate that no attribute of GAINS addressed by these questions attracted the uniform approval or disapproval of most or all respondents. Not surprisingly therefore, chi-squared analysis of distributions of responses to each of the Questions 12-23 reveals no significantly disproportionate response distribution for any question ($p>.05$ for distribution of responses to each question).

Next to Questions 12-23 on some questionnaires, respondents included written comments along with their forced-choice responses to these questions, presumably to try and explain reasons for responses selected. These comments are summarized in Table 2-2. Some comments are paraphrased (brackets) to aid understanding. Some of the implications of the comments in Table 2-2 for understanding strengths and weaknesses of IVNS technology generally are discussed in Section 5.1.1.

2.4.2. Responses to Narrative Questions

Questions 24-28 in the survey questionnaire (Appendix A) ask respondents to enter narrative responses about possible strengths, weaknesses, and utility of the system. Tables 2-3 through 2-7, respectively, tabulate the responses to each of these questions noted on the questionnaires returned. In each table, responses are ordered by respondent number. As in Table 2-2, some comments in Tables 2-3 through 2-7 are paraphrased (indicated by brackets) to aid understanding. Some of the implications of the comments in Tables 2-2 through 2-7 for understanding strengths and weaknesses of IVNS technology generally are discussed in Sections 4.1 and 5.1.1.

Table 2-1. Individual responses to selected questions in survey questionnaire administered to on-road driving respondents. Refer to Appendix A for content of each question. For questions 12-23 (last 12 columns of table), a '1' response indicates a 'Strongly Disagree' opinion, and a '5' response indicating a 'Strongly Agree' opinion, for the question specified. The 2nd and 3rd columns of the table, respectively, list responses to questions dealing with computer usage (1=use computer daily; 2= use computer 2-3 times a week) and gender (M=male; F=female) of respondents.

Survey Respondent #	Question #9 Response	Question #11 Response	Question #12 Response	Question #13 Response	Question #14 Response	Question #15 Response	Question #16 Response	Question #17 Response	Question #18 Response	Question #19 Response	Question #20 Response	Question #21 Response	Question #22 Response	Question #23 Response
1	1	M	4	3	4	3	2	4	4	4	4	3	4	4
2	1	M	4	2	2	4	1	5	5	1	5	5	4	3
3	1	M	4	3	5	5	1	4	4	4	4	5	5	4
4	1	M	3	3	2	4	2	4	4	4	4	4	3	2
5	1	F	3	4	1	2		1	5	4	3	5	1	1
6	1	M	1	1	1	1	2						1	
7	1	M	3	3	3	3	2	3	2	3	3	4	3	3
8	1	M	4	4	4	4	4	4	3	4	4	4	4	4
9	1	F	4	4	3	2	4	1	1	3	3	4	3	4
10	1	M	2	2	2	4	1	3	4	3	5		2	4
11	1	M	4	5	3	4	1	5	5	4	5	5	4	4
12	1	F	4	5	4	3		3	2	3	4	4	3	2
13	1	M	3	4	4	4	2	2	2	4	4	3	5	2
14	1	M	2	3	2	2	4	1	1	2	1	2	2	4
15	2	M	4	5	5	5	2	4	4	4	3	5	5	5
16	1	M	2	3	1	2	5	1	4	4	5		1	1
17	1	F	4	4	4	4		3	3	3	2	3	4	3
18	1	M	4	3	1	1	1	4	4	1	4	1	1	1
19	1				2		4						2	
Mean Response			3.28	3.39	2.79	3.17	2.38	3.06	3.35	3.24	3.71	3.80	3.00	3.00

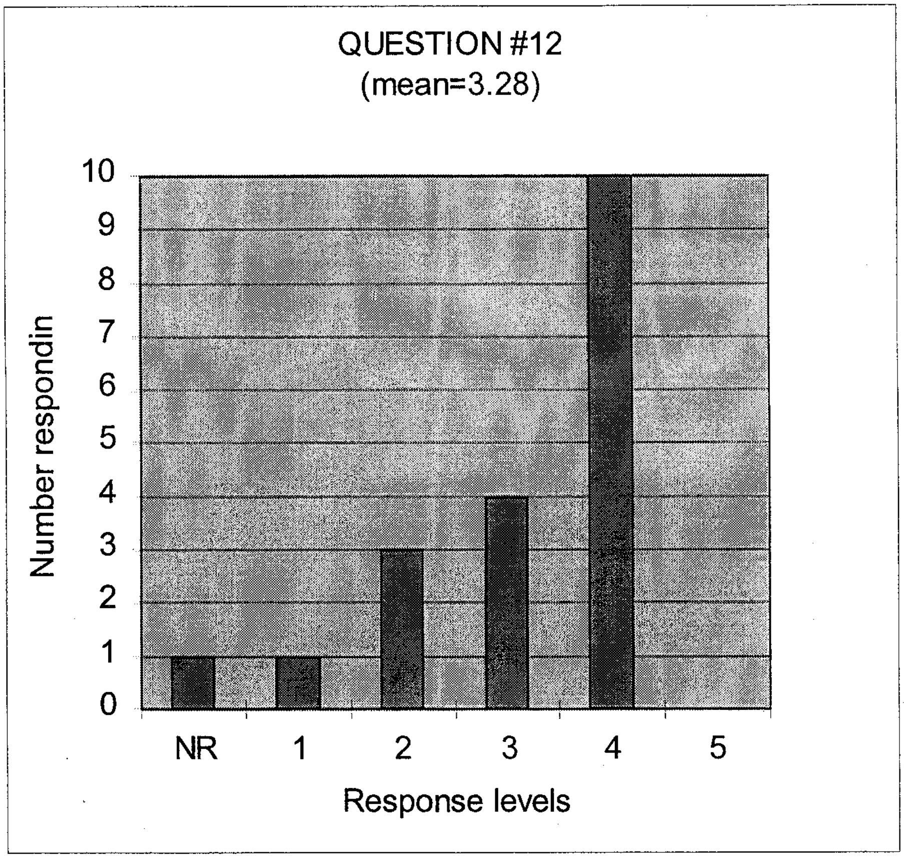


Figure 2-1. Distribution of responses to Question 12 in survey questionnaire administered to on-road driving respondents - 'The system is easy to understand' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

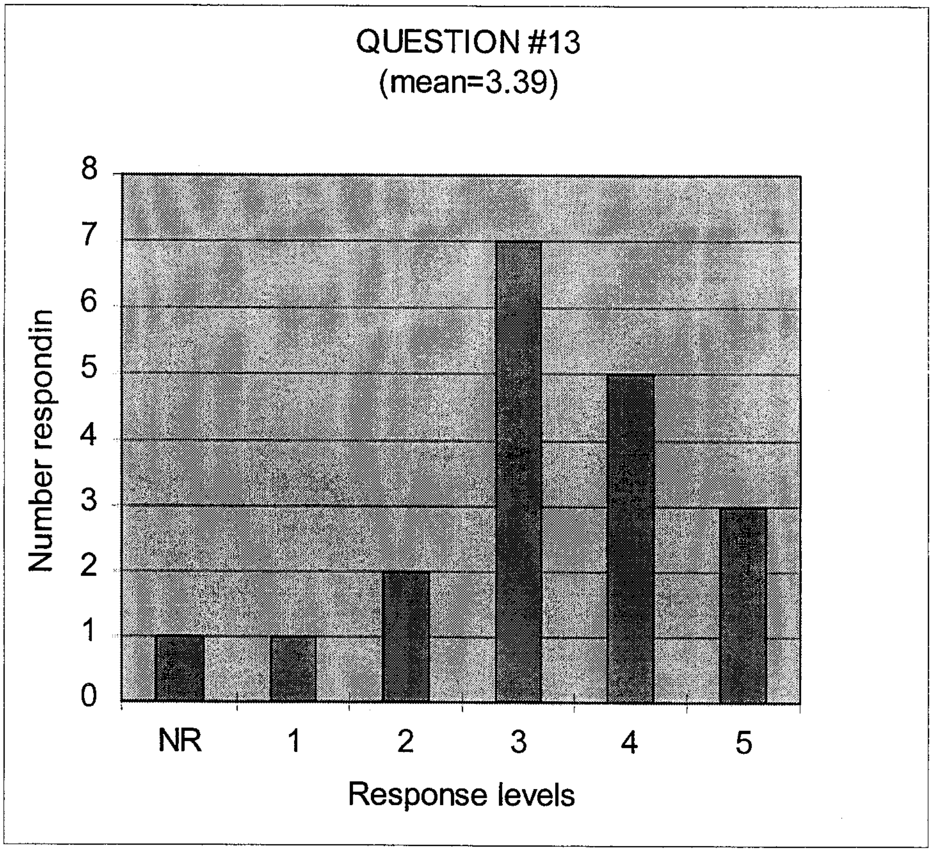


Figure 2-2. Distribution of responses to Question 13 in survey questionnaire administered to on-road driving respondents - 'The system is easy to learn' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

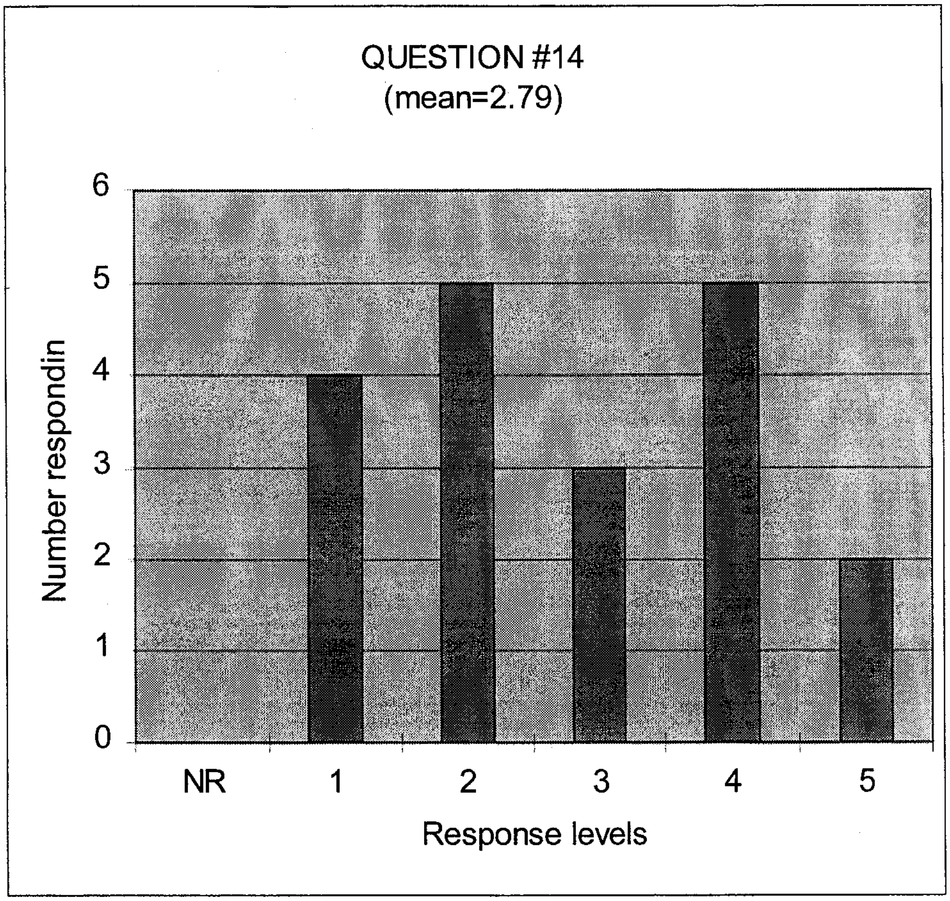


Figure 2-3. Distribution of responses to Question 14 in survey questionnaire administered to on-road driving respondents - 'The system helped me find my way' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

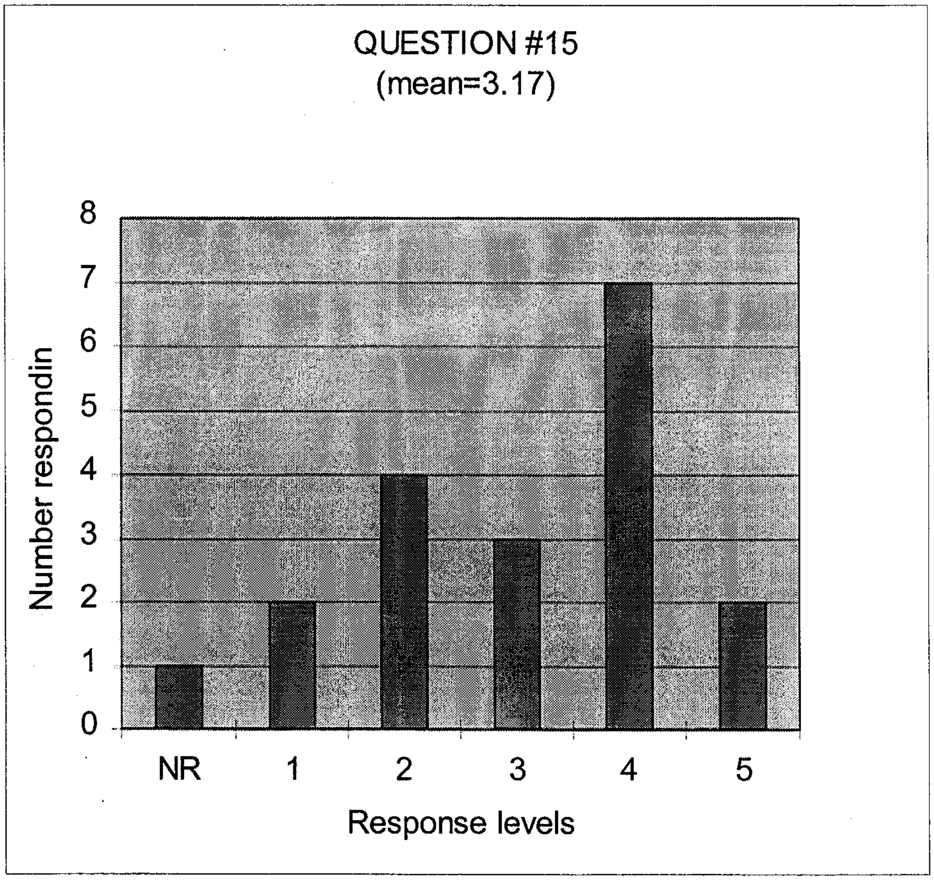


Figure 2-4. Distribution of responses to Question 15 in survey questionnaire administered to on-road driving respondents - 'The system functioned properly' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

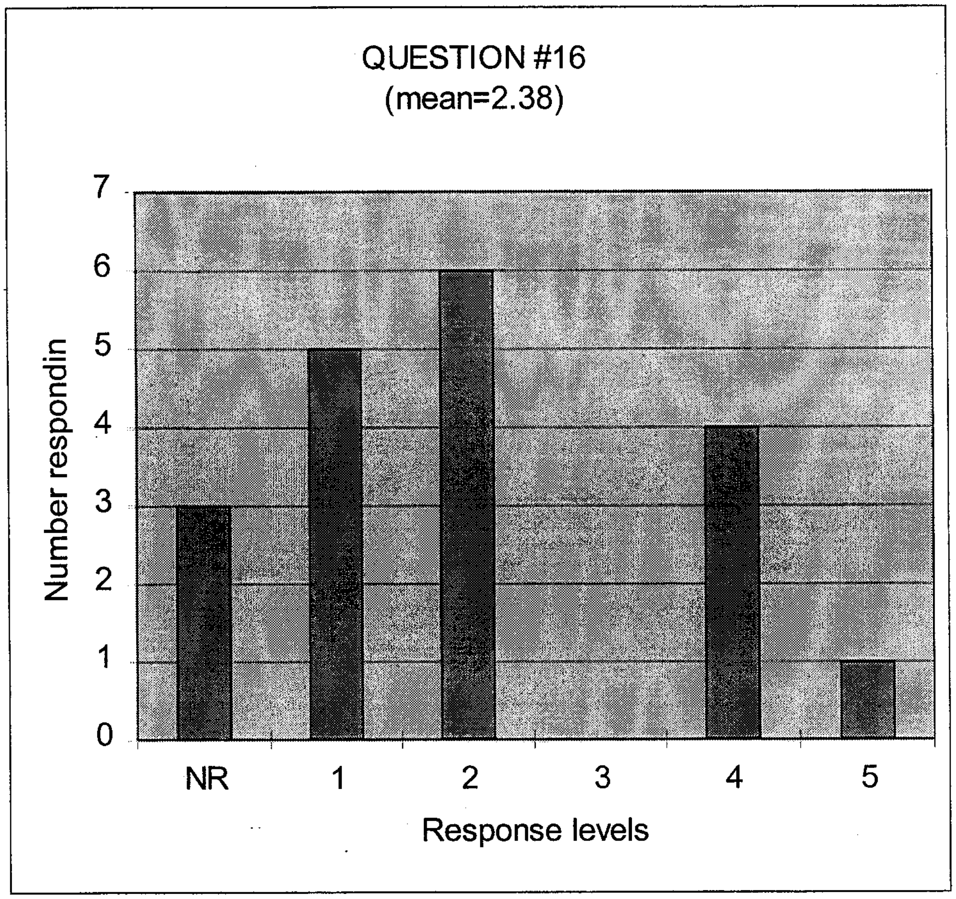


Figure 2-5. Distribution of responses to Question 16 in survey questionnaire administered to on-road driving respondents - 'The system interfered with my driving' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

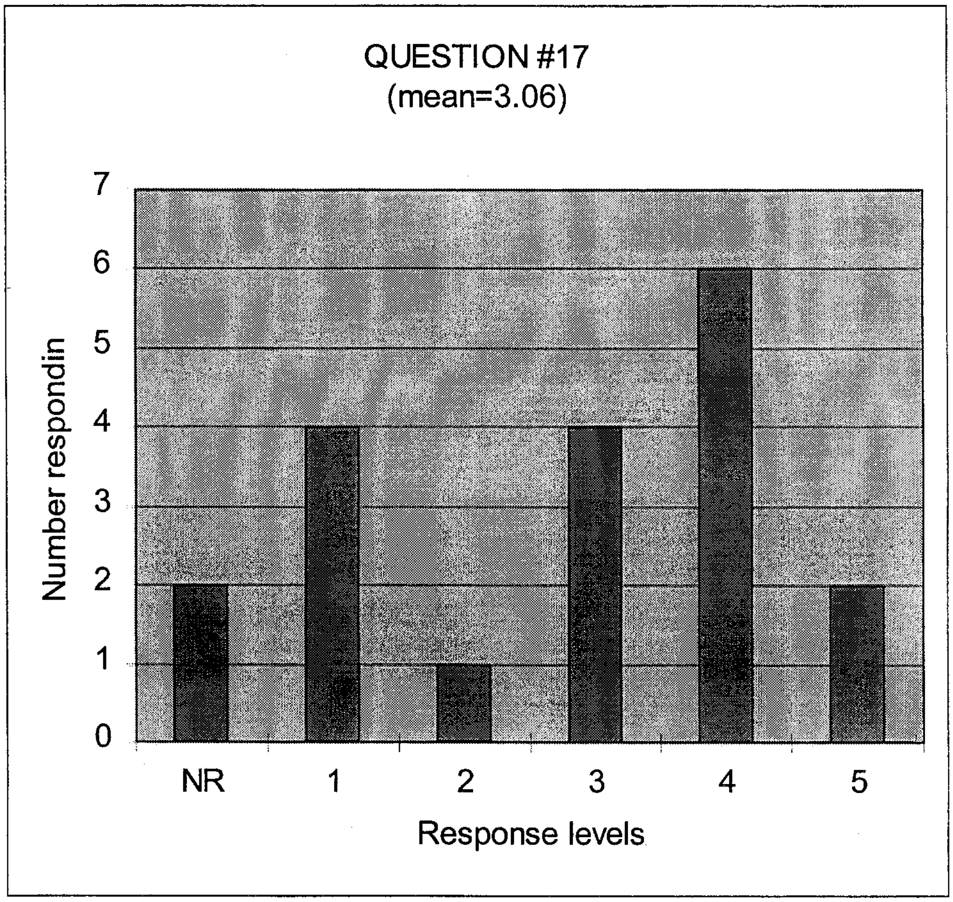


Figure 2-6. Distribution of responses to Question 17 in survey questionnaire administered to on-road driving respondents - 'It was easy to see the display' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

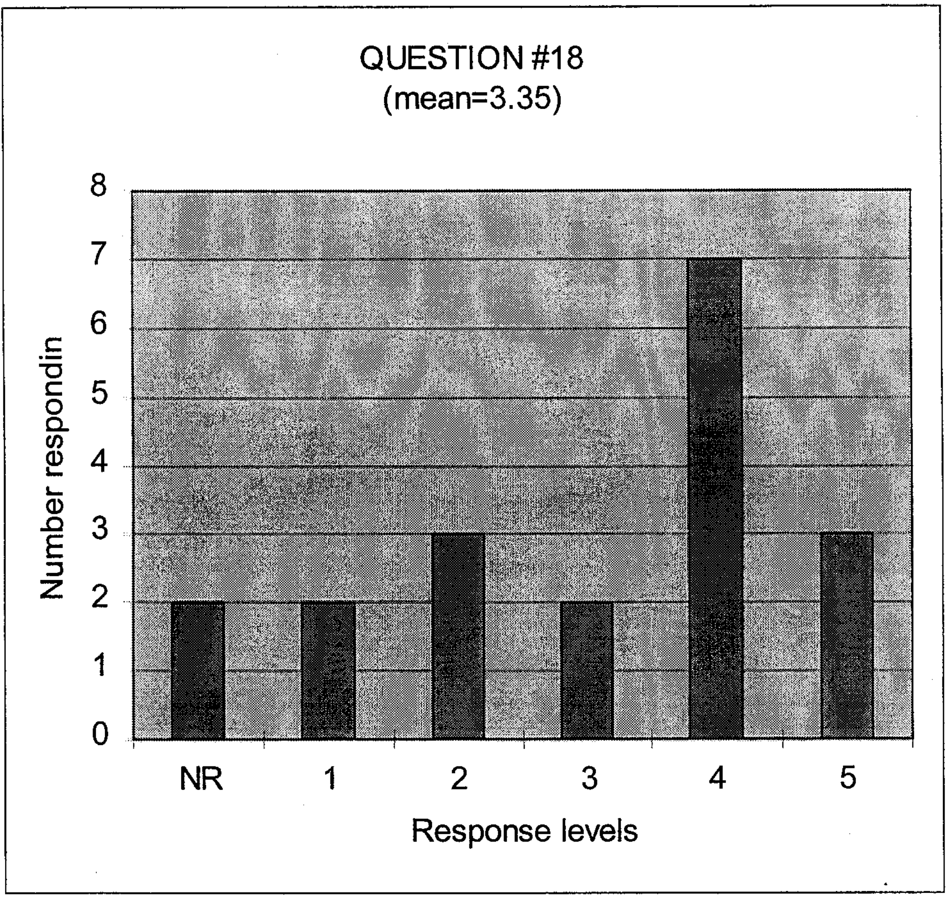


Figure 2-7. Distribution of responses to Question 18 in survey questionnaire administered to on-road driving respondents - 'The display was easy to read' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

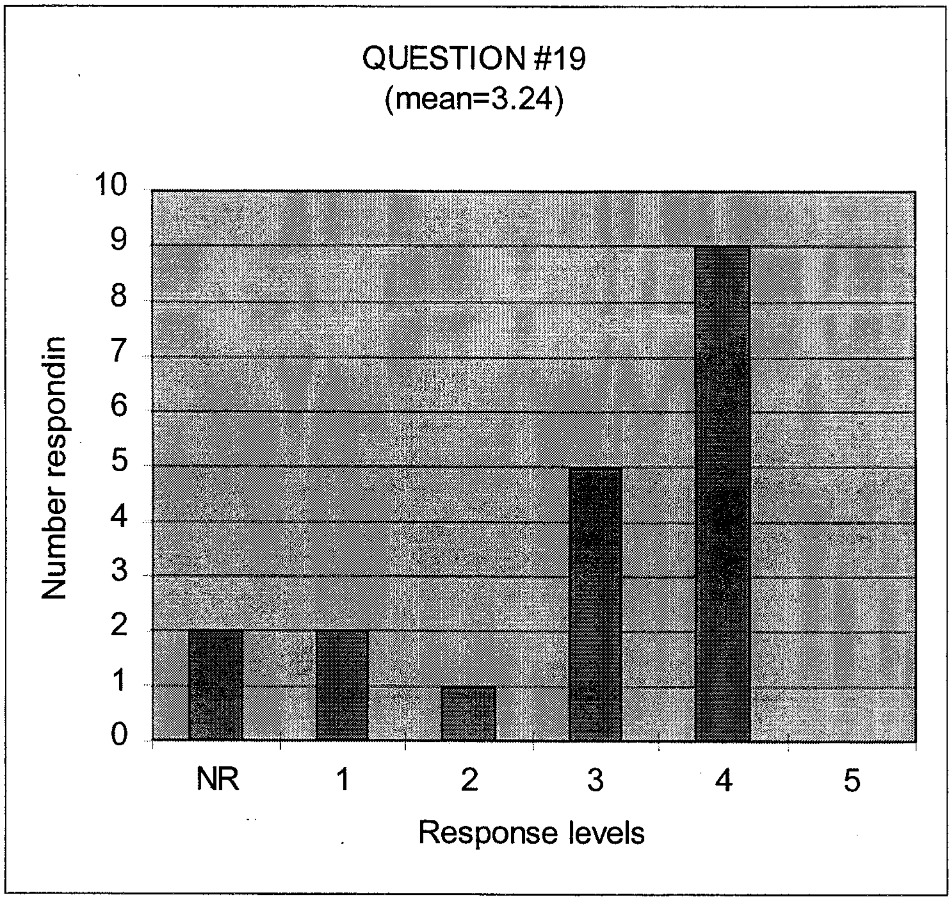


Figure 2-8. Distribution of responses to Question 19 in survey questionnaire administered to on-road driving respondents - 'It was easy to understand the information presented' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

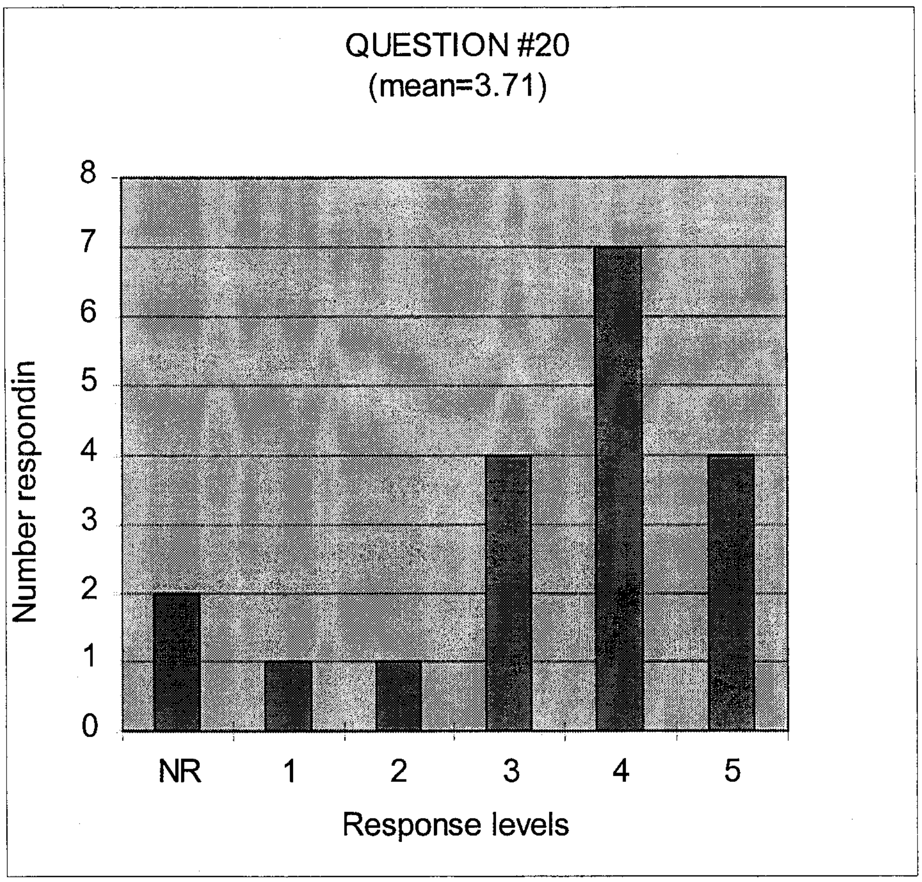


Figure 2-9. Distribution of responses to Question 20 in survey questionnaire administered to on-road driving respondents - 'I like the display colors' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

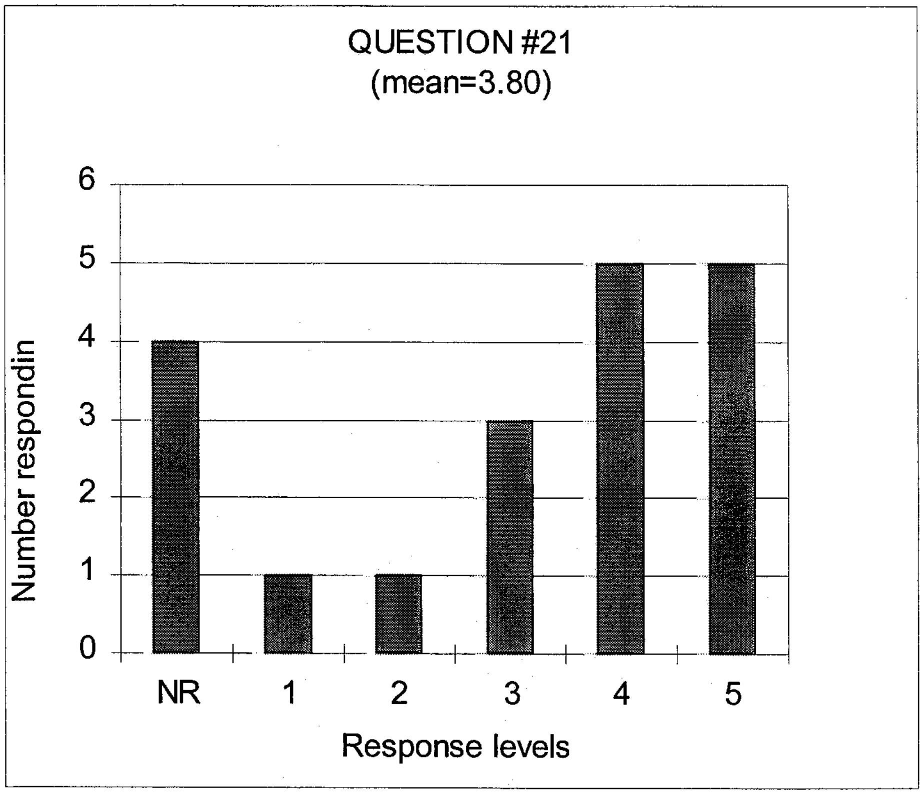


Figure 2-10. Distribution of responses to Question 21 in survey questionnaire administered to on-road driving respondents - 'The remote control was easy to use' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

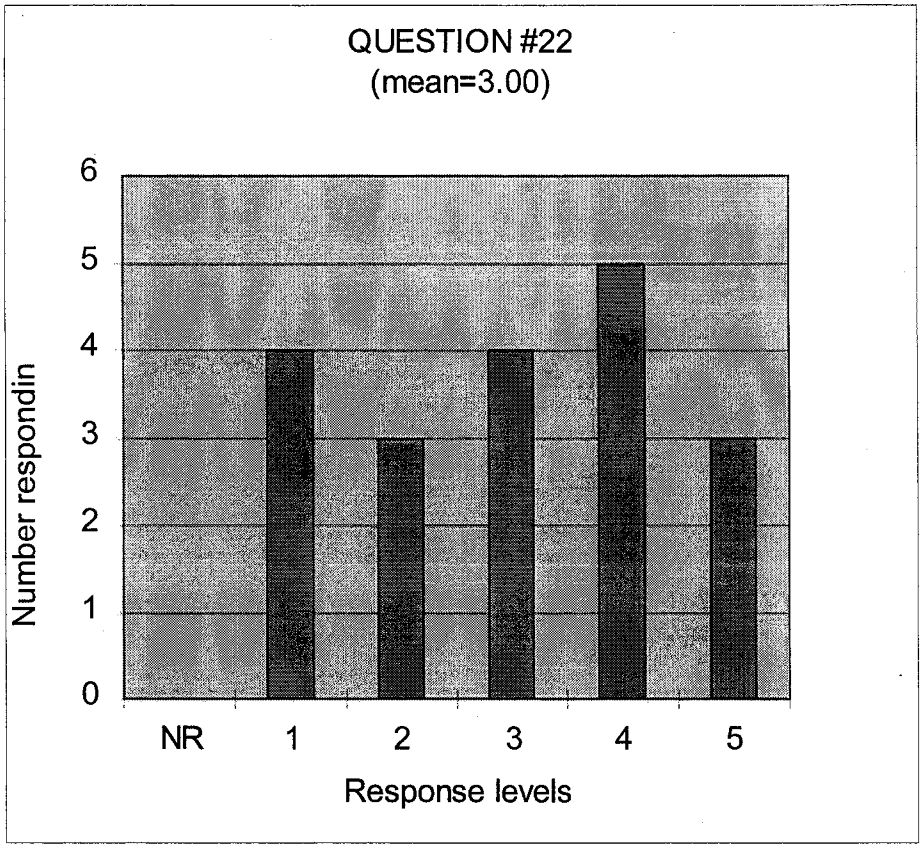


Figure 2-11. Distribution of responses to Question 22 in survey questionnaire administered to on-road driving respondents - 'I found the system useful' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).

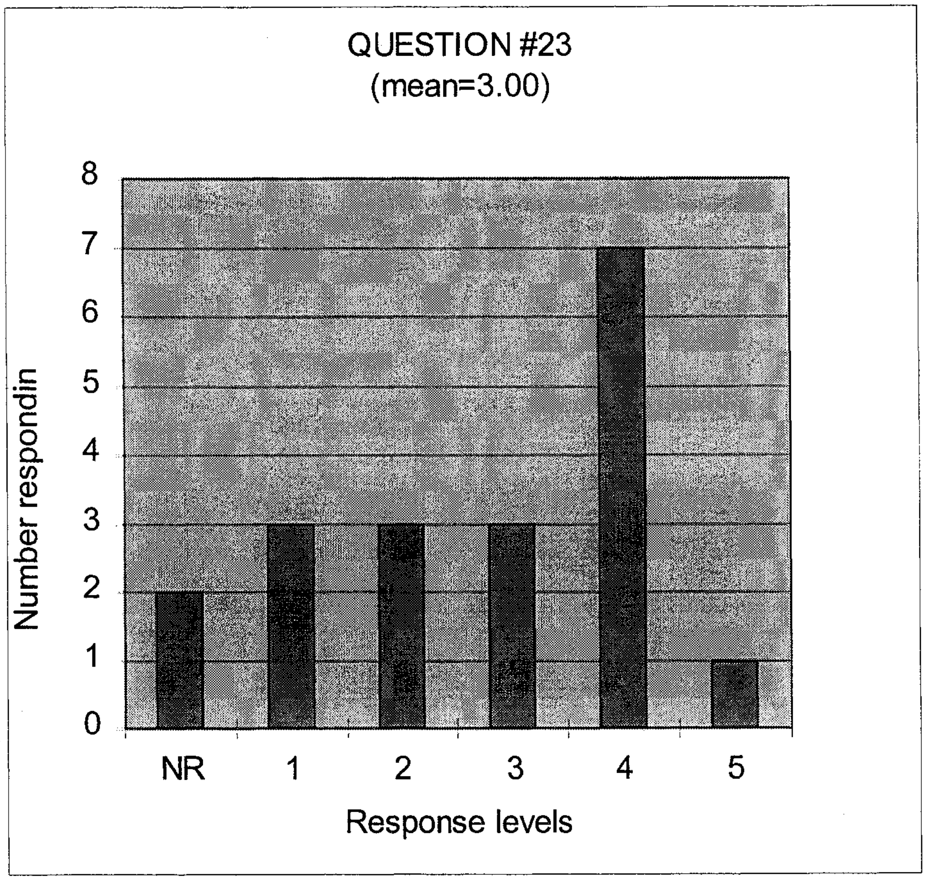
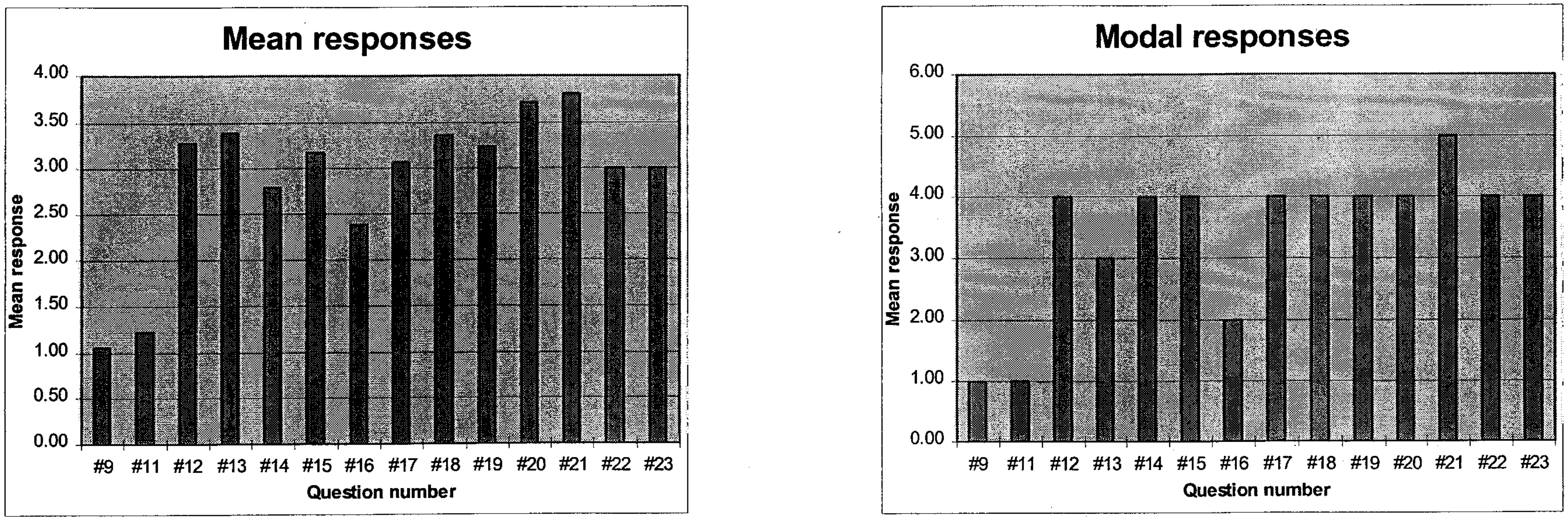


Figure 2-12. Distribution of responses to Question 23 in survey questionnaire administered to on-road driving respondents - 'The electronic map is accurate and complete' (1=Strongly Disagree; 5=Strongly Agree; NR=No Response).



	#9	*#11*	*#12*	*#13*	*#14*	*#15*	*#16*	*#17*	*#18*	*#19*	*#20*	*#21*	*#22*	*#23*
Mean	**1.05**	**1.22**	**3.28**	**3.39**	**2.79**	**3.17**	**2.38**	**3.06**	**3.35**	**3.24**	**3.71**	**3.80**	**3.00**	**3.00**
Mode	**1.00**	**1.00**	**4.00**	**3.00**	**4.00**	**4.00**	**2.00**	**4.00**	**4.00**	**4.00**	**4.00**	**5.00**	**4.00**	**4.00**
Standard Deviation	**0.23**	**0.43**	**0.96**	**1.09**	**1.36**	**1.25**	**1.36**	**1.39**	**1.32**	**1.03**	**1.10**	**1.21**	**1.41**	**1.27**
Count	**19.00**	**18.00**	**18.00**	**18.00**	**19.00**	**18.00**	**16.00**	**17.00**	**17.00**	**17.00**	**17.00**	**15.00**	**19.00**	**17.00**

Figure 2-13. Mean and modal responses to selected questions in survey questionnaire administered to on-road driving respondents. Questions 12-23 (specified in table and histograms) on the questionnaire solicit respondent opinions about various features of GAINS on a forced choice scale, with a '1' response indicating a 'Strongly Disagree' opinion, and a '5' response indicating a 'Strongly Agree' opinion, on each question (Y axes on histograms). Statistics in the table are based on pooled responses across all respondents for each question. Refer to Appendix A for content of each question.

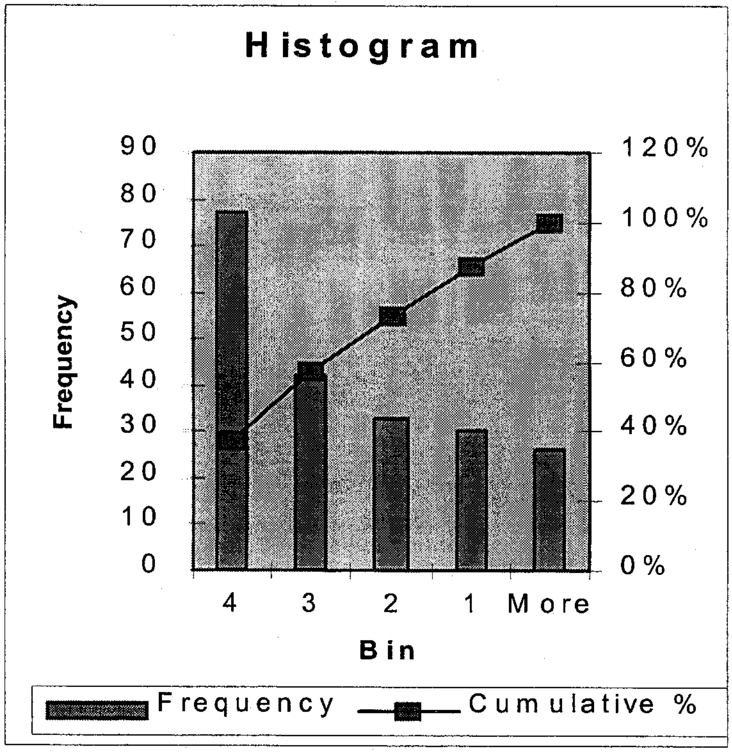


Figure 2-14. Cumulative distribution of responses to Questions 12-23 in survey questionnaire administered to on-road driving respondents. These questions solicit respondent opinions about various features of GAINS on a forced choice scale, with a '1' response indicating a 'Strongly Disagree' opinion, and a '5' response indicating a 'Strongly Agree' opinion, on each question. The legend 'more' refers to the '5' response. Refer to Appendix A for content of each question.

Table 2-2. Comments written by on-road driving respondents to accompany forced-choice responses to Questions 12-23 in survey questionnaire.

Comment	Survey Question	Accompanying Written Comment
1	12. The system is easy to understand.	- Some of the menus did not clearly tell me what I was looking for.
2	14. The system helped me find my way.	- Information incomplete.
3	15. The system functioned properly.	- Have to make sure GPS is fully attached.
4	16. The system interfered with my driving.	- Came close to having an accident while looking at the display.
5	17. It was easy to see the display.	- [Not] in sun, but inside yes.
6	18. The display was easy to read.	- Some of the data [used] very small fonts (speed, etc.)
7	21. The remote control was easy to use.	- I had to use the remote, the mouse and the keys to make everything work.
8	22. I found the system useful.	- [The system] showed me a good route!
9	23. The electronic map is accurate and complete.	- Map did not have [locator for] Mankato [MN] City Hall, which was my destination.
10	23. The electronic map is accurate and complete.	- Database did not include at least one interchange built within the past 2 years.

Table 2-3. Narrative responses to Question 24 in survey questionnaire administered to on-road driving respondents - 'What kind of technical problems, if any, did you experience?'

Respondent	Narrative Response to Question
1	It seemed to take several minutes for the system to locate the car.
2	Locator missing the location by up to 1/4 mile at times.
3	None.
4	Instructions are inaccurate and in the wrong order.
5	Getting [system to] resume once car was shut off and started again.
6	Figuring out how to use the mouse.
7	Screen a bit difficult to read easily on sunny days.
8	Directions somewhat vague. Map not detailed enough in [St. Paul] capital area.
9	Remote could not be used.
10	Screen washes out in sun.
11	System unexpectedly lost power in my private vehicle - could be [that] my lighter socket is the problem.
12	System didn't generate points of interest for Rochester [MN] area.
13	GPS not easy to boot.
14	Addresses incomplete; map inaccurate.
15	Was not able to get the system to work. It jammed up.
17	I couldn't understand the start-up instructions. While the format is excellent, the content needs to be simpler to understand. What does 'select' mean?
18	The location of the vehicle was sometimes shown to be a block or so away from its actual location. That would be difficult if [the system] was being used to find the right direction in a very tightly packed metro area. Is the GPS accurate?
19	Not booting up. Locking up.

Table 2-4. Narrative responses to Question 25 in survey questionnaire administered to on-road driving respondents - 'What did you use the system for today?'

Responses to this question are grouped below into 'route finding' and 'finding points of interest' categories.

	Route Finding					
Respondent	Destination Not Specified	Destination Outside of Twin Cities	Destination in Twin Cities Area	Finding Points of Interest	General Travel Info	Additional Comments
1		✓				[System] did not find my address in Mankato
2	✓			✓		
3		✓				
4		✓				
5	✓			✓	✓	
7	✓					
9	✓					
10		✓				
11	✓					
12	✓			✓		
16	✓					
17	✓					I couldn't get Points of Interest to work.
18	✓					
19	✓					

Table 2-5. Narrative responses to Question 26 in survey questionnaire administered to on-road driving respondents - 'Overall, what did you like about the system?'

Respondent	Narrative Response to Question
1	It gave a good route and accurately showed my location. Made looking for turns much easier.
2	Global positioning capability and address/location search.
3	It was extremely accurate as to where you were on the map. I really like the ability to see yourself on the map.
4	Colors. Updating of movement.
5	Interesting [system] - good source of information.
6	Accuracy of display.
7	Points of interest - food stops by type. Ability to zoom in and out. The remote works very well. Easy to use buttons. Takes up little space.
10	It is a good navigation tool.
11	Ease of use, location tracking, ease of finding locations for the 1st time.
12	Showed where I was on a very readable map, and what [destination] I was about to reach.
13	[System] told where located on map.
16	Being able to find my way around.
17	I think it could be an excellent tool, particularly for employees like me who travel widely in areas with which we are not too familiar.
18	Clear map.
19	Address location feature. Location of where [vehicle is] at.

Table 2-6. Narrative responses to Question 27 in survey questionnaire administered to on-road driving respondents - 'Overall, what did you dislike about the system?'

Respondent	Narrative Response to Question
1	[System] needs to mounted in car. Remote needs to control all functions needed for navigation.
2	Too clumsy in present configuration. Too many [hardware] pieces to connect.
3	System is not very accurate when you enter downtown St. Paul.
4	Couldn't find me a Dairy Queen. Too small monitor. Directions didn't work well. Route from St. Cloud to St. Paul not the best. Gave me option to print but...no printer to print directions.
5	Hard to see display. Keyboard too small to use effectively. Poor mounting.
6	Screen updating. Change display to English.
7	Can be difficult to read small screen on bright day.
8	Mapped area too small
9	Clicking on 'start' location could only be done from overview map. There were too many highways to click accurately without zooming in.
10	Screen washes out in sun. Screen too small [and] has to update rapidly. Does not leave a bread crumb trail. Color of dot that shows you where you are at blends in with color of the road [and is] hard to see.
11	Small keyboard. Limited to plotting a path in only the 'overview' map.
12	Drop down menus - especially if using in a car. Should be icons to point and click on.
14	Old outdated information - not all points of interest included [and] not all addresses/streets included. [System] gave you 2 addresses for some locations but only 1 could be right.
16	The map was inaccurate in several locations. Very difficult to see during the day.
17	The instructions need some revision. Have someone like me ([who] uses computer but doesn't understand them) review the written instructions to make them more understandable.
18	Showed vehicle one or two blocks from actual location sometimes. Did not really show which direction front of vehicle is pointing.
19	Impossible to read with sunglasses on. Entering info difficult (especially if driver) & dangerous.

Table 2-7. Narrative responses to Question 28 in survey questionnaire administered to on-road driving respondents - 'Do you have any suggestions for overall system improvement?'

Respondent	Narrative Response to Question
1	Make remote function better. Make sure map is accurate at the city street level.
2	Need a self-contained package - preferably installed conveniently in vehicle. System needs to come up automatically when vehicle is started.
3	Enter Mn/DOT sites/offices on the map.
4	Check instructions - specifically page order and menu paths referenced.
5	Mount differently in car.
6	Change display to English. Set screen updating at a greater time interval.
7	Voice follow along [option]. Larger screen. Can screen be separate from keyboard---would that help place larger screen in car?
8	Blow up [map area] for more detail. Cursor to show 'where am I.'
9	If [system] was permanently mounted with buttons specifically for use in a navigation system, it would be much more user friendly and then would be beneficial. What was GPS used for? The system didn't track our location. We shouldn't have to enter starting point.
10	To me it seems to be a superior product because features and detail [are] down to street level, not just major roads.
11	See [dislikes - Table 2-5, Respondent 12]. Build [system] into dash. Address to address path plotting. [Include] traffic congestion information.
12	[Eliminate] drop down menus - especially if using in a car. Should be icons to point and click on.
13	Update map info - information too limited.
14	It seems that this [system] is too cumbersome. [System] would probably be too expensive for the average person.
15	Could not get system to unjam. Would have loved to use it.
16	System needs to be integrated into car.
17	[I couldn't get Points of Interest to work] - it could be there are no points of interest in the system for the area I was in. If so, a message should pop up to say 'no points of interest available,' or something similar.
18	The device should have a large 'choice of orientation' button for 'direction' of vehicle or 'north' - at top of screen (would help showing when to turn and which way - usually more important to know quickly which way is north or south, etc.).
19	Different screen and screen location. More complete database.

CHAPTER 3

EVALUATION OF DRIVER INTERACTION WITH GAINS DURING SIMULATED DRIVING - METHODS AND RESULTS

3.1 INTRODUCTION

The simulation testing phase of the project work plan (project work plan Tasks 3, 4, and 5) calls for use of the HFRL fixed-base driving simulator to evaluate possible effects on driving performance of driver interaction with GAINS during simulated driving. This chapter describes the approach, method, and results for this phase of the project. An interim report describing progress in completing Tasks 3, 4, and 5 of the project work plan was submitted to Mn/DOT [2]. Sections below deal with development of a simulated driving environment (project work plan Task 4), interfacing GAINS with the SGI Onyx computer (project work plan Task 5), experimental design, protocol and Ss (project work plan Task 3), and results (project work plan Task 7) for the simulation testing research.

3.2. DEVELOPMENT AND IMPLEMENTATION OF SIMULATED DRIVING ENVIRONMENT

The objective of the simulation testing phase of the project is to evaluate driver interaction with GAINS under simulated driving conditions, in order to assess how such interaction might influence driving performance. The experimental approach developed to achieve this objective involves evaluating different measures of driving performance when Ss are required to drive through a simulated driving environment with (test condition) or without (control condition) having to interact with GAINS for navigation purposes (Section 3.4). In order to implement this approach, two methodological hurdles had to be overcome: (1) developing a simulated driving environment to be used for S testing; and (2) interfacing GAINS with the HFRL driving simulator computer, so that Ss would be presented with a digital map showing the position of their vehicle as they navigated through the simulated driving environment. This section describes the approach used to develop and implement the simulated driving environment. The next section describes the approach used to interface GAINS with the driving simulator computer. Once these methodological stages have been described, the experimental design, protocol and Ss for the study will be delineated (Section 3.4).

Developing and implementing a simulated driving environment involved the following stages: (1) selection of desired environment to model; (2) specification of layout and dimensions for selected environment; (3) software development to model specified environment, using an SGI Onyx computer with an SGI Reality Engine 2 graphics board to generate visual environment for HFRL fixed-based wrap around driving simulator; and (4) addition of ancillary features to software model to create a simulated driving environment acceptable for navigation purposes. Each of these stages is described in subsections below.

3.2.1. Selection of Driving Environment for Simulation Modeling

Two basic considerations governed selection of a driving environment acceptable for simulation modeling: (1) the environment selected should present a reasonably rigorous challenge for driving navigation purposes---that is, under the test condition, directional navigation through the environment should be difficult enough so that Ss must rely on interaction with GAINS in order to monitor current position and the route that must be taken to reach the desired goal; and (2) it must be possible to either calculate or retrieve GPS coordinates for the streets and intersections modeled in the specified environment, so that GAINS can be interfaced with the driving simulator computer to update position of the vehicle in real time as Ss drive through the simulated environment (Section 3.3).

It was decided that a maze-like navigation task, utilizing a maze route laid out within a grid of streets and intersections with known GPS coordinates, would satisfy both of these criteria. Two alternative approaches were considered for developing a simulated driving environment within which a maze-like navigation task could be implemented.

The first approach envisioned an imaginary driving environment, comprising three embedded concentric circles of streets centered upon the North Pole, with radial streets (spokes) connecting the circles. GPS coordinates for this kind of design are readily calculated for specified circle circumferences and radial street latitudes. However, it was determined that generating a digital map of this imaginary environment that could be displayed on GAINS would not be feasible, and this approach was abandoned.

Based on a suggestion by Larry Sweeney of Etak, the second approach considered was to identify a grid of streets for which an Etak digital map already exists, for which street and intersection GPS coordinates therefore were available, and within which a navigation maze could be established. Fortunately, it was possible to identify a highly regular North-South (N-S) and East-West (E-W) grid of streets in the southwest quadrant of the city of Minneapolis that satisfied all of these criteria, and the decision was made to model this grid for the simulated driving phase of the study.

Appendix C shows a map of the southeast quadrant of Minneapolis containing the street grid selected for the study. The grid is bounded by Dupont Avenue (running N-S) on the west, 28th Street (running E-W) on the north, 42nd Avenue (running N-S) on the east, and 58th Street (running E-W) on the south. Only a subset of all of the streets in this grid are used to establish the simulation model. In particular: (1) the N-S streets selected for modeling (from W to E) are Dupont Ave., I-35W, and Chicago, Cedar, 28th, and 42nd Avenues; and (2) the E-W streets selected for modeling (from N to S) are 28th, 35th, 39th, 42nd, 48th, and 58th Streets. The black spots on the map in Appendix C designate intersections for all of the E-W and N-S streets specified.

It is evident from the map in Appendix C that, although the grid appears to be highly regular, there are discontinuities in some of the streets specified for the grid. In particular, Hiawatha Avenue introduces an E-W discontinuity in 28th Street, and N-S discontinuities in 28th and 42nd Avenues. Diamond Lake introduces an E-W discontinuity in 58th Street. In addition, there are two noticeable departures from the highly regular N-S and E-W pattern of the grid: (1) I-35W bends to the northeast shortly before it intersects 28th Street; and (2) 58th Street bends to the northeast to follow the contour of I494 shortly before it intersects 42nd Avenue. In the simulation model for the grid (next subsection), it is assumed that these discontinuities and irregularities do not exist. Ss were instructed (Section 3.4): (1) to disregard the GAINS digital map display if their simulated street route takes them across a portion of the map where there is no street on the GAINS map corresponding to the vehicle position icon; and (2) that under these circumstances, if they continue driving on the simulated street, the vehicle position icon would soon reorient itself over a street shown on the digital map display.

3.2.2. Specification of Layout and Dimensions for Street Grid Simulation Model

Appendix D contains a schematic diagram of the street grid selected for simulation modeling, abstracted from the map shown in Appendix C. For modeling purposes, as described in the previous subsection, all of the discontinuities and irregularities that exist in the actual map grid have been eliminated in this schematic grid. Also included in Appendix D are instructions for creating a simulation model for the grid, along with a table of distances for each of the grid street segments labeled on the schematic map. The grid comprises 26 E-W street segments, 26 N-S street segments, and 32 intersections.

To determine distances for the grid street segments labeled on the schematic map in Appendix D, two street maps covering the geographic area in question were obtained from the Mn/DOT Engineering Services Division (maps for Sections 3D and 3E of the Mn/DOT St. Paul-Minneapolis Seven County Area map series; 1 inch (in) to 2000 ft scale). Division staff noted that these maps were generated using GPS data accurate to approximately 12 m. A millimeter (mm) ruler was used to measure distances of each street grid segment (labeled on the map in Appendix D) to the nearest 0.5 mm. Street segment distances in feet shown in the table in Appendix D then were calculated using the 1 in/2000 ft conversion scale. A measurement error of ±0.25 mm equates to a calculated street segment distance error of approximately ±6 m. Combined with the GPS error of approximately ±12 m, each street grid segment distance has an approximate error of ±18 m.

As indicated by the maps in Appendices C and D, the grid selected for modeling is highly regular in terms of both layout and rectilinear distances. The Mn/DOT maps show that the grid streets are very close to true N-S and E-W alignment. The street segment distances tabulated in Appendix D show that the total E-W distance across the grid is invariant at 6,351 m (20,823 ft; 3.94 miles (mi)), along 28th Street on the north edge and 58th Street on the south edge, whereas the total N-S distance across the grid differs by 71.7 m (235 ft), from 5,980 m (19,608 ft; 3.71 mi) along Dupont Avenue on the west edge to 5,909 m (19,373 ft; 3.67 mi) along 42nd Avenue on the east edge.

The total distance of all of the N-S and E-W grid street segments specified on the schematic map in Appendix D is 67,530 m (221,411 ft; 41.93 mi). The shortest segments (Appendix D map, segments NS-8, NS-12, NS-16, and NS-21A) are 598 m (1,961 ft; 0.37 mi); the longest segments (Appendix D map, segments EW-3 and EW-24) are 2,165 m (7,098 ft; 1.34 mi).

3.2.3. Generating Simulation Model of Specified Street Grid

An SGI Onyx computer with a Reality Engine 2 graphics board, that generates the visual environment for the HFRL fixed-base wrap around driving simulator (Appendix I), was used to model the street grid shown on the maps in Appendices C and D. Programming was carried out by Peter Easterlund using MEDIT software, a three-dimensional (3D) modeling platform designed primarily for use with SGI systems. All streets in the grid are modeled as 2-way streets using standard dimensions for such streets in the state of Minnesota, namely 3.6 m lane widths and 2 m shoulder widths, with a solid white line separating the two lanes. The grid is modeled as a flat driving environment, with no elevation changes. All streets in the grid model are laid out along true N-S and E-W axes; any deviations from these axes in the actual grid (Appendix D) were ignored for purposes of developing the model.

3.2.4. Ancillary Features of Simulated Driving Environment

Once the simulation model of the specified street grid had been developed, stops signs were modeled at each intersection for each converging lane, and a 60 mi/hour (hr) (mph) speed limit signs was modeled just off the shoulder of the right lane at a distance of 213.5 m (700 ft) beyond each intersection. In order to provide an anticipatory cue to Ss driving through the simulated environment that an intersection is upcoming: (1) the simulated elevation level of 'gravel' adjacent to the street shoulders is reduced below the level of the street on each side for a simulated distance of 91.5 m (300 ft) prior to each intersection; and (2) a simulated intersection warning sign (yellow diamond-shaped sign with black intersection cross) is placed at a simulated distance of 305 m (1000 ft) before each intersection adjacent to the right-hand street shoulder. Street name signs also are modeled at each intersection, to help Ss relate the simulated environment to the map display. Standard shapes, dimensions, colors, and placements for these signs, using Mn/DOT criteria, are employed in the model.

As described in Section 3.4.2.2., to implement the navigation mazes employed in the simulated driving tasks, some street segments between selected intersections are removed from the grid model to prevent access by Ss to these segments.

3.3. INTERFACING GAINS WITH HFRL DRIVING SIMULATOR COMPUTER

For a driver to be able to interact with GAINS while driving through the simulated driving environment, it was necessary to interface GAINS with the SGI Onyx computer that serves as the simulation engine for the HFRL driving simulator, so that movement of the vehicle through the simulated environment could be displayed on the digital map of the environment, just as occurs under on-road driving during use of GAINS. To develop and implement this interface, a 'dummy' data stream of GPS coordinates, corresponding to the position of the vehicle in the simulated environment, had to be generated and input to GAINS, so that as a S navigates through the simulated driving environment, the position of the vehicle in the simulated environment is presented on a map display of the environment to benefit navigation.

During on-road use of GAINS, a given Skymap digital map references a data base of GPS coordinates for street intersections included in the map area. A Sony GPS receiver (Appendix B; Photograph B-1) mounted on the vehicle dash detects GPS satellite signals and passes on a data stream of GPS coordinates (latitude, longitude) for vehicle position to Skymap at a rate of 1 set of coordinates per second (sec). Skymap interpolates vehicle position from known GPS coordinates for street intersections bracketing the vehicle, and displays vehicle position in real time on the map display as a vehicle icon superimposed on the map.

The methodological challenge of interfacing GAINS with the HFRL driving simulator computer arises from the fact that this is a simulated driving task---actual GPS satellite signals indicating vehicle position do not exist. Therefore, the approach adopted to satisfy the task is as follows: (1) generate GPS coordinates for each intersection in the simulated street grid model (Appendix D); and (2) use the SGI Onyx computer to generate a data stream of calculated 'dummy' GPS coordinates, corresponding to vehicle position in the simulated driving environment, and pass these coordinates on to Skymap in a format identical to that acquired from the actual GPS receiver, so that vehicle position relative to bracketing intersections can be displayed and updated by Skymap in real time on the GAINS map display as the vehicle moves through the environment. The stages in Step 2 parallel stages involved in acquisition and processing of a real GPS coordinate data stream by Skymap, except that a dummy GPS coordinate data stream transmitted from the SGI Onyx is substituted for a real one. Subsections below detail methods used to implement these steps.

For the simulation testing phase of the project, GAINS was configured as Skymap installed on a Toshiba Satellite 205CDS laptop PC with 11 inch screen. As detailed below, the Toshiba laptop PC then was interfaced with the SGI Onyx computer to provide the in-vehicle digital map display of the simulated driving environment.

3.3.1. GPS Coordinates of Intersections In Simulated Driving Environment

One of the capabilities of Skymap is presentation of the GPS coordinates for a given intersection included on the map being displayed, when the mouse curser is centered on that intersection. A map of the street grid modeled for the simulated driving environment (Appendices C and D) was displayed using GAINS. GPS coordinates for the 32 intersections in the grid were recorded off the display by centering the mouse cursor over each intersection in the grid. Results are in Appendix E, with the intersection (cross street) identified in the lefthand column, the intersection latitude (N-S) listed in the middle column, and the intersection longitude (E-W) listed in the right hand column. Latitude and longitude units are degrees.

3.3.2. Generating Data Stream of Dummy GPS Coordinates For Vehicle Position in Simulated Driving Environment

Etak was asked to provide information about how to generate a data stream of dummy GPS coordinates that could be recognized by Skymap. Appendix F contains information provided in response to this question. The two parts of the appendix consist of: (1) Etak explanation of how a data stream of GPS coordinates is transmitted to Skymap; and (2) details of the format for a 160-character GPS coordinate message string provided to Skymap by the GPS receiver.

Based on the information set forth in Appendix F, plus additional details provided by Etak, the following approach is employed for generating a data stream of dummy GPS coordinates.

1. As a S drives through the simulated street grid model, real time (x,y) coordinates of vehicle position in the simulated environment are known to an accuracy of 1 mm by SGI Onyx software.
2. Known (x,y) and GPS coordinates of the two intersections in the simulated street grid bracketing the vehicle at any given time (Appendix D) are used to calculate GPS coordinates for vehicle position from its (x,y) position, using interpolation.
3. The calculated GPS coordinates for vehicle position are properly formatted as a message string, using instructions detailed in Appendix F.

Software for implementing Steps 1-3 was written in C++ language for the SGI Onyx computer.

One factor that complicated the programming pertains to two different GPS models used by GAINS for referencing the earth's latitude/longitude coordinates. These are termed the NAD27 and the WGS-84 models; GPS coordinates determined by one model are not identical to those determined by the other. GPS satellites, and the Sony GPS receiver used by GAINS, generates GPS coordinates using the WGS-84 model. However, Skymap converts the WGS-84 coordinates it receives from the receiver to NAD27 coordinates; the intersection coordinates listed in Appendix E therefore are NAD27 coordinates. Etak has provided software for converting GPS coordinates between the two model reference systems.

3.3.3. Transmitting Data Stream of Dummy GPS Coordinates From SGI Computer to GAINS

For GAINS to be able to display and update the position of the vehicle position icon on the digital map display in real time, as the vehicle moves through the simulated environment, a data stream of successive formatted message strings containing dummy GPS coordinates of vehicle position had to be transmitted from the SGI computer to the GAINS Toshiba Satellite laptop PC computer at a rate of 1 string/sec (Skymap is programmed to expect a 1 hz transmission rate for the GPS data stream).

It was initially believed that this task could be accomplished in a simple, straightforward way with a direct transmission link between the SGI and the GAINS Toshiba Satellite laptop PC. However, an extensive effort to implement this approach failed. Ultimately, it was necessary to use 3 computers to accomplish the task, involving the following steps.

1. The data stream of dummy GPS coordinates of vehicle position first is transmitted via an Ethernet connection from the SGI Onyx computer to a desktop IBM clone PC on which the Linux operating system is installed, using customized software developed by HFRL for network data communication between the SGI and a Linux platform PC.
2. The data stream then is transmitted from the Linux computer to the GAINS Toshiba Satellite laptop PC using a null modem cable connecting the RS232 serial ports on the two computers.

Appendix G illustrates a representative data stream of formatted message strings, containing dummy GPS coordinates (based on the WGS-84 reference system) corresponding to successive updates of vehicle position, and transmitted to the GAINS Toshiba Satellite laptop PC at a rate of

1 string/sec. During an experimental session (Section 3.4), a digital map of the street grid selected for simulation modeling (Appendix D) is displayed by Skymap on the GAINS Toshiba Satellite laptop PC display. The transmitted data stream of dummy GPS coordinates is read by Skymap software and used to display a moving icon representing vehicle position in the simulated environment superimposed on the map display. In this manner, Ss are able to refer to the map display to aid navigation of the vehicle through the simulated driving environment.

3.4. EXPERIMENTAL DESIGN, PROTOCOL AND SUBJECTS FOR SIMULATION TESTING

This section describes the experimental design, protocol and Ss for the simulation testing phase (project work plan Task 3) of the project. Subsections below outline the objectives, scope, experimental design, protocol, and Ss employed, for the research.

3.4.1. Objectives and Scope of Simulation Testing

The overall objective of simulation testing is to collect subjective response measures, plus objective measures of driving performance, from Ss under simulated driving conditions, with GAINS interfaced with the HFRL fixed-base wrap around driving simulator. The scientific premise is that subjective responses and driving performance of Ss under simulated driving conditions, during interaction with GAINS, may be influenced in ways that do not occur when such interaction is not required. This evaluation is intended to address the following questions about the system.

- Is GAINS easy to operate and use during simulated driving?
- Is interaction with GAINS disruptive during simulated driving?
- Does interaction with GAINS introduce patterns or degrees of variability in driving performance (particularly variability in control of speed, braking, and vehicle heading) that differ from variability observed when such interaction is not required?
- Do patterns or degrees of variability observed in driving performance during driver interaction with GAINS have implications for driving safety, relative to those observed when interaction with GAINS is not required?

3.4.2. Experimental Design for Simulation Testing

Subsections below summarize the approach employed for collecting subjective response measures and objective measures of driving performance from Ss evaluated during the simulation testing phase of the project, followed by descriptions of the protocol employed and Ss recruited for the study.

3.4.2.1. Subjective Responses of Simulation Testing Subjects

A modified version of the GAINS usability survey questionnaire, developed for collecting subjective responses from Ss involved in on-road use of GAINS (Appendix A), was used to collect subjective responses from the simulation testing Ss. These latter Ss were tested with two sessions in the HFRL driving simulator (next section). The modified questionnaire was administered at the end of the second testing session. Appendix H contains a copy of the modified questionnaire.

Because Ss drove in a simulated rather than on-road driving environment during simulation testing, some of the questions in the original survey questionnaire (Appendix A) are not applicable. In particular, in the simulation testing version of the questionnaire, Questions 2, 3, 7, 10, and 11 and 25 are deleted from the on-road questionnaire, and Question 8 is revised to ask about general familiarity with IVNS technology.

3.4.2.2. Evaluation of Objective Measures of Performance During Simulated Driving

For purposes of evaluating objective measures of driving performance during simulation testing, Ss were asked to navigate through the street grid modeled as a simulated driving environment (Appendix D) with and without reliance on GAINS as a navigation aid during the driving task. Paragraphs below describe the HFRL driving simulator, in-vehicle placement and viewing conditions for GAINS, the experimental design, task definition, independent measures, dependent measures, null hypotheses, and the data reduction and analysis approach.

HFRL Driving Simulator and In-Vehicle Placement and Viewing Conditions for GAINS. For simulation testing, the HFRL fixed-base wrap around driving simulator was employed. It comprises: (1) a 360 deg concave screen that is 2.5 m (8.2 ft) high, 4.7 m (15.5 ft) in diameter at floor level, and 5.5 m (18 ft) at its widest concave diameter; (2) a Silicon Graphics (SGI) Onyx computer with a Reality Engine 2 graphics board; (3) four projectors (3 forward, 1 reverse) driven by the Onyx, providing a forward image subtending a 165 deg horizontal field of view, a rear image subtending a 55 deg horizontal field of view, and a 55 deg field of view vertically for all images---only the 3 forward projectors were used for the simulation testing reported here; (4) a full-sized 1990 Acura Integra positioned in the center of the simulator, with sensory input from accelerator, brake, and steering wheel actuation provided to the Onyx and used to update the projected image in real time; and (5) a stereo system that generates engine noise broadcast on speakers within the Acura---volume of engine noise is varied directly with simulated vehicle speed.

To facilitate viewing and interaction with GAINS by Ss during simulation testing, the GAINS Toshiba Satellite laptop PC was placed on the passenger seat with the display screen facing the driver. Viewing distances were closely comparable to those that prevailed during on-road testing of GAINS (Chapter 2; Appendix B), namely a viewing distance of approximately 0.6 m (2 ft) from driver eye position to the display, and the center of the display centered approximately 15 deg below driver eye level. As with on-road testing, viewing distances varied somewhat in relation to the height and head position of the driver.

One important distinction between GAINS viewing conditions for simulation versus on-road testing is that interior lights in the wrap around driving simulator were turned off during S testing, such that reflection off the screen from projected images provided the only interior illumination within the simulator housing. With this dim lighting, GAINS viewing conditions were more consistent, with better visibility of the digital map, for simulation relative to on-road testing.

A series of 5 photographs are presented in Appendix I to illustrate various features of the HFRL fixed-base wrap around driving simulator, the simulated driving environment, and in-vehicle placement and the digital map for GAINS, during simulation testing. Photograph I-1 shows two of the forward projectors from a position in front of the Acura Integra; Peter Easterlund, HFRL systems programmer, also is shown (Acknowledgments). Photograph I-2 shows the three PCs located within the wrap around simulator during simulation testing. On a table next to the Acura are the Linux PC (to the left), for transmitting the data stream of dummy GPS coordinates from the SGI Onyx to the GAINS Toshiba Satellite laptop PC (Section 3.3.3), and a host PC (to the right) interfaced with the SGI Onyx and used to control the Onyx from within the wrap around simulator. The GAINS Toshiba Satellite laptop PC is shown on the roof of the Acura, with the null modem cable connected to the Linux PC evident. Photograph I-3 shows a representative data stream of formatted message strings containing dummy GPS coordinates displayed on the Linux PC monitor (compare with Figure G-1 in Appendix G); the display is updated continuously at a rate of 1 message string/sec as the data stream is transmitted from the Linux to the GAINS Toshiba Satellite laptop PC.

The digital map of the driving environment was displayed on the monitor of the GAINS Toshiba Satellite laptop PC situated on the passenger seat of the Acura, with the monitor facing and easily visible to the driver. Photograph I-4 shows a close-up of the Skymap digital map of a portion of the simulated driving environment (Appendix D) as displayed on the Toshiba laptop PC monitor. The starting point for every experimental session was on Dupont Ave. (to the left in Photograph I-4) just north of 28th Street, with the vehicle facing south. Photograph I-5 illustrates this point with a viewing perspective through the windshield of the Acura; the projected image of the starting point in the simulated driving environment for each experimental session is shown on the screen in front of the Acura, with the vehicle facing south on Dupont Ave. just north of the intersection with 28th Street.

A decision was made not to display the digital map of the entire simulated environment grid (Appendix D) for navigation purposes, because of poor viewing resolution of map details with the complete grid displayed. Instead, to provide acceptable viewing resolution of the digital map, for Ss interacting with GAINS to aid navigation through the simulated driving environment, only a portion of the environment was displayed with the digital map at any one time. This point is evident in Appendix I, Photograph I-4. The N-S grid streets shown on the map display illustrated in this photo extend from Dupont Ave. on the west side to Cedar Ave. on the east side, whereas the entire grid extends W-E from Dupont Ave. on the west to 42nd Ave. on the east (Appendix D). Similarly, the E-W grid streets shown on the map display illustrated in this photo extend from 28th Street on the north side to 35th Street on the south side, whereas the entire grid extends N-S from 28th Street on the north to 58th Street on the south side (Appendix D).

The maximal (simulated) grid distances that are displayed on a digital map sector at any one time are 3,836 m (12,576 ft; 2.38 mi) in the W-E (horizontal) dimension, and 2,439 m (7, 998 ft; 1.51 mi) in the N-S (vertical) dimension. When Ss drive their vehicle 'off the map,' from one sector into an adjacent one, the digital map sector update feature of Skymap automatically displays the new sector on the monitor. In this manner, a reference indication of vehicle position on the digital map always is available for viewing with sufficient resolution as a S navigates through the grid.

Experimental Design. A case-control, repeated measures, prospective experimental design was employed for the simulation testing phase of the study. Simulated driving performance of Ss was evaluated under two task conditions: (1) navigation through a maze-like route laid out through the street grid modeled as simulated driving environment (Appendix D), with interaction with GAINS not required (control condition); and (2) navigation through a different maze-like route laid out through the street grid model, with interaction with GAINS required for navigation purposes (test condition). This design is based on the secondary task paradigm widely employed in HF research, in which interaction with GAINS is treated as a secondary task during performance of the primary simulated driving task.

Under both testing conditions, GAINS was placed on the passenger seat of the Acura, with a digital map of the simulated street grid driving environment, and the vehicle position icon superimposed on the map, displayed on the Toshiba Satellite laptop display (Appendix I, Photograph I-4). Under the control condition, Ss were given auditory instructions by a researcher (Hammond or Smith) about which direction to turn as they approached each intersection. The researcher sat on a chair within the wrap around simulator near the open window of the front passenger door of the Acura (Appendix I, Photograph I-2), and was able to verbally convey turning instructions to Ss through the window. Ss therefore did not have to interact with GAINS as a navigation aid under the control condition, although they were free to do so. Conversely, under the test condition, Ss were not given supplementary instructions about which direction to turn at each intersection, and therefore were encouraged to rely on GAINS as a navigation aid to monitor the position of their vehicle during the driving task. Results for S head turns towards GAINS (Section 3.5) confirm that relative to the control condition, the frequency of visual interaction with GAINS was markedly higher during the test condition.

With one exception, Ss participated in control and test sessions on separate days. For most Ss, the two sessions were on successive days at about the same time of day. The order of administration of control and test conditions was fixed, with the control session always administered first, and the test session always administered second. This design was selected for two reasons: (1) it was anticipated that any variability in driving performance attributable to lack of familiarity with simulated driving would be more pronounced during the first testing session, and therefore always associated with the control condition; and (2) Point 1 strengthens the argument that any increase in variability in driving performance associated with the test relative to the control condition is more likely to be associated with interaction with GAINS rather than lack of task familiarity. In other words, it may be argued that always administering the control condition as the first testing session strengthens the robustness of the design, by more stringently placing emphasis on interaction with GAINS, rather than lack of task learning, as a more likely source of any heightened degree of driving performance variability observed under the test condition compared with the control condition.

Task Description. Two different maze-like street grids were employed as navigation environments for the control and test conditions. Each contained a subset of streets contained in the complete grid (Appendix D). Two separate navigation environments were employed to minimize chances of transfer of learning of a navigation route between control and test conditions. During a testing session, Ss were asked to find their way from a designated start point to a designated end point in the navigation environment, which were the same for both testing conditions. The start point is the intersection of Dupont Avenue and 28th Street, and the end point is on 28th Avenue just to the north of the intersection of 28th Avenue and 48th Street (Appendix D).

The two figures in Appendix J show the maze-like street grids employed as navigation environments for the control and test conditions respectively. For each grid, it is evident that different selected street sectors have been removed, which allows different grids to be defined as distinct navigation environments for the two testing conditions. It also is evident that a number of different alternative routes between the start and end points are possible for each grid.

Figures 3-1 and 3-2, respectively, show the routes that were defined for navigation through the street grids for the control and test conditions. For the control condition, every S followed the route shown in Figure 3-1, guided by verbal instructions for turning at each intersection provided by the researcher (above). As noted above, the start point is at Dupont Avenue and 28th Street, and the end point is at 28th Avenue and 48th Street. Photograph I-5 in Appendix I shows the vehicle positioned just north of the start point at the onset of a testing session.

For the test condition, it was deemed desirable that Ss should have their choice of different routes for driving from the start to the end points, in order to encourage Ss to use GAINS as a navigation aid. Figure 3-2 shows an 'optimal' (minimal distance) route. No alternative route for the test condition has a shorter distance than the optimal route shown in Figure 3-2.

Table 3-1. Properties of navigation routes employed for control and test conditions during simulation testing[1].

Testing Condition	Route Properties Simulated Distance (ft)	Number of Intersections	Number of Left Turns	Number of Right Turns
Control (Figure 3-1)	45,883	11	4	2
Test (Figure 3-2)	44,077	10	3	5

[1] For the test condition, properties specified above are for the 'optimal' (minimal distance) route shown in Figure 3-2.

Table 3-1 indicates that the properties of the navigation routes for the two testing conditions shown in Figures 3-1 and 3-2 are comparable. The distance for the control condition route is 13,994 m (45,883 ft; 8.69 mi), that for the optimal test condition route 13,443 m (44,077 ft; 8.35 mi), a difference of 551 m (1,806 ft; 0.34 mi). The intersection count for the control condition route is one greater, and the total turn count two less, than comparable counts for the optimal test condition route. The intersection and turn counts shown in the table do not include the start point and end point intersections.

The navigation routes shown in Figures 3-1 and 3-2 are defined so that Ss could complete the routes in 10-15 min. The total simulated distance for each route is between 12.9 and 14.5 kilometers (km) (8-9 mi) (Table 1). At a speed of about 100 km/hr (kph) (about 60 mph), with no stops, the completion time for each route therefore should be between 8 and 10 min. With 10 intersections at which stops are required (Table 1), and assuming an extra 30 sec elapsed at each intersection for deceleration from 100 kph, stopping, and acceleration back to 100 kph, an additional 5 min approximately should be required for intersection stops. This brings the projected completion time for each route to between 13 and 15 min. A task completion time of about 15 min was targeted because of experience with other HFRL research projects showing that some Ss may experience discomfort with simulated driving tasks of extended duration.

Data recorded for task completion times (Section 3.5) indicate that for the control condition, Ss actually did finish the control driving task in 11-15 min. However, as noted above, the navigation environment shown in Appendix J for the test condition offers a number of alternative routes that Ss driving under the test condition may choose other than the optimal route. It was therefore predicted

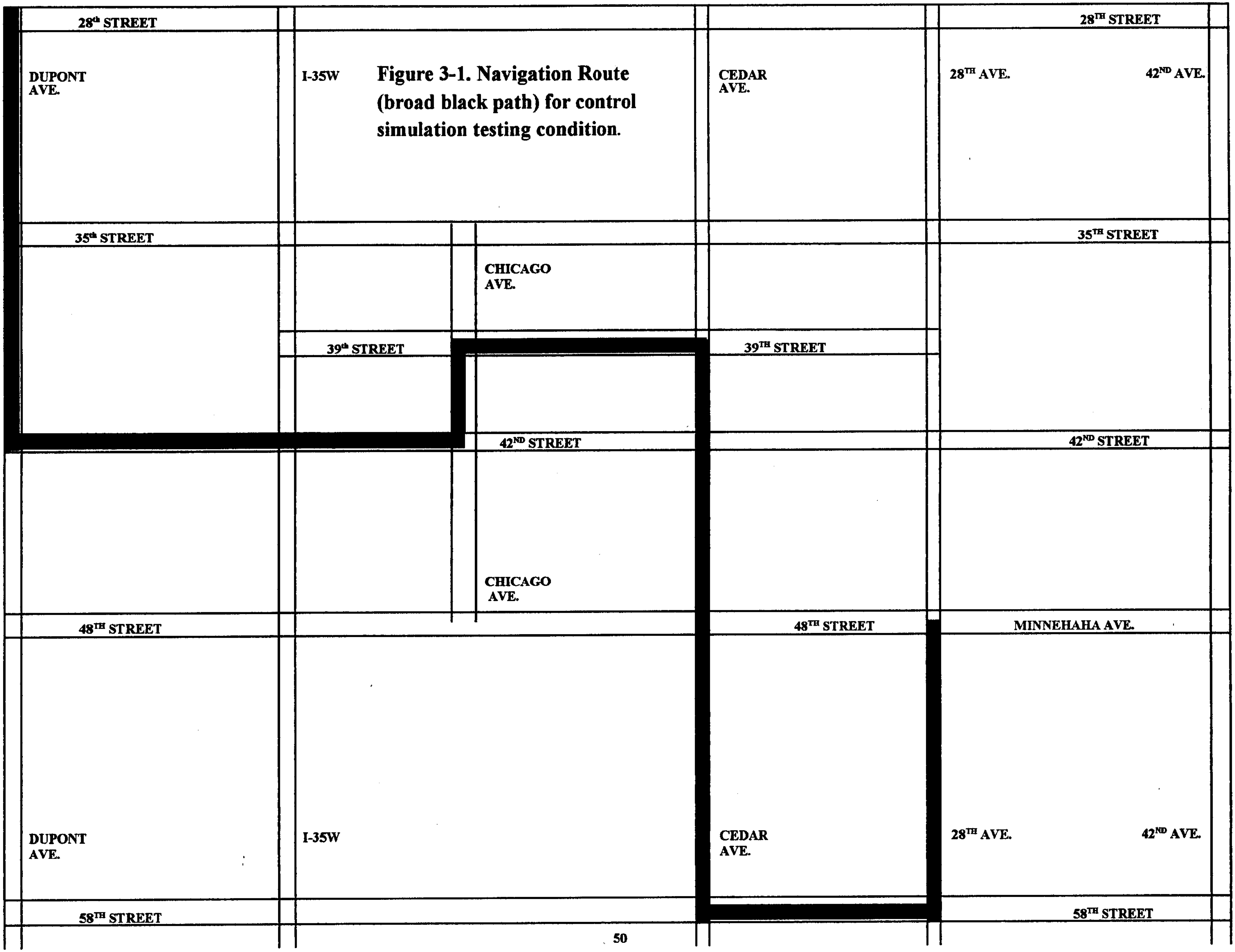


Figure 3-1. Navigation Route (broad black path) for control simulation testing condition.

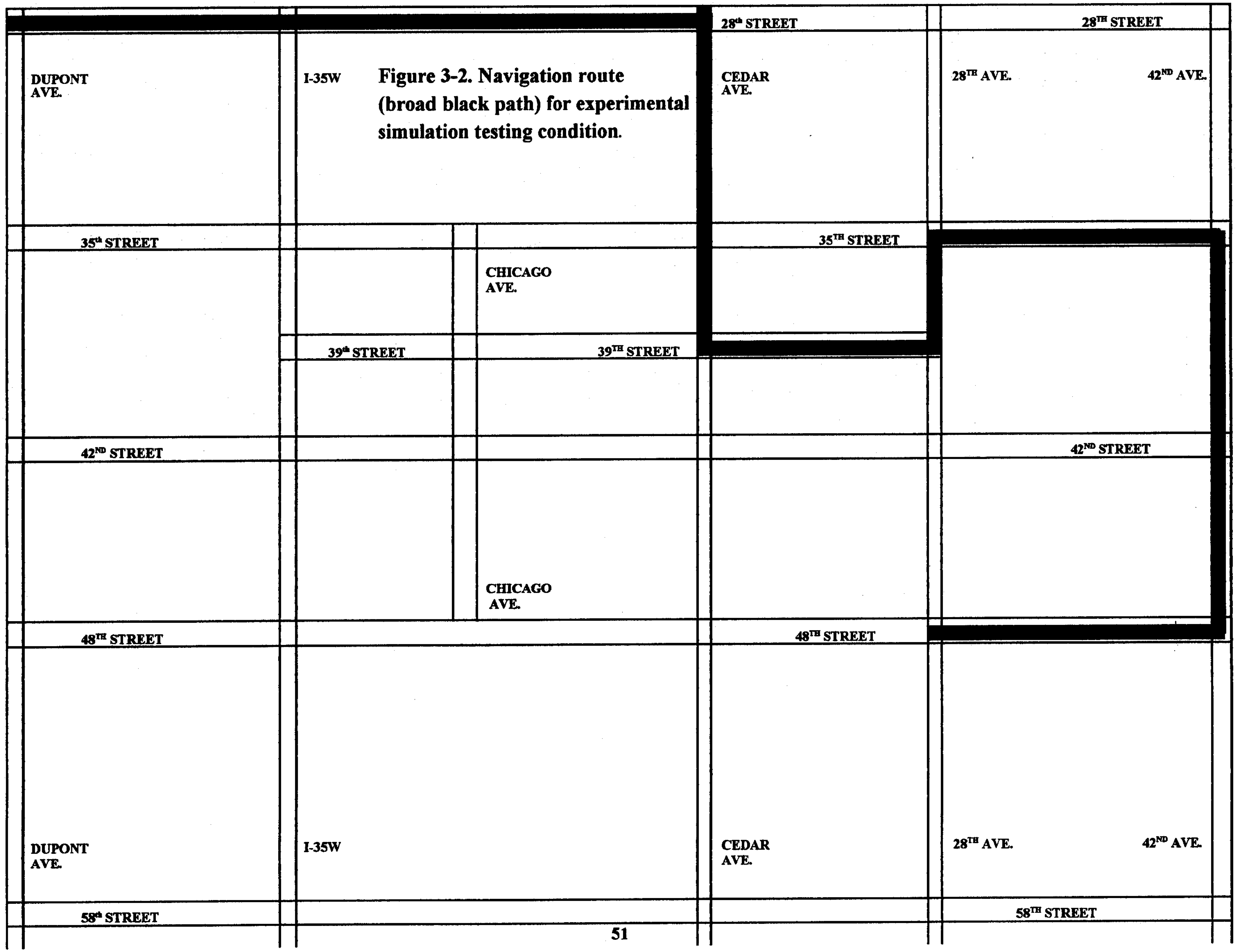


Figure 3-2. Navigation route (broad black path) for experimental simulation testing condition.

that under the test condition, route selection by Ss would be varied, and task completion times would be longer than those observed for Ss driving under the control condition. For this reason, each S was told that the maximum duration of a simulated driving trial would be 30 min, under the assumption (based on HFRL experience with testing Ss under simulated driving conditions) that the degree of discomfort that may occur among some Ss after 30 min of simulated driving would not be of a magnitude to seriously confound the performance measures. Observations of actual driving task performance for the test condition (Section 3.5) in fact confirm that: (1) no S followed the same route; (2) no S followed the 'optimal' route shown in Figure 3-2; and (3) task completion times all were 16 min or longer.

Independent Measures. Based on the experimental design outlined above, the independent objective response measures for simulation testing are: (1) the simulated driving condition (driving with [control condition] or without [test condition] verbal instructions about which direction to turn at each intersection); and (2) Ss.

Dependent Measures. A total of 8 dependent objective response measures of simulated driving performance, grouped into four different categories, were collected. These are summarized in Table 3-2. Paragraphs below summarize methods used to collect each measure.

Navigation Performance. Two dependent measures in this category were collected (Table 3-2): (1) task completion time; and (2) head turns towards GAINS. These measures pertain to navigation behavior as Ss attempted to traverse the navigation routes employed (Figs. 3-1 and 3-2) for the control and test conditions. Task timing was initiated when the vehicle was engaged in 'drive.'. Task completion time was recorded in one of two ways: (1) as the difference between task initiation time and the time a S reached the task end point (intersection of 48th Street and 28th Avenue, Figs. 3-1 and 3-2); or (2) with a value of 30 min, if a S had not reached the end point of the navigation route by the time 30 min had elapsed---this occurred only under the test condition for some Ss. Because there was some variability in the manner in which different Ss approached the first intersection (Dupont Avenue and 28th Street, Figs. 3-1 and 3-2) after vehicle 'drive' was engaged, task completion time was recorded only to the nearest min.

Because GAINS was placed on the passenger seat of the Acura during simulation testing, to the right and somewhat below eye level of the driver, Ss had to turn their heads slightly to the right to

Table 3-2. Dependent objective response measures collected during simulation testing.

Category	Dependent Measure	Units	Derivation
Navigation Performance	- Task Completion Time	min	directly measured
	- Head Turns Towards GAINS	number	directly measured
Simulated Driving Performance			
Vehicle Speed	- Mean Speed	kph	calculated
	- Mean Peak Speed	kph	calculated
Vehicle Braking	- Mean Braking Pressure	volts	calculated
	- Mean Percent Braking Time	percent	calculated
	- Mean Number of Braking Adjustments Per Intersection	number	calculated
Vehicle Heading	- Variability in Vehicle Heading	standard deviation	calculated

visually interact with the GAINS digital map displayed on the Toshiba Satellite monitor. As a consequence, it was possible for the researcher to visually observe the number of times a given S turned his/her head to look at the GAINS Toshiba Satellite display during a testing session. For this purpose, the researcher sat inside the HFRL wrap around driving simulator on a chair placed near the open window of the front passenger door of the Acura (Appendix I, Photograph I-2), and manually recorded the number of S head turns towards the Toshiba Satellite monitor during a testing session.

Simulated Driving Performance. The remaining 6 dependent measures listed in Table 3-2 pertain to simulated driving performance, and are derived from data recorded automatically during each testing session. These data pertain to driver control of vehicle speed, braking, and heading. During a testing session, the SGI Onyx computer continuously monitors input from sensors in the Acura sensitive to driver actuation of the vehicle accelerator, brakes, and steering wheel, along with continuous time values. Data derived from this input are recorded automatically into a Microsoft Excel spreadsheet updated continuously at an approximate rate of 10 hz. Specifically, the Excel spreadsheet generated during a testing session contains the following data by column: (1) Column 1 - time mark in approximate intervals of 0.1 sec; (2) Column 2 - X coordinate of vehicle position; (3) Column 3 - Y coordinate of vehicle position; (4) Column 4 - vehicle heading in deg; (5) Column

5 - vehicle speed in kph; (6) Column 6 - vehicle braking pressure in volts (V); and (7) Column 7 - vehicle accelerator pressure in V.

Points below detail methods used to acquire these vehicle performance data, and the dependent measures of driving performance calculated therefrom.

1. **Vehicle Speed**. Readout from the Acura accelerator is used to control how rapidly projected visual feedback of the simulated driving environment is updated by the SGI Onyx software for a driver. From known dimensions of the simulation model, the software is able to determine successive positions of the vehicle in the simulated driving environment to an accuracy of 1 mm during a driving task. From this information, successive measures of vehicle speed are calculated in kph and recorded in an Excel file.

   Two dependent measures were derived from the vehicle speed data (Table 3-2). Mean vehicle speed (in kph) was calculated by averaging successive values of vehicle speed collected over the duration of a testing session. Peak vehicle speed was derived manually, using the single data point display feature of Excel. First, overlapping profiles of vehicle speed and braking pressure data were generated for each S and each testing session, using the raw data and the graphing capabilities of Excel. These profiles are shown in Appendix M. The hump-like peaks in each panel in Appendix M portray vehicle speed profiles between successive intersections, as the S accelerated to a peak speed after leaving an intersection, and then decelerated as the stop sign at the next intersection approached. Peak speed was determined by displaying each panel with Excel and positioning the mouse cursor on the speed profile over points between successive intersections corresponding to peak speed levels. The speed values of these peak speed points then were displayed with a mouse click and recorded manually. Peak speed results reported are based on values averaged over the entire testing session.

2. **Vehicle Braking**. A potentiometer coupled to the brake pedal shaft of the Acura, with a 0-1 V readout, provides continuous input to the SGI Onyx on the status of the brake pedal. When potentiometer voltage varies from 0 V, the software is designed to record successive values of brake pedal position. Values are recorded in volts in an Excel file. A high voltage value indicates a large displacement of the brake pedal and therefore represents a high braking pressure. A low voltage value indicates a small pedal displacement and a low braking pressure. The spike-like

records in the panels in Appendix M represent braking pressure and illustrate how control of braking performance is coordinated with control of vehicle speed. The braking pressure data shown in the panels in Appendix M were used to calculate the three dependent measures of braking performance listed in Table 3-2: (1) <u>percent braking time</u> was calculated as the ratio of the sum of successive brake actuation-release time intervals over a testing session to the total time duration for a session; (2) <u>mean braking pressure</u> was calculated by averaging successive values of braking pressure over an entire testing session; and (3) <u>mean braking adjustments per intersection</u> were calculated by visually examining the individual S profiles for braking pressure data in Appendix M (using Excel to enlarge the profiles), manually counting and recording the number of braking adjustments at each intersection for a given testing session, and averaging the results across the entire testing session. Because of low levels of noise in readouts from the brake pedal potentiometer (see braking profiles in Appendix M), voltage levels below 0.03 V were removed from the braking pressure data before the calculations described above were carried out.

3. **Vehicle Heading.** A quadrature encoder counter, coupled to the steering wheel shaft, provides continuous input on steering wheel position, defined as deviation of the wheel from its null position. Using input from the steering wheel, the known position of the vehicle in the simulated driving environment, and the orientation of the driving lane at that position, SGI Onyx software is able to calculate successive values of vehicle heading during a driving task. Heading error is defined as the deviation between heading of the vehicle and lane heading. For purposes of calculating heading error, the convention employed with the HFRL simulator is that straight N is defined as 0 deg, straight E as -90 deg, straight W as +90 deg, and straight S as -180 deg (deviation to the E) or +180 deg (deviation to the W). With these conventions, deviation to the right of the lane heading (i.e., deviation towards the right-hand shoulder) is recorded as a negative heading error, whereas deviation to the left of the lane heading (i.e., deviation towards the center line) is recorded as a positive heading error. Successive values of heading error are calculated in degrees and recorded in an Excel file.

The dependent measure of vehicle heading evaluated in this study pertains to <u>variability</u> in heading performance (Table 3-2). For this purpose, means and standard deviations (SD) of heading error across an entire testing session were calculated for each session, and the SD data used to assess possible differences in variability in heading performance between the control and test conditions.

Null Hypotheses. The experimental design outlined above enables testing of a series of null hypotheses pertaining to the dependent measures. Specifically, the null hypotheses predict that no differences in both magnitudes and variances of mean values for the following 7 dependent measures exist for driving performance observed under the control condition versus that observed under the test condition: (1) head turns towards the GAINS digital map display; (2) average vehicle speed; (3) peak vehicle speed; (4) percent braking time; (5) mean braking pressure; (6) number of braking adjustments; and (7) variability in vehicle heading error.

Data Reduction and Analysis. The experimental design outlined above enables the main effect of simulation testing condition (control versus test) on dependent measures to be evaluated using analysis of variance (ANOVA) with repeated measures. One of the *a priori* assumptions guiding design of the study is that interaction with GAINS may not disrupt the basic magnitudes of different driving performance measures. Under this assumption, the main effect of task condition on the different measures will not be statistically significant. Therefore, another key feature of the data to be carefully evaluated is the variability observed for the different dependent measures, under a second *a priori* assumption that variability in driving performance may differ under the two task conditions even if absolute magnitudes of performance measures do not differ. It may be argued that shifts in variability as well as in magnitudes for measures of driving performance have important safety implications.

For both testing conditions, it was observed for a number of Ss that a short period of acclimatization to the simulated driving environment was required after a testing session was initiated, even though each session was preceded by a training session (next section). To reduce possible performance variability in driving performance attributable to this acclimatization period, only data collected after Ss stopped at the second intersection in the navigation route were used for calculating the 6 dependent measures of simulated driving performance listed in Table 3-2 (for all testing sessions, the first intersection is defined as the one at the start point of Dupont Avenue and 28th Street). Data collection continued until the Ss stopped at the last intersection of the testing session.

For the control navigation route, the second and last intersections are identical for all testing sessions. The second intersection is the one at Dupont Avenue and 35th Street; the last intersection is the one at 28th Avenue and 48th Street (Figure 3-1). For the test condition, the second intersection is either the one at Dupont Avenue and 35th Street, or the one at 28th Street and I-35W (Figure 3-2), depending on the direction that Ss under the test condition turned at the first intersection. The last intersection encountered by Ss during test sessions depends on the driving route selected through the navigation environment (Appendix J).

Because task completion times, and therefore the amount of data, were greater for the test sessions compared with the control sessions, S mean values across the entire session (from 2nd to last intersections) for each of the 6 dependent measures of simulated driving performance listed in Table 3-2 were computed for each testing session, before ANOVA was used to test the main effect of interaction with GAINS. With this approach, possible bias in the ANOVA results due to unbalanced weighting of data from the test sessions was eliminated. In the remainder of this report, mean values will be reported ±1 SD.

3.4.3. Experimental Protocol For Simulation Testing

Simulation testing of Ss was initiated on Aug. 3, 1998, and was completed on Aug. 14, 1998. The experimental protocol followed for testing driving performance of Ss under simulated driving conditions comprises the following steps.

1. A schedule was drawn up for testing volunteers for the study. To the extent possible, control and test sessions were scheduled in sequence at about the same time of day on successive weekdays for each S.
2. Prior to beginning their first control session, each individual volunteering to serve as a S in the study was asked to sign an informed consent form introducing and explaining the study.
3. A series of steps were required to initialize the HFRL wrap around driving simulator equipment and computers prior to simulation testing, and to conduct the simulation test. While the S was reading and completing the informed consent form, the initialization procedures were carried out.
4. After the informed consent form had been signed by the S and the researcher, the S was asked to complete a pre-test questionnaire, shown in Appendix K. The purpose of this questionnaire is to collect information about the driving experience of the S, plus any evidence of S susceptibility to

dizziness, nausea, and/or emotional disturbance while driving. A S who reports a history of these conditions also may be susceptible to queasiness during simulated driving, which warns the researcher to pay close attention to problems with queasiness that may emerge during a test. Based on pre-test questionnaire responses, all Ss who completed simulation testing for the project report little or no past history of dizziness, nausea, and emotional reactions while driving. One volunteer reported a history of susceptibility to motion sickness on the pre-test questionnaire, did in fact become queasy during the training session (below), and decided to drop out of the study. The pre-test questionnaire was administered only once, prior to the control session.

5. The S then was asked to complete a practice drive in the simulator. The purpose of the practice drive is to allow the researcher to judge the suitability of the S for continuing with simulation testing. Both simulated driving performance and any problems with queasiness on the part of the S were monitored by the researcher during the practice session. Criteria used for judging acceptable driving performance in the simulator include: (1) lack of serious discomfort and/or disorientation; (2) ability to stop consistently and accurately at stop signs; (3) ability to maintain vehicle at reasonably steady speed of 60 mph between intersections; and (4) ability to keep vehicle consistently and accurately positioned in right-hand lane while driving. Performance was monitored by a researcher positioned within the wrap around driving simulator.

   Practice sessions were administered prior to both the control and the test sessions. Each practice session lasted approximately 10 min. The navigation environment for the control condition (Appendix J) also was used as the practice session driving environment. The practice session was initiated by launching the simulation without recording data, and without the GAINS digital map being available for viewing in the Acura. All but one volunteer (Point 4) displayed acceptable driving performance during the practice sessions and went on to serve as Ss for the study.

6. Upon successful completion of the practice session, the S left the wrap around driving simulator and was introduced to the study with a series of instructions. The S was asked to examine the instructions while the researcher read each instruction out loud. The instructions call attention of Ss to distinctive features of the simulation testing, such as: (1) task objective to navigate from start point to end point in simulated driving environment; (2) participation in two testing sessions; (3)

provision of verbal instructions for turning at each intersection during the first, but not during the second, testing session; (4) availability of digital map for viewing during both testing sessions; (5) some discrepancies between digital map display and features of simulated driving environment; and (6) need for compliance with traffic laws. The instructions emphasize that the task for the S is to navigate from the start to the end point of the driving environment. Although the instructions indicate that a digital map display will be available for viewing, they do not explicitly indicate that interaction with the digital map display is either required or necessary for completing the task.

7. After review of instructions had been completed, the S was invited to ask any questions. Once these were dealt with, the simulation testing process was reinitialized, the S was seated in the Acura, and the simulation testing session (either control or test condition) was launched.
8. Under the control condition, the S was informed at the beginning of the testing session that turning instructions at each intersection would be provided. A researcher seated in the wrap around driving simulator, near the open window of the front passenger door of the Acura, provided verbal instructions to the S about which way to turn at each intersection. A map of the control condition navigation route, similar to that in Figure 3-1, enabled the researcher to monitor progress of the S through the navigation environment. Each turning instruction was issued when the S passed the intersection warning sign prior to the intersection stop sign. Each turning instruction consisted of one of three two-word phrases: (1) 'turn left'; (2) 'turn right'; or (3) 'go straight.'
9. Under the test condition, the S was informed at the beginning of the testing session that turning instructions at each intersection would not be provided. A researcher was seated within the wrap around driving simulator in the same manner as for the control session, but did not communicate with the S.
10. During both the control and test sessions, the seated researcher observed and recorded the number of head turns by the S towards the GAINS digital map display. All head turns during simulated driving between the first and last intersections of a session were counted.
11. For both testing conditions, a testing session was terminated for one of two reasons: (1) the S arrived at the end point of the navigation route before a 30-min period had elapsed; or (2) 30 min elapsed without the S reaching the end point of the navigation route. Although the

informed consent form and the S instructions indicate that the S was free to terminate a testing session at any time, all Ss completed all simulation testing sessions without incident.

12. After termination of the control session, the S was asked to return for the test session at the scheduled day and time. To initiate the test session, Steps 5-7 above were repeated, followed by Steps 9-11.
13. After completing the test session, the S was asked to complete a subjective response usability questionnaire, modified from that used for on-road testing (Chapter 2). This questionnaire is in Appendix H.
14. After completing the usability questionnaire at the end of the test session (Step 13), the S was paid a fee of $30, and also awarded a UM Kinesiology T-shirt as a bonus. Although instructions for Ss indicate that T-shirts would be awarded only for acceptable driving performance, all Ss in the study who completed the test session received a T-shirt.

3.4.4. Subjects for Simulation Testing

An emphasis was placed on recruiting Ss affiliated with the UM Division of Kinesiology, because of their availability and their general familiarity with human performance testing. To recruit volunteers for the study, announcements were posted on bulletin boards in Kinesiology buildings. In addition, verbal announcements were made to selected Kinesiology 1998 summer session classes.

Three criteria were used to screen those who initially volunteered for the study: (1) possession of a valid driver's license; (2) 20/20 vision in both eyes, corrected with glasses or contact lenses; and (3) no problems with color blindness.

A total of 13 Ss participated in the simulation testing; two volunteers dropped out. Table 3-3 summarizes the characteristics of the 13 Ss tested. There were 7 females and 6 males, with a median age of 23 years, a mean age of 24.4 years, and an age range of 20-42 years. Table 3-3 also lists the original and revised identification (ID) numbers assigned to Ss. In the remainder of the report, the revised ID number will be used to refer to individual Ss.

Table 3-3. Characteristics of Ss participating in simulation testing.

Original Subject ID Number	Revised Subject ID Number	Gender	Age (years)
002	001	F	21
003	002	M	23
005	003	F	24
006	004	F	21
008	005	F	20
010	006	F	42
011	007	M	20
012	008	M	20
013	009	M	23
014	010	M	21
015	011	M	26
016	012	F	28
017	013	F	28
Mean Age:			24.4
Median Age:			23

3.5. RESULTS FOR SIMULATION TESTING

Results for dependent measures collected during the simulation testing phase of the project are grouped in the subsections below by the categories indicated in Table 3-2, namely navigation performance results (Section 3.5.1; 2 measures) and simulated driving performance results (Section 3.5.2; 6 measures). Section 3.5.3 summarizes results from the modified usability survey questionnaire (Appendix H) that simulation Ss completed at the end of the second (test condition) experimental session.

3.5.1. Navigation Performance Results

Two measures of navigation performance were collected (Table 3-2): task completion time and number of head turns per min towards the GAINS digital map display. For the control condition, mean task completion time (N=13) was 13.8 ± 1.2 min (range 11-15 min). For the test condition, mean task completion time (N=13) was 24.9 ± 5.7 min (range 16-31 min). Under the test condition, 7 Ss (5 female and 2 male Ss) found the end point of the navigation environment (Appendix J) within the 30 min time limit, whereas testing sessions for the remaining 6 Ss (2 female and 4 male Ss) were terminated after 30-31 min of simulated driving because they still had not successfully navigated to the end point.

Figures L-1 through L-13 in Appendix L illustrate the route trajectories followed by each of the 13 Ss under the test condition. The revised ID number for each S is shown in each panel (Table 3-3). In each panel, 'Start' indicates the start point and 'End' the designated end point for the test condition task. Streets are not labeled in the figures in Appendix L---refer to Appendix D, Figure D-1, for diagram of streets modeled in simulated environment, and to Appendix J, Figure J-2, for diagram of streets accessible under test condition. To clarify trajectories in some figures, sequentially numbered arrows are used to show the sequence of streets traversed. For those cases where the S did not find the end point, "F' indicates where the task was terminated for the S at the end of 30 min.

The route trajectory profiles in Appendix L provide some insight into why some Ss were not able to navigate successfully to the end point. In particular, each of the 6 Ss who was unsuccessful in completing the task showed a tendency to back track and retrace his/her route, often to a substantial degree. Conversely, only 2 of the 7 Ss who were successful in completing the task showed any evidence of back tracking (Ss 008 and 012), and both of these cases involved only one circular excursion around part of the grid. The findings in Appendix L support the conclusion that the navigation environment employed for the test condition (Appendix J) confronted Ss with a reasonably challenging navigation task.

Figure 3-3 shows results for individual Ss for head turns towards the GAINS digital map display during simulated driving under both the control and test conditions. It is evident from the figure that with one exception (data missing for Subject (S) 4), each S executed more head turns under the test relative to the control condition. For the control condition, Ss averaged 1.1 ± 1.1 head turns/min (N=12; variance=1.2; range 0 to 3.1). For the test condition, Ss averaged 2.8 ± 1.8 head turns/min (N=12; variance=3.1; range 0.7 to 6.1). That is, Ss visually interacted with the GAINS digital map display about 2.5 times more frequently under the test condition, relative to the control condition. By the paired-t test, the difference in the means is highly significant (two-tailed t_{11}=-4.88; p<0.00).

3.5.2. Simulated Driving Performance Results

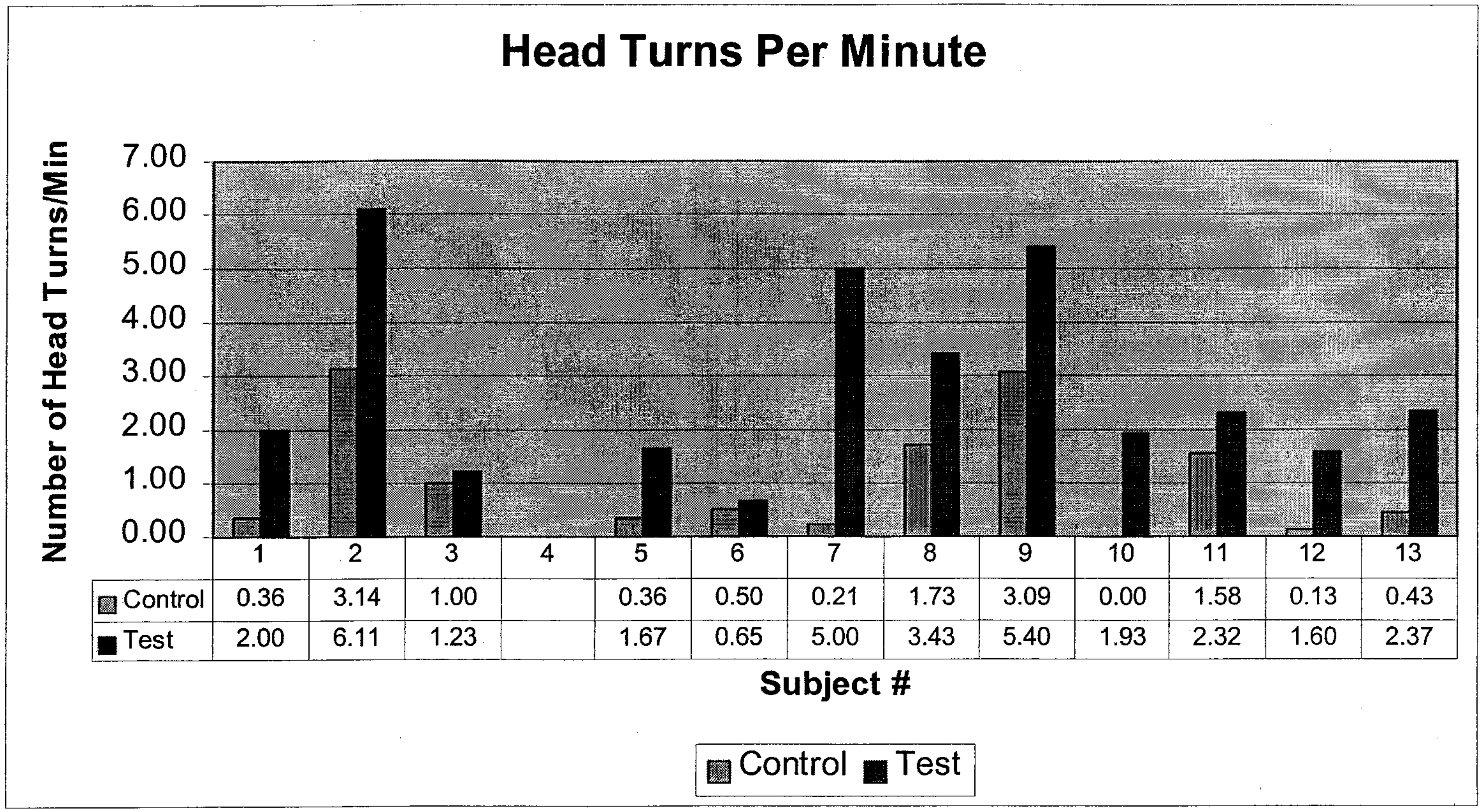
Subsections below presents results for dependent measures (Table 3-3) of vehicle speed (Section 3.5.2.1), vehicle braking (Section 3.5.2.2), and vehicle heading (Section 3.5.2.3). Except where noted, the SD values for the means reported below reflect variability in all session data, not just S mean data, for the measure being considered.

3.5.2.1. Vehicle Speed Results

Appendix M presents profiles for both vehicle speed (kph) and braking pressure (V) for each S and each testing session (original subject ID numbers (Table 3-3) are indicated in each panel). For each S, results for the control session are in the top panel, those for the test session in the bottom panel. In each panel, the braking pressure data (spike-like profiles) are superimposed on the vehicle speed data (hump-like profiles). The semi-regular patterns of change apparent for both types of data in each panel reflect the nature of the simulated driving task, with Ss leaving an intersection, accelerating to a peak speed, then decelerating as the next intersection approaches. A change in brake pressure reflect S depression of the brake pedal, which typically occurs just prior to an intersection, and which causes vehicle speed to drop to close or equal to 0 kph.

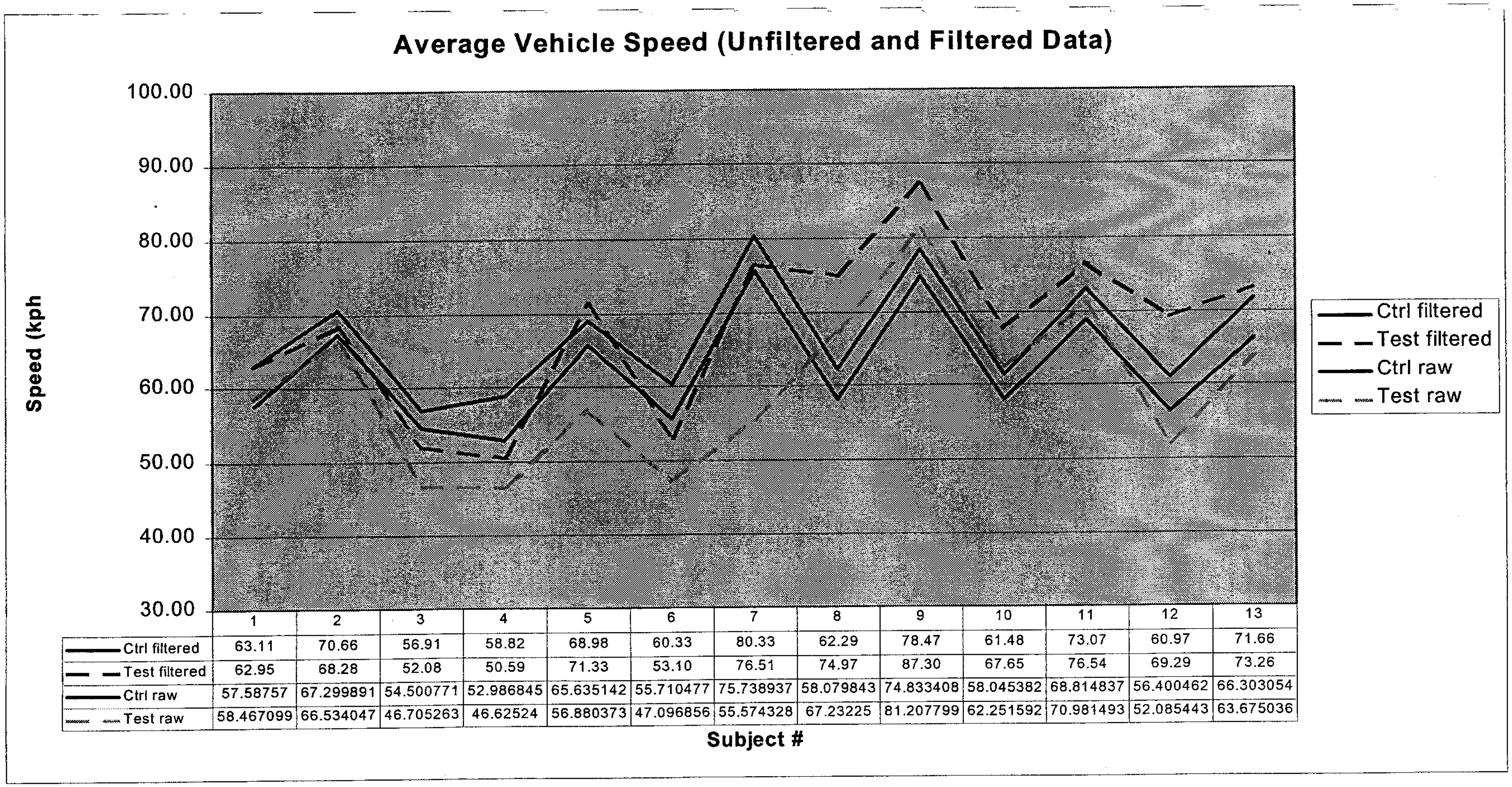
Figure 3-4 illustrates mean values for vehicle speed for each S, based on speed data averaged across each testing session for simulated driving between the second and last intersections. Mean vehicle speed levels illustrated in the figure are calculated in two ways: (1) using all speed values (unfiltered); and (2) removing all speed values below 10 kph before computing the means (filtered data). The rationale for the latter approach is the assumption that any observed differences in variability in vehicle speed control between the control and test conditions is likely to be more pronounced at higher vehicle speeds.

Results in Figure 3-4 indicate no consistent differences across Ss in mean vehicle speed levels between the control and test conditions, for either the unfiltered or filtered measures. Comparing the two conditions: (1) only 3 of 13 Ss exhibit higher unfiltered mean speeds under the test condition; and (2) 6 of 13 Ss exhibit higher filtered mean speeds under the test condition. For the unfiltered data, mean levels of vehicle speed across all 13 Ss are 62.5 ± 7.7 kph (variance=59.7; range 53.0 to 75.7) for the control condition, and 59.6 ± 10.4 kph (variance=108.2; range 46.6 to 81.2) for the test condition. For the filtered data (values <10 kph removed), mean levels of vehicle speed across all 13



Subject #	1	2	3	4	5	6	7	8	9	10	11	12	13
▨ Control	0.36	3.14	1.00		0.36	0.50	0.21	1.73	3.09	0.00	1.58	0.13	0.43
■ Test	2.00	6.11	1.23		1.67	0.65	5.00	3.43	5.40	1.93	2.32	1.60	2.37

Figure 3-3. Number of head turns per minute towards GAINS digital map display by subject, under control and test conditions (paired-t test, two-tailed t_{11}=-4.88; $p<0.00$; paired-t test used because of lack of normal distribution of data).



	1	2	3	4	5	6	7	8	9	10	11	12	13
Ctrl filtered	63.11	70.66	56.91	58.82	68.98	60.33	80.33	62.29	78.47	61.48	73.07	60.97	71.66
Test filtered	62.95	68.28	52.08	50.59	71.33	53.10	76.51	74.97	87.30	67.65	76.54	69.29	73.26
Ctrl raw	57.58757	67.299891	54.500771	52.986845	65.635142	55.710477	75.738937	58.079843	74.833408	58.045382	68.814837	56.400462	66.303054
Test raw	58.467099	66.534047	46.705263	46.62524	56.880373	47.096856	55.574328	67.23225	81.207799	62.251592	70.981493	52.085443	63.675036

FILTERED DATA (values <10 kph removed)

Summary Statistics	*Count*	*Sum*	*Mean*	*Variance*
Control	13.00	867.06	66.70	58.42
Test	13.00	883.84	67.99	117.60

UNFILTERED DATA

Summary Statistics	*Count*	*Sum*	*Mean*	*Variance*
Control	13.00	811.94	62.46	59.66
Test	13.00	775.32	59.64	108.22

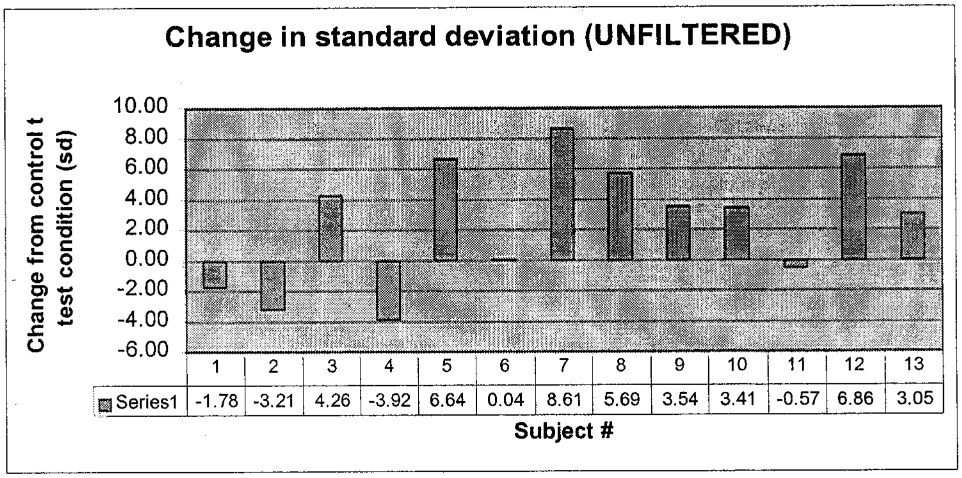
FILTERED DATA ANOVA: Two-Factor Without Replication

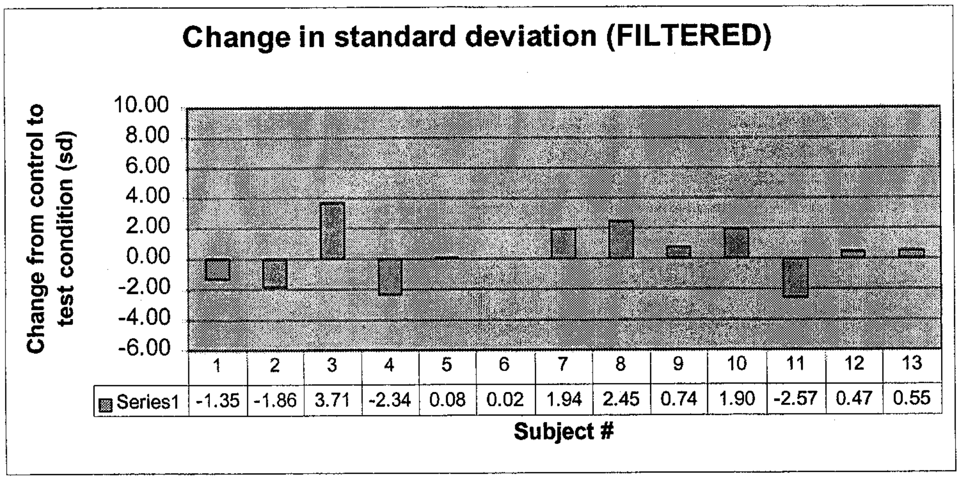
Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Subjects	1858.07	12.00	154.84	7.31	0.00	2.69
Control vs Test	10.82	1.00	10.82	0.51	0.49	4.75
Error	254.14	12.00	21.18			
Total	2123.03	25.00				

UNFILTERED DATA ANOVA: Two-Factor Without Replication

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Subjects	1649.95	12.00	137.50	4.53	0.01	2.69
Control vs Test	51.58	1.00	51.58	1.70	0.22	4.75
Error	364.60	12.00	30.38			
Total	2066.13	25.00				

Figure 3-4. Mean vehicle speed data (kph) by subject, under control and test conditions for filtered (values <10 kph removed) and unfiltered data, with summary statistics and ANOVA tables. Definitions of abbreviations in ANOVA tables: SS = sum of squares; df = degrees of freedom; MS = mean sum of squares; p-value = probability value; F crit = critical F value for p<.05.





KPH (UNFILTERED) TEST VS CONTROL COMPARISON OF STANDARD DEVIATION VALUES

t-Test: Paired Two Sample for Means

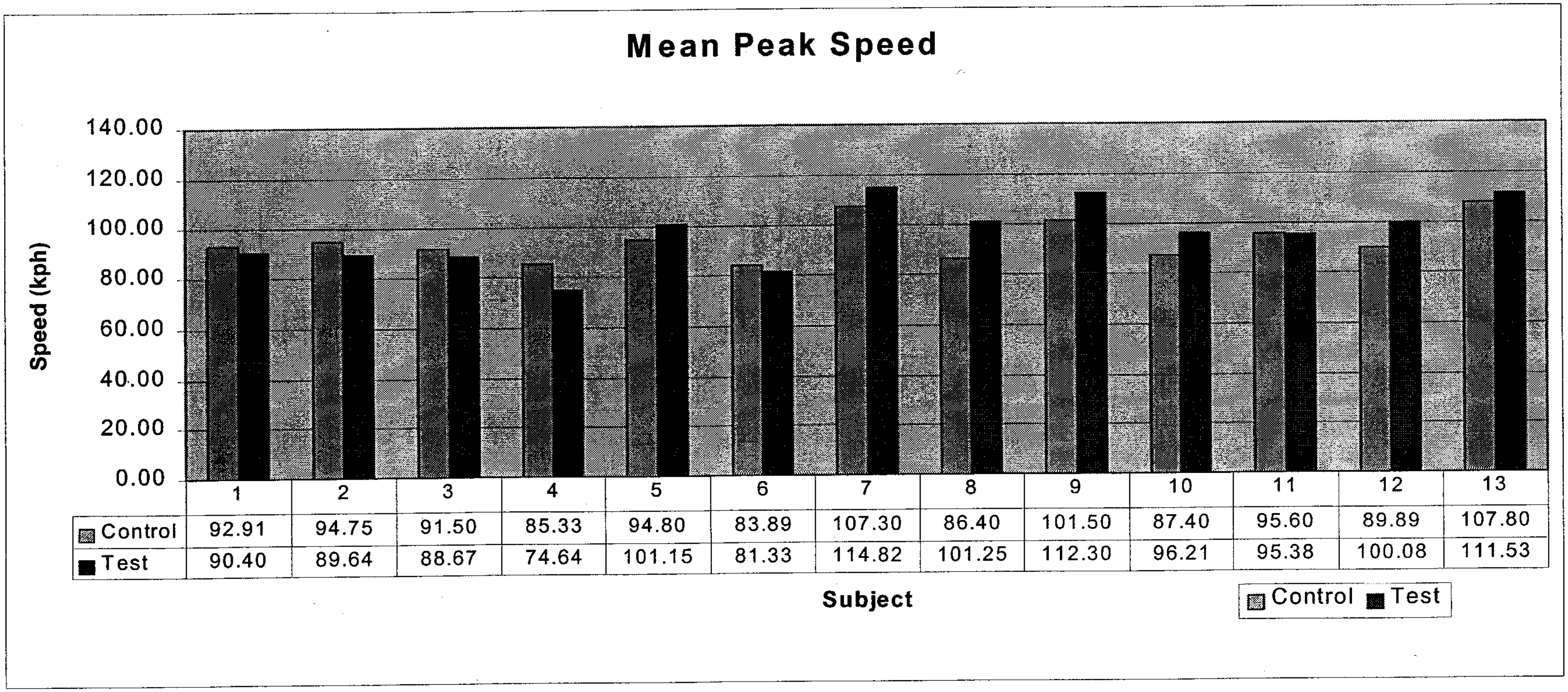
	Control	*Test*
Mean	30.629	33.137
Variance	8.514	32.284
Observations	13.000	13.000
Pearson Correlation	0.737	
Hypothesized Mean Difference	0.000	
df	12.000	
t Stat	-2.235	
p(T<=t) one-tail	0.023	
t Critical one-tail	1.782	
P(T<=t) two-tail	0.045	
t Critical two-tail	2.179	

KPH (FILTERED) TEST VS CONTROL COMPARISON OF STANDARD DEVIATION VALUES

t-Test: Paired Two Sample for Means

	Control	*Test*
Mean	27.317	27.605
Variance	7.575	11.759
Observations	13.000	13.000
Pearson Correlation	0.828	
Hypothesized Mean Difference	0.000	
df	12.000	
t Stat	-0.539	
p(T<=t) one-tail	0.300	
t Critical one-tail	1.782	
P(T<=t) two-tail	0.600	
t Critical two-tail	2.179	

Figure 3-5. Comparison of kph standard deviation values for individual Ss under control and test conditions, with paired t-test results. Top panel - test minus control SD values for unfiltered kph data. Bottom panel - test minus control SD values for filtered kph data (values <10 kph removed). (Abbreviations in paired t-test table: df - degrees of freedom; t Stat - value of t statistic for paired t-test; t Critical - critical t value (one-tail or two-tail) for p<.05).



PEAK SPEED (KPH)

Summary Statistics	*Count*	*Sum*	*Mean*	*Variance*
Control	13	1219.07	93.7746	60.8074
Test	13	1257.39	96.7222	143.52

ANOVA: Two-factor without replication

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Subjects	2113.01	12	176.084	6.23463	0.00172	2.68663
Control vs Test	56.4739	1	56.4739	1.99957	0.18276	4.74722
Error	338.915	12	28.2429			
Total	2508.4	25				

Figure 3-6. Mean peak speed data (kph) by subject under control and test conditions, with summary statistics and ANOVA table (ANOVA table abbreviations in caption to Figure 3-4).

Ss are 66.7 ± 7.6 kph (variance=58.4; range 56.9 to 80.3) for the control condition, and 68.0 ± 10.8 kph (variance=117.6; range 50.6 to 87.3) for the test condition. ANOVA with repeated measures for the main effect of testing condition reveals no significant difference in the means for either set of data (p>.05 for differences in means for both unfiltered and filtered data). However, variance in overall vehicle speed is almost twice as high for performance under the test condition, compared with the control condition. These observations indicate that driver interaction with the GAINS digital map display under the test condition may not have influenced average speed levels, but did influence the variability with which speed was controlled, relative to the control condition.

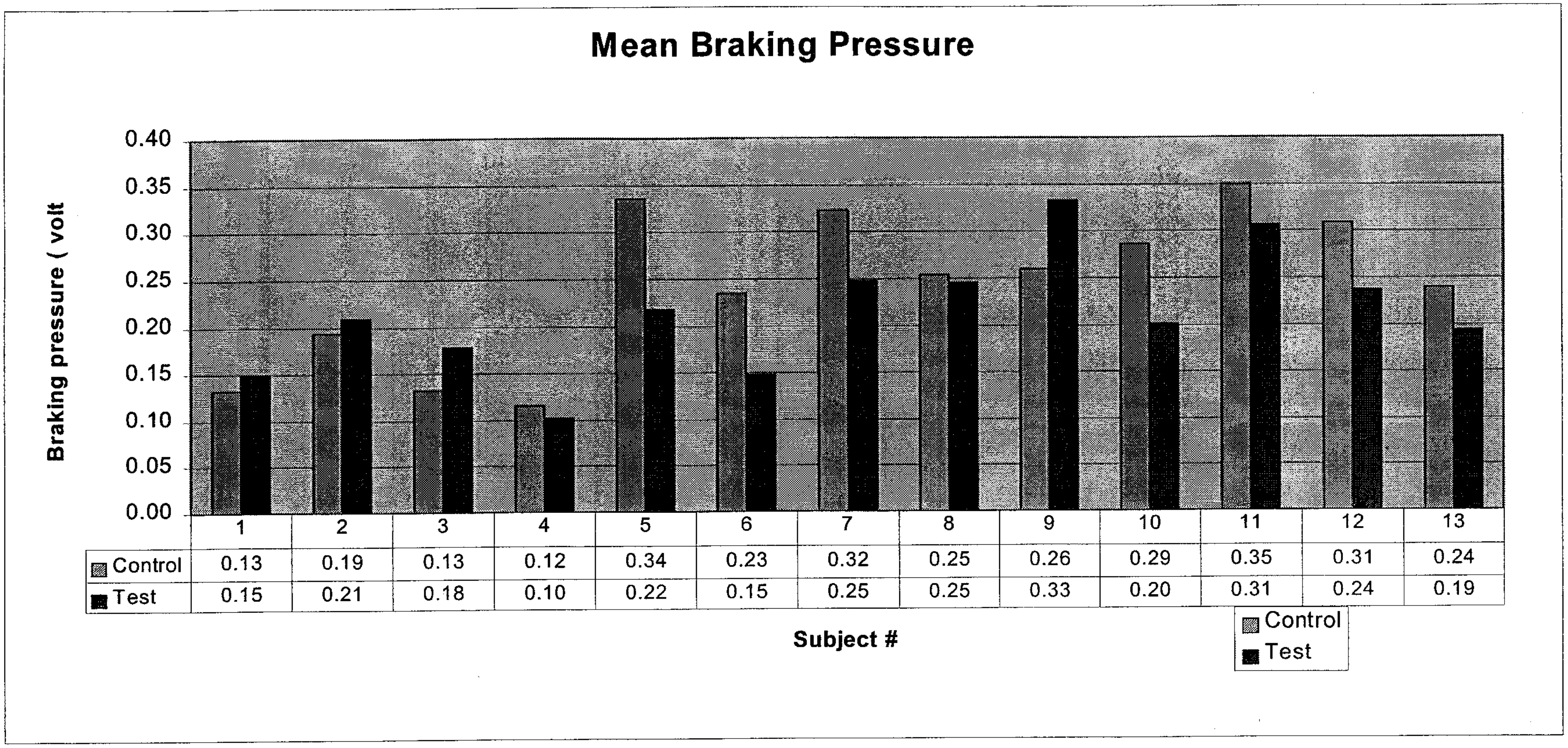
This conclusion is partially, but not entirely, supported by a comparison of kph SD values for individual Ss for test versus control experimental conditions. Results of this comparison are in Figure 3-5. Each panel in Figure 3-5 indicates differences between levels of kph SD values for the test and control conditions (test minus control differences are plotted) for individual Ss. Test versus control SD differences for unfiltered kph data are shown in the top panel; SD differences for filtered kph data are in the bottom panel. The paired t-test results (table below 2 panels) show that for the unfiltered kph data (top panel), SD levels under the test condition are significantly higher than those under the control condition (p=.023 for one-tailed t-test; p=.045 for two-tailed t-test). However, for the filtered kph data (bottom panel), differences in SD levels between the test and control conditions are not significantly significant (p>.05 for both one- and two-tailed t-tests).

The kph SD results (Figure 3-5) indicate that the greater variability observed in control of overall vehicle speed under the test relative to control condition (Figure 3-4) is attributable to more variability in vehicle speed at lower rather than higher speeds. However, observations of <u>peak</u> vehicle speed levels (collected as the second dependent measure of vehicle speed control) indicate that Ss also are more variable in control of peak vehicle speeds under the test condition. Peak speed results are in Figure 3-6, plotted as average peak speed levels for all 13 Ss under both control and test conditions. As with overall mean speed, Figure 3-6 shows no consistent differences across Ss in peak speed levels between the control and test conditions. Comparing the two conditions, 7 of 13 Ss exhibit higher mean peak speeds under the test condition. Mean levels of peak vehicle speed across all 13 Ss are 93.8 ± 7.8 kph (variance=60.8; range 83.9 to 107.3) for the control condition, and 96.7 ± 12.0 kph (variance=143.5; range 74.6 to 114.8) for the test condition. ANOVA with repeated measures for the main effect of testing condition reveals no significant difference in mean peak speed levels (p>.05). Comparable to overall vehicle speed however, variance in peak vehicle speed is well over twice as high for performance under the test condition, compared with the control condition.

3.5.2.2. Vehicle Braking Results

Figure 3-7 illustrates mean values for braking pressure for each S, based on braking pressure data averaged across each testing session for simulated driving between the second and last intersections. All braking pressure values below 0.03 V were deleted from the data before the means were calculated. Results in Figure 3-7 indicate between Ss variability in mean braking pressure levels, with control condition mean values higher than corresponding test condition mean values for 9 of 13 Ss. Across all 13 Ss, mean braking pressure levels are 0.24 ± 0.08 V (variance=.064; range 0.12 to 0.35) for the control condition, and 0.21 ± 0.06 V (variance=.036; range 0.10 to 0.33) for the test condition (the SD values are calculated from S means). ANOVA with repeated measures for the main effect of testing condition reveals a significant difference in the means at the 0.1 level ($F_{1,12}=3.60$, p=0.08).

Figure 3-8 illustrates mean values for percent braking time for each S, based on braking pressure data averaged across each testing session between the second and last intersections. All braking pressure values below 0.03 V were deleted from the data before the means were calculated. Percent braking time is calculated as the ratio of the sum of successive time intervals of brake actuation-release activity (using brake pressure data) over a testing session to the total time duration for a session. Results in Figure 3-8 indicate some variability between Ss in mean percent braking time levels, with mean values under the control condition higher than corresponding mean values for the test condition for 5 of 13 Ss. Across all 13 Ss, mean percent braking times are 12.8 ± 3.5 % (variance=12.2; range 8.0 to 20.6) for the control condition, and 16.4 ± 6.7 % (variance=44.8; range 9.0 to 30.2) for the test condition. ANOVA with repeated measures for the main effect of testing condition reveals no significant difference in the means (p>.05). The variance values indicate, however, that variability in percent braking time is almost 4 times as high for performance under the test condition, compared with that under the control condition. These observations indicate that interaction with the GAINS digital map display under the test condition may not have influenced average braking time levels, but did increase variability in the durations of brake actuation-release episodes, relative to the control condition.



	1	2	3	4	5	6	7	8	9	10	11	12	13
▨ Control	0.13	0.19	0.13	0.12	0.34	0.23	0.32	0.25	0.26	0.29	0.35	0.31	0.24
■ Test	0.15	0.21	0.18	0.10	0.22	0.15	0.25	0.25	0.33	0.20	0.31	0.24	0.19

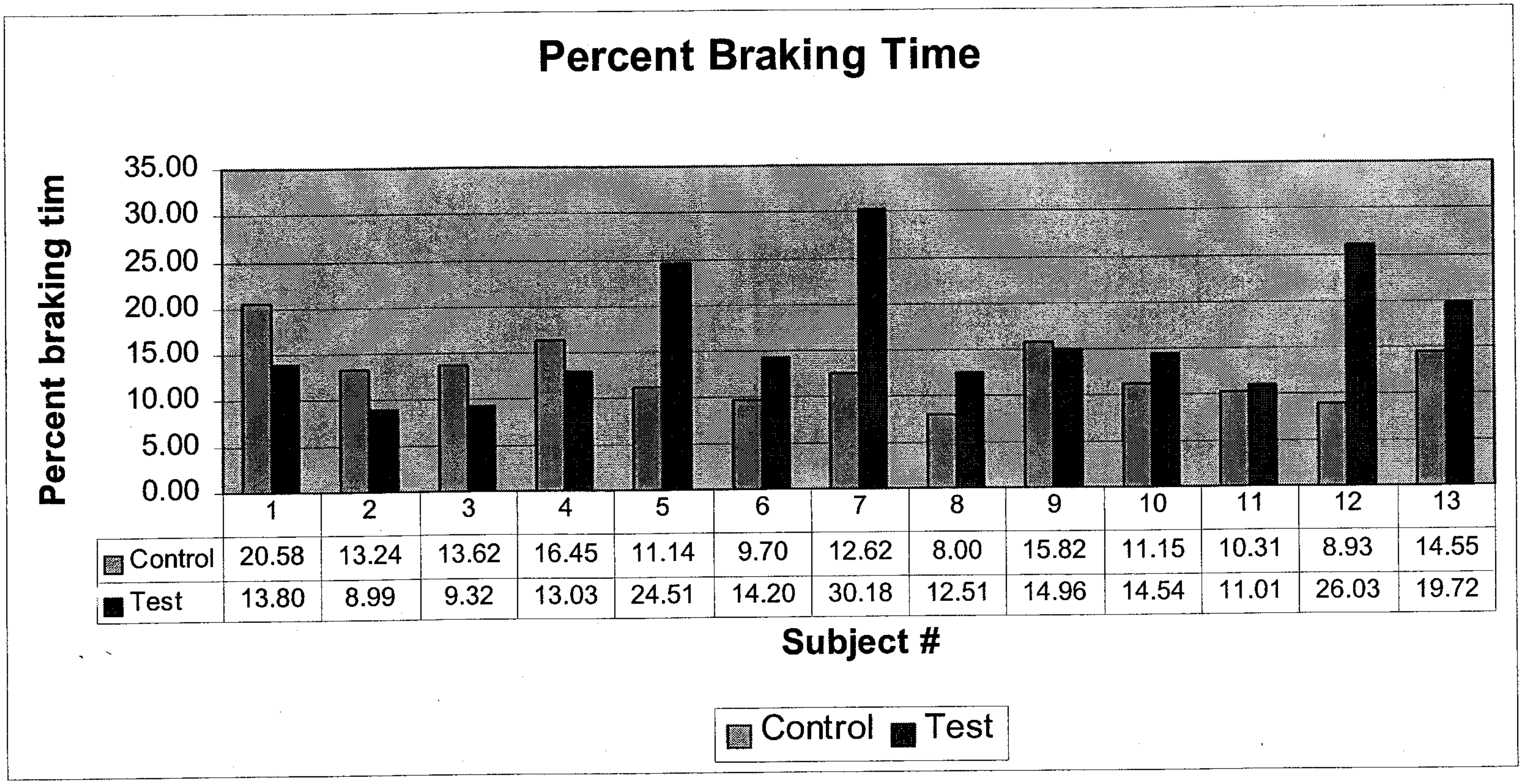
BRAKING PRESSURE (volts)

Summary Statistics	*Count*	*Sum*	*Mean*	*Variance*
Control	13.00	3.16	0.24	0.064
Test	13.00	2.77	0.21	0.032

ANOVA: Two-factor without replication

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Subjects	0.10	12.00	0.01	5.25	0.00	2.69
Control vs Test	0.01	1.00	0.01	3.60	0.08	4.75
Error	0.02	12.00	0.00			
Total	0.13	25.00				

Figure 3-7. Mean braking pressure data (volts) by subject under control and test conditions, with summary statistics and ANOVA table (ANOVA table abbreviations in caption to Figure 3-4).



	1	2	3	4	5	6	7	8	9	10	11	12	13
▨ Control	20.58	13.24	13.62	16.45	11.14	9.70	12.62	8.00	15.82	11.15	10.31	8.93	14.55
■ Test	13.80	8.99	9.32	13.03	24.51	14.20	30.18	12.51	14.96	14.54	11.01	26.03	19.72

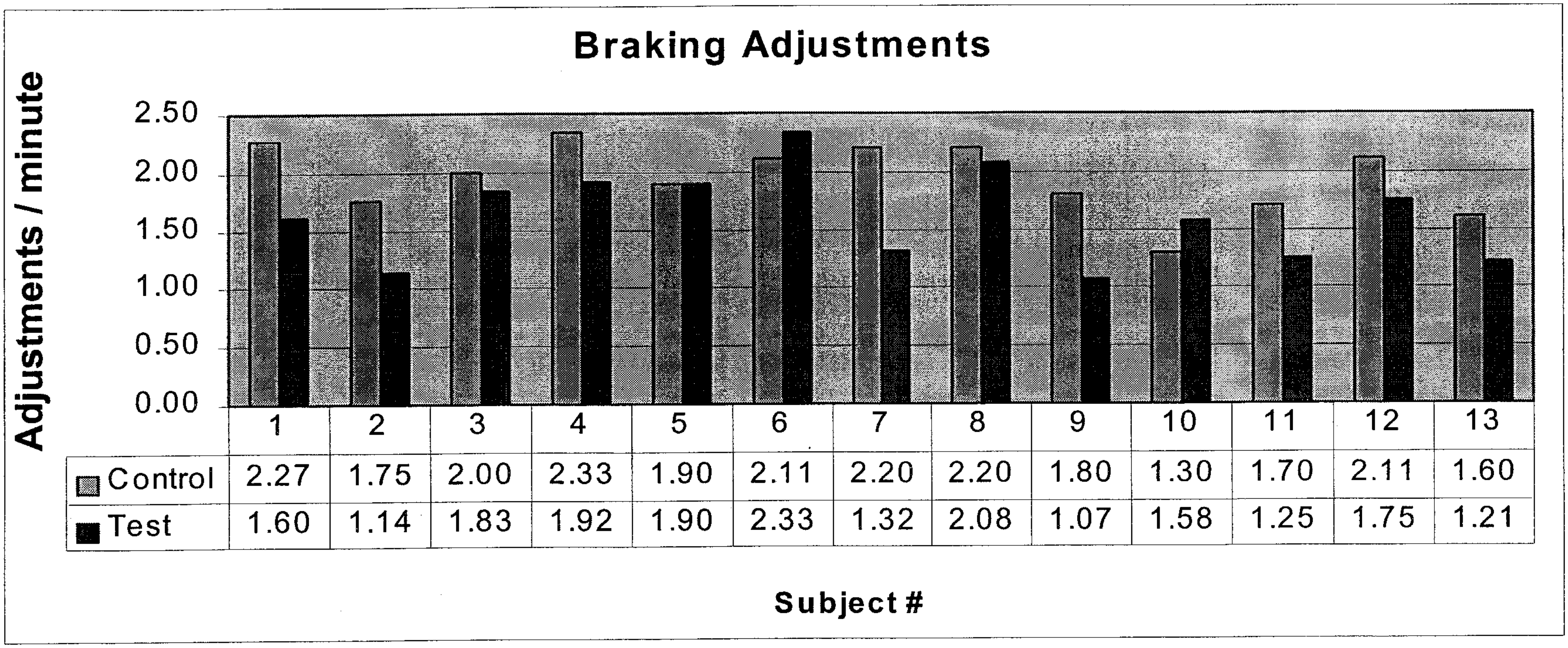
PERCENT BRAKING TIME

Summary Statistics	*Count*	*Sum*	*Mean*	*Variance*
Control	13.00	166.10	12.78	12.19
Test	13.00	212.80	16.37	44.76

ANOVA: Two-factor without replication

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Subjects	290.32	12.00	24.19	0.74	0.70	2.69
Control vs Test	83.88	1.00	83.88	2.56	0.14	4.75
Error	393.08	12.00	32.76			
Total	767.28	25.00				

Figure 3-8. Mean percent braking time by subject under control and test conditions, with summary statistics and ANOVA table (ANOVA table abbreviations defined in caption to Figure 3-4).



	1	2	3	4	5	6	7	8	9	10	11	12	13
▨ Control	2.27	1.75	2.00	2.33	1.90	2.11	2.20	2.20	1.80	1.30	1.70	2.11	1.60
■ Test	1.60	1.14	1.83	1.92	1.90	2.33	1.32	2.08	1.07	1.58	1.25	1.75	1.21

BRAKING ADJUSTMENTS

Summary Statistics	*Count*	*Sum*	*Mean*	*Variance*
Control	13.00	25.28	1.94	0.09
Test	13.00	20.99	1.61	0.16

ANOVA: Two-factor without replication

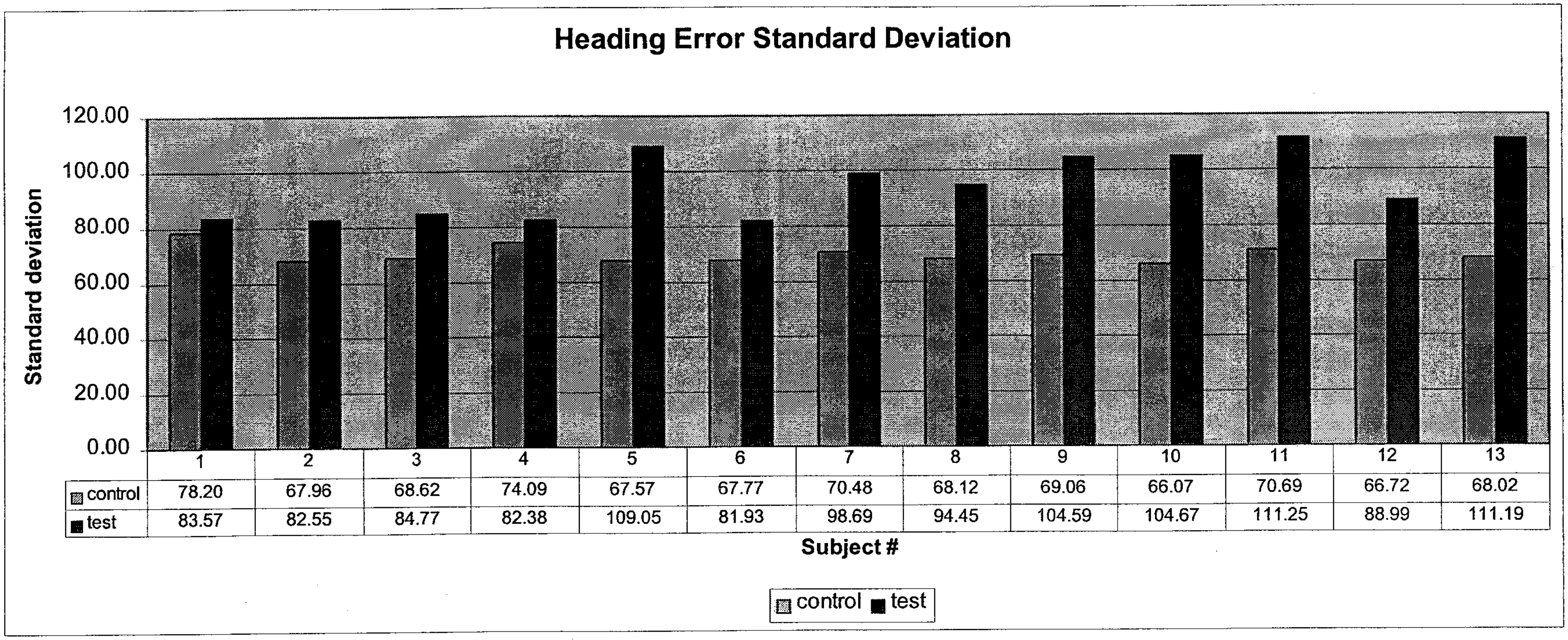
Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Subjects	2.21	12.00	0.18	2.87	0.04	2.69
Control vs Test	0.71	1.00	0.71	11.02	0.01	4.75
Error	0.77	12.00	0.06			
Total	3.68	25.00				

Figure 3-9. Mean braking adjustments by subject under control and test conditions, with summary statistics and ANOVA table (ANOVA table abbreviations defined in caption to Figure 3-4).

Figure 3-9 illustrates mean values for braking adjustments for each S, based on braking pressure data averaged across each testing session between the second and last intersections. All braking pressure values below 0.03 V were deleted from the data before the means were calculated. Results in Figure 3-9 indicate some variability between Ss in mean levels for braking adjustments, with mean values under the control condition higher than corresponding mean values for the test condition for 10 of 13 Ss. Across all 13 Ss, the mean number of braking adjustments is 1.9 ± 0.3 adjustments (variance=0.09; range 1.3 to 2.3) for the control condition, and 1.6 ± 0.4 adjustments (variance=0.2; range 1.1 to 2.3) for the test condition. ANOVA with repeated measures for the main effect of testing condition reveals that the mean number of braking adjustments under the control condition is significantly higher than those under the test condition ($F_{1,12}$=11.0, p=0.01). The variance values indicate that variance in the number of braking adjustments is over twice as high for performance under the test condition, compared with that under the control condition. These observations indicate less activity but more variability in braking adjustments by Ss under the test compared with the control condition.

3.5.2.3. Vehicle Heading Results

Figure 3-10 illustrates SD values for mean heading error for each S. Each SD value plotted in the figure is derived from heading error data averaged across each testing session for simulated driving between the second and last intersections. Results in Figure 3-10 indicate only modest variability between Ss in heading error SD levels, but SD levels under the control condition are lower than corresponding levels for the test condition for all 13 Ss. Across all 13 Ss, the mean values for heading error SD are 69.5 ± 3.3 deg (variance=11.1; range 66.1 to 78.2) for the control condition, and 95.2 ± 11.8 deg (variance=139.9; range 81.9 to 111.3) for the test condition. ANOVA with repeated measures for the main effect of testing condition reveals a highly significant difference in the means ($F_{1,12}$=48.8, p<0.00). These results indicate that interaction with the GAINS digital map under the test condition is associated with about a 1.3-fold increase in the variability of driver control of vehicle heading, relative to the control condition.



Subject #	1	2	3	4	5	6	7	8	9	10	11	12	13
▨ control	78.20	67.96	68.62	74.09	67.57	67.77	70.48	68.12	69.06	66.07	70.69	66.72	68.02
■ test	83.57	82.55	84.77	82.38	109.05	81.93	98.69	94.45	104.59	104.67	111.25	88.99	111.19

HEADING ERROR STANDARD DEVIATION

Summary Statistics	*Count*	*Sum*	*Mean*	*Variance*
Control	13.00	903.37	69.49	11.06
Test	13.00	1238.08	95.24	139.90

ANOVA: Two-factor without replication

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Subjects	751.21	12.00	62.60	0.71	0.72	2.69
Control vs Test	4308.91	1.00	4308.91	48.76	0.00	4.75
Error	1060.34	12.00	88.36			
Total	6120.45	25.00				

Figure 3-10. Standard deviation values for mean heading error by subject under control and test conditions, with summary statistics and ANOVA table (ANOVA table abbreviations defined in caption to Figure 3-4).

3.5.3. Responses to Modified GAINS Usability Survey Questionnaire

Questions 7 through 17 in the modified GAINS usability survey questionnaire (Appendix H) solicit respondent opinions about GAINS using a forced choice scale, with a response of '1' denoting that the respondent strongly disagrees, and that of '5 denoting that the respondent strongly agrees, with the question. Each question solicits respondent opinion about an attribute or usability feature of GAINS. Simulation testing Ss were asked to fill out the questionnaire after completion of their second (test condition) experimental session. Figures 3-11 through 3-21 are histograms showing the distribution of responses for these questions.

The distribution of responses for Questions 7-17 in the modified questionnaire (Figures 3-11 through 3-21) indicate that responses are mixed for some questions, but disproportionately distributed for others. This point is further documented by Figure 3-22, which plots mean and modal response levels across all Ss for the 11 questions. Specifically the histograms in Figures 3-11 through 3-21, and the mean and modal response levels plotted in Figure 3-22, indicate mixed responses for Questions 9, 11, 16, and 17, but distributions favoring '4' (Agree) or '5' (Strongly Agree) responses for Questions 7, 8, 10, 12, 13, 14, and 15. Chi-squared analyses of distributions of responses for Questions 7-17 in the modified survey questionnaire reveal: (1) a significantly disproportionate response distribution ($p<.05$) for Questions 8, 12, 14, and 15; (2) a disproportionate response distribution of marginal significance ($.10<p<.05$) for Questions 7 and 10; and (3) a lack of significance ($p>.05$) for distribution of responses to Questions 9, 11, 13, 16, and 17.

Questions 7-9, 11, and 16 in the modified survey questionnaire address the usability and utility of GAINS. Responses to these questions show that : (1) most respondents agree with statements that GAINS is easy to understand (Figure 3-11; Question 7), and that the system is easy to learn (Figure 3-12; Question 8); and (2) responses are mixed to statements that the system aided navigation (Figure 3-13; Question 9), interfered with driving (Figure 3-15; Question 11), and was useful (Figure 3-20; Question 16). For remaining questions with a disproportionate response distribution of high or marginal significance (above), the responses indicate that most respondents agree with statements that the system functioned properly (Figure 3-14; Question 10), that it was easy to see the display (Figure 3-16; Question 12), that it was easy to understand the information presented (Figure 3-17; Question 14), and that they liked the display colors (Figure 3-19; Question 15).

Questions 18-20 in the modified GAINS usability survey questionnaire (Appendix H) ask respondents to enter narrative responses about their likes (Question 18), dislikes (Question 19), and recommendations for improvement (Question 20) regarding the system. Tables 3-4 through 3-6, respectively, tabulate the responses to each of these questions noted on the questionnaires returned. In each table, responses are ordered by subject number. Some comments in Tables 3-4 through 3-6 are paraphrased (indicated by brackets) to aid understanding. Some of the implications of the comments in Tables 3-4 through 3-6 for understanding strengths and weaknesses of IVNS technology generally are discussed in Sections 4.1 and 5.1.2.

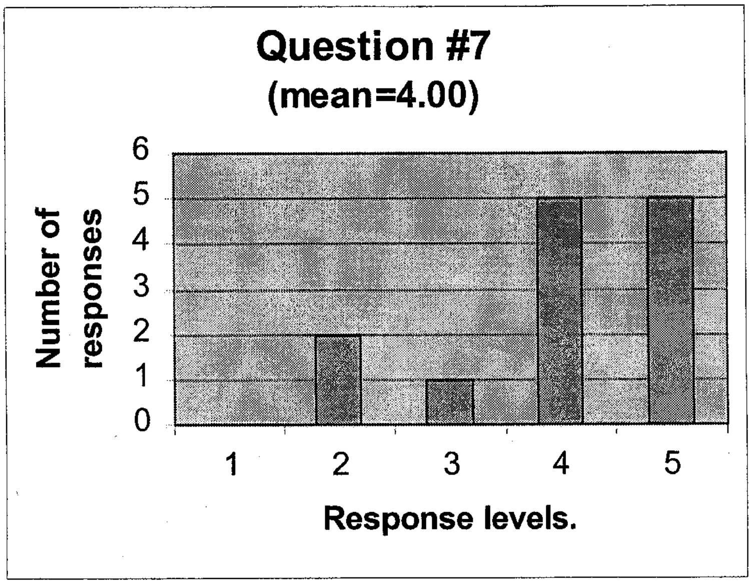


Figure 3-11. Distribution of responses to Question 7 in modified survey questionnaire administered to simulated driving subjects - 'The system is easy to understand' (1=Strongly Disagree; 5=Strongly Agree).

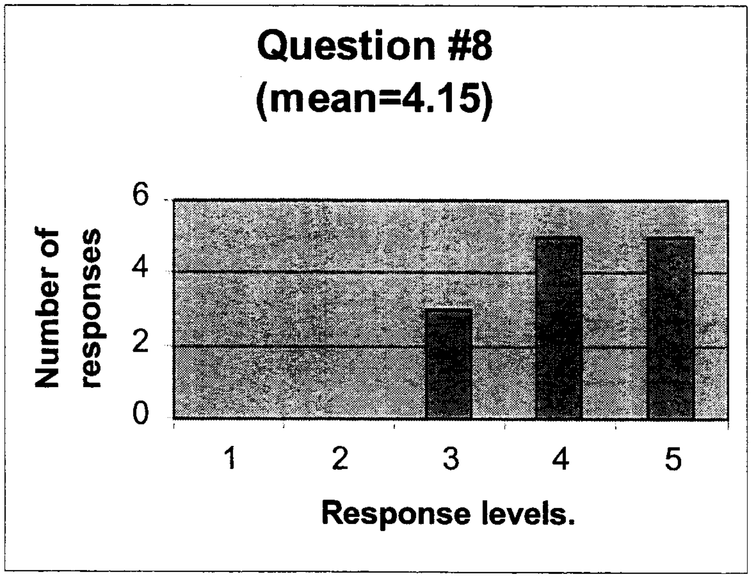


Figure 3-12. Distribution of responses to Question 8 in modified survey questionnaire administered to simulated driving subjects - 'The system is easy to learn' (1=Strongly Disagree; 5=Strongly Agree).

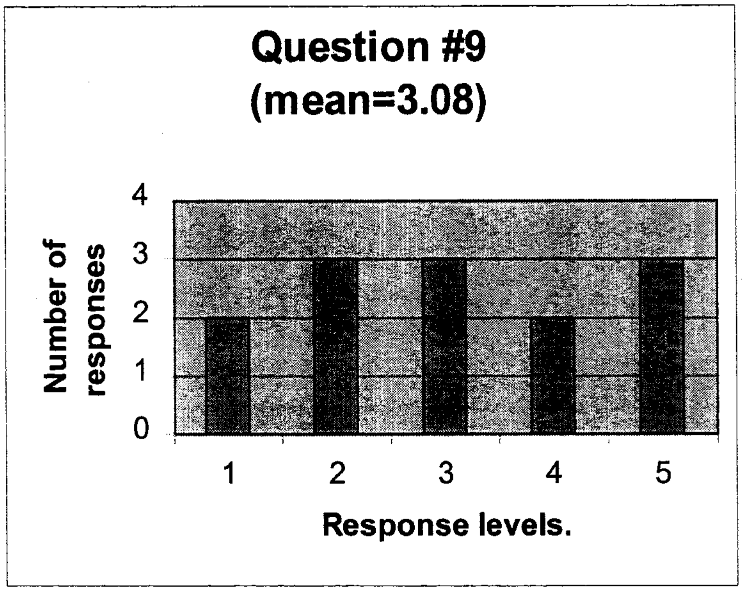


Figure 3-13. Distribution of responses to Question 9 in modified survey questionnaire administered to simulated driving subjects - 'The system helped me find my way' (1=Strongly Disagree; 5=Strongly Agree).

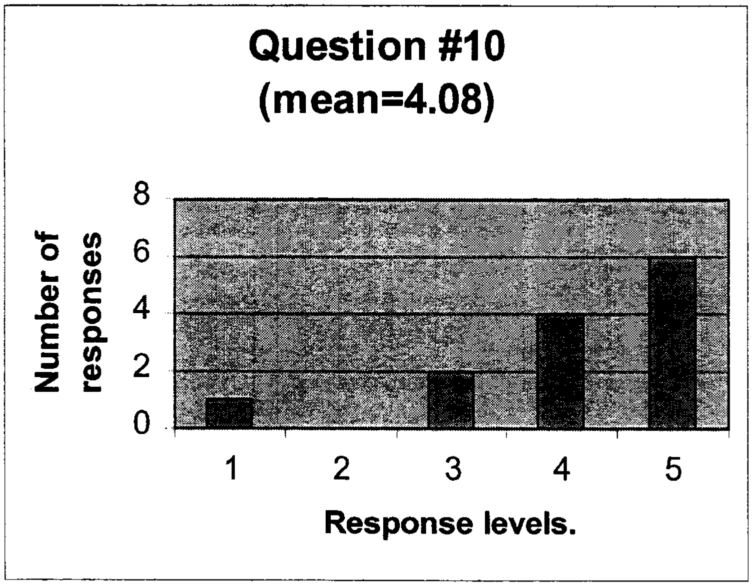


Figure 3-14. Distribution of responses to Question 10 in modified survey questionnaire administered to simulated driving subjects - 'The system functioned properly' (1=Strongly Disagree; 5=Strongly Agree).

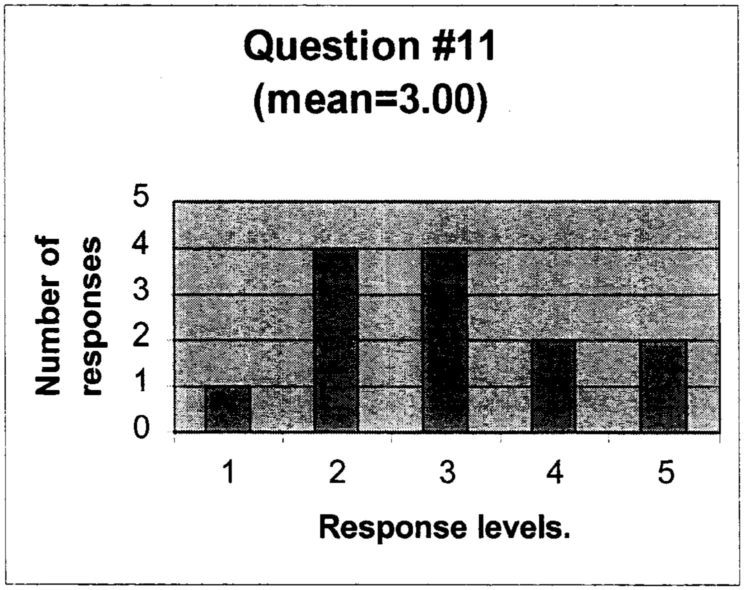


Figure 3-15. Distribution of responses to Question 11 in modified survey questionnaire administered to simulated driving subjects - 'The system interfered with my driving' (1=Strongly Disagree; 5=Strongly Agree).

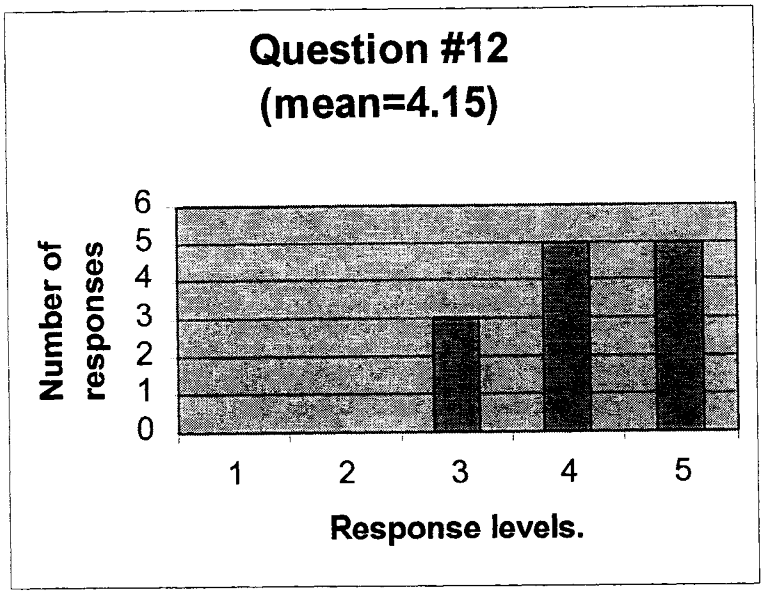


Figure 3-16. Distribution of responses to Question 12 in modified survey questionnaire administered to simulated driving subjects - 'From where I was sitting, it was easy to see the display' (1=Strongly Disagree; 5=Strongly Agree).

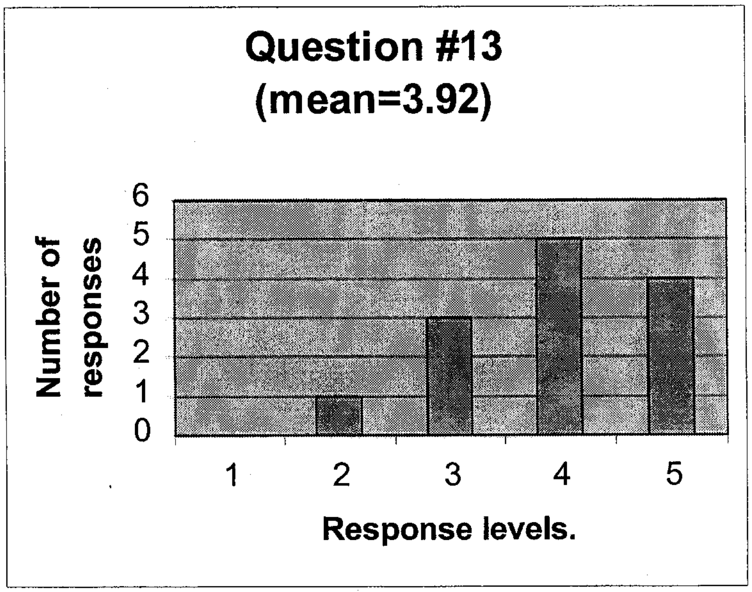


Figure 3-17. Distribution of responses to Question 13 in modified survey questionnaire administered to simulated driving subjects - 'The display is easy to read' (1=Strongly Disagree; 5=Strongly Agree).

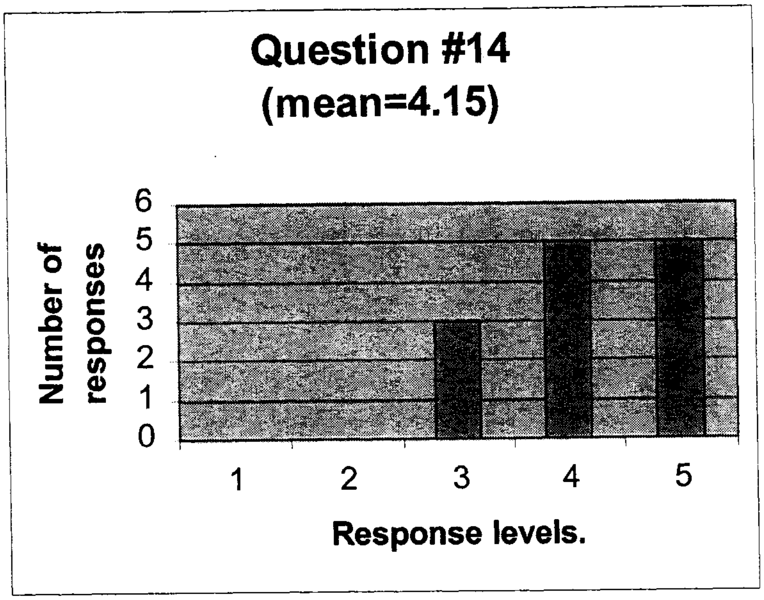


Figure 3-18. Distribution of responses to Question 14 in modified survey questionnaire administered to simulated driving subjects - 'It is easy to understand the information presented' (1=Strongly Disagree; 5=Strongly Agree).

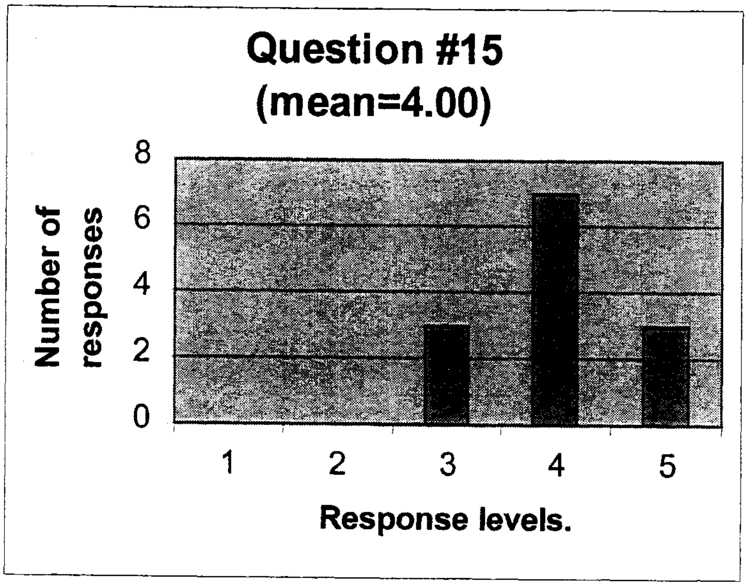


Figure 3-19. Distribution of responses to Question 15 in modified survey questionnaire administered to simulated driving subjects - 'I like the display colors' (1=Strongly Disagree; 5=Strongly Agree).

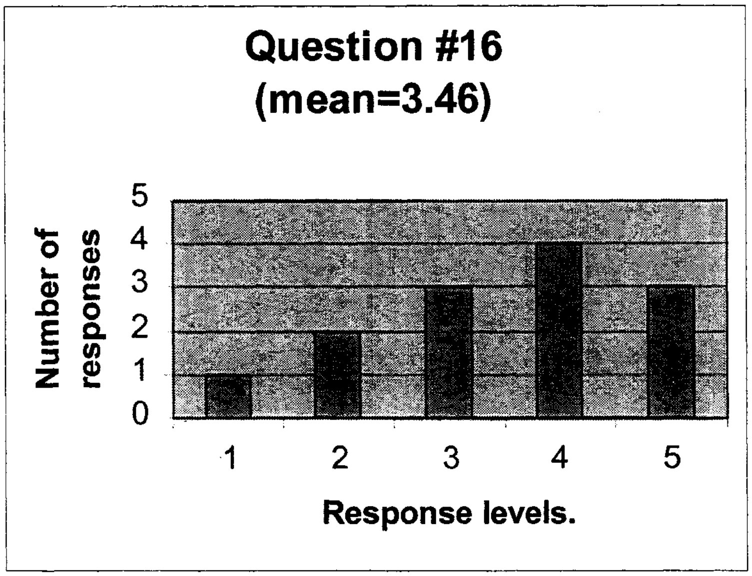


Figure 3-20. Distribution of responses to Question 16 in modified survey questionnaire administered to simulated driving subjects - ‘I found the system useful’ (1=Strongly Disagree; 5=Strongly Agree).

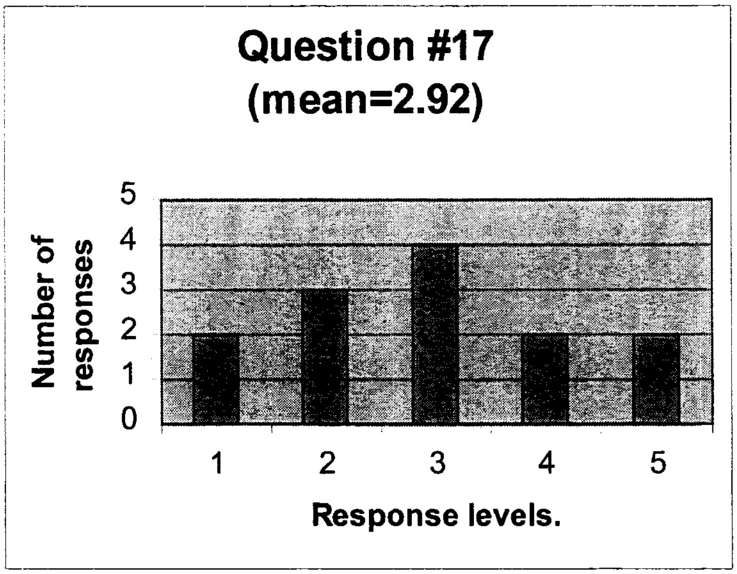
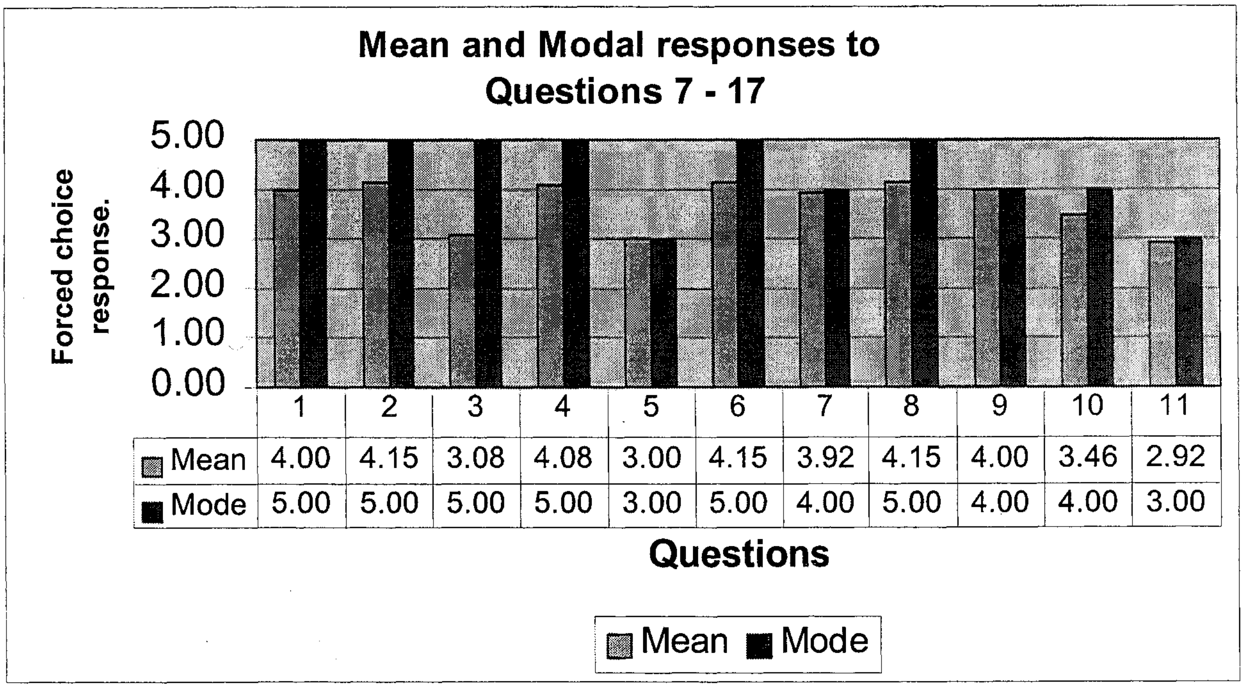


Figure 3-21. Distribution of responses to Question 17 in modified survey questionnaire administered to simulated driving subjects - 'The electronic map is accurate and complete' (1=Strongly Disagree; 5=Strongly Agree).



	1	2	3	4	5	6	7	8	9	10	11
▨ Mean	4.00	4.15	3.08	4.08	3.00	4.15	3.92	4.15	4.00	3.46	2.92
■ Mode	5.00	5.00	5.00	5.00	3.00	5.00	4.00	5.00	4.00	4.00	3.00

Figure 3-22. Mean and modal responses to Questions 7-17 on modified survey questionnaire administered to simulated driving subjects. Questions 7-17 (denoted by numbers 1-11 along the X axis) on the questionnaire solicit respondent opinions about various features of GAINS on a forced choice scale, with a '1' response indicating a 'Strongly Disagree' opinion, and a '5' response indicating a 'Strongly Agree' opinion, on each question (Y axis). The histograms plot mean and modal response levels based on pooled responses across all subjects for each question. Refer to Appendix H for content of each question.

Table 3-4. Narrative responses to Question 18 in modified survey questionnaire administered to simulated driving subjects - 'Here Is What I Like About the System.'

Subject	Narrative Response to Question
1	It helped me figure out where I was in the 'big picture.' It's nice if you're unfamiliar with an area. You can look at the map and figure out how to get there and where you are compared to the destination.
2	[The vehicle position] icon.
3	You don't have to find your place on the map. [Things are] easy to find [with a] more distant view.
4	I like having the information there. It lets you know you are on the right track and where you are at a specific time. It also lets you know the direction you are traveling in.
5	Without it I would have been really lost.
6	It was colorful & added areas on the display.
7	Clarity of display. Accurate simulation. Driving like a monkey and not having to worry about killing yourself!!
8	Useful if in unknown place.
9	Gives a display of the streets around you.
10	It could be of great use if you are lost or in an unfamiliar city or state.
11	The system allowed you to know where you were and where other streets were located.
12	The moving dot made orienting myself very easy when it came to be time to make a turn, and the display was much clearer than a map.
13	I could see all the roads and their location on the map as I drove.

Table 3-5. Narrative responses to Question 19 in modified survey questionnaire administered to simulated driving subjects - 'Here Is What I Dislike About the System.'

Subject	Narrative Response to Question
1	It did affect my driving at times, because I was paying attention to the map, when the route I had planned to take ended up being incomplete.
2	Changing quadrants.
3	It [the map] is highly inaccurate to the point of absolute uselessness.
4	It doesn't tell you if streets are accessible. It also doesn't give distances so that you know how far you are from somewhere. It also forces you to stop looking at the road.
5	The roads which are not on the actual [driving environment] should not have been on the [map].
6	[Some] items listed on the display (landmarks) are not seen on the actual [driving environment]. The direction you headed seemed opposite to the way I read the screen---i.e., I approached a stop sign & turned left, when it looked as if I should turn right to obtain my goal end point.
7	Every so often there might be a street that does not exist and consequently 'throws' you off chosen course.
8	Takes up too much room. Some people may be afraid of the technology and cost.
9	Doesn't show a big picture or beginning and end points.
10	It is not something you see every day. It was hard to get used to. It sometimes made me feel as if I was driving totally the wrong way.
11	It was difficult to know which way to turn without [stopping] to analyze your direction. (For example, when traveling south [and] you must turn left, but an immediate view of the screen will make you want to turn the opposite direction.) It takes some time to get used to as a navigational aid.
12	I would not be able to consult it in traffic, and since the display can't be big enough to always display my destination as well as my current location, it led to feeling uncertain about the obstacles in between.
13	I was distracted by the IVNS. It confused me when I would turn left, but the map would show that I had turned right.

Table 3-6. Narrative responses to Question 20 in modified survey questionnaire administered to simulated driving subjects - ‘Here Is How the System Could Be Improved.’

Subject	Narrative Response to Question
1	[You] may want the map near the dash so that a driver can first look down for a brief second & check where they are or need to go.
2	[Improve the method for] changing quadrants.
3	Accuracy. Include only roads that actually exist.
4	Give street directions, such as 1-way [streets]. It [the display} could also be closer to the line of driving sight.
5	[Don’t include] roads which are not on the actual [driving environment] on the [map].
6	Directional states could be added on the display (N, S, E, W).
7	Personally, for me, smaller scale grids might be of help so I can also [figure] where I have been stopping or going around in circles.
8	Set destination and the screen will show you the quickest way to get there.
9	Have a line of directions to end point or show more area than just a few streets in the immediate proximity.
10	Use a voice operated system (so the computer would tell you [that] you are at the corner of 35W and 35th Street as an example).
11	The system could provide a view from the driver’s perspective on the map, or show L/R turn options in addition to NSWE directions.
12	I can’t think of any ways. It’s still a lot better than a map.
13	I do not know.

CHAPTER 4

STATIC HF/E ANALYSIS OF GAINS INTERFACE DESIGN FEATURES

This chapter concerns itself exclusively with the design and legibility features of the GAINS digital map, as assessed using two sets of criteria: (1) subjective responses from on-road and simulated driving respondents to questions in the survey questionnaires dealing with design features of GAINS (Section 4.1); and (2) published guidelines and recommendations pertaining to HF design of visual displays (Section 4.2). Both sets of criteria are useful. Observations from on-road and simulated driving respondents offer insights into strengths or weaknesses of digital map design and legibility features under actual conditions of driver interaction with the system. Published guidelines and recommendations offer commonly accepted criteria for presenting information on a visual display that should serve as a reference for any information display system targeted for public use.

Because GAINS is a prototype system, it was judged that a HF/E evaluation of the GAINS hardware (i.e., keyboard, remote, control functions, etc.) would not be useful, in that the hardware design features of the prototype system differ markedly from those of commercially available in-vehicle information systems. On the other hand, it is likely that some design features of the digital map display will not undergo marked change in any transition from a prototype to a commercial system, and that a HF/E evaluation of the design and legibility features of the digital map therefore is warranted.

4.1. SUBJECTIVE RESPONSES FROM ON-ROAD AND SIMULATED DRIVING RESPONDENTS PERTAINING TO DESIGN AND LEGIBILITY OF GAINS DIGITAL MAP DISPLAY

Survey questionnaire responses of Mn/DOT employees, following on-road use of GAINS, offer a number of insights into design and legibility features of the digital map display, in terms of both strengths and weaknesses. Forced choice questions 17-20 in the survey questionnaire (Appendix A) deal respectively with user opinions regarding the ease of seeing, reading, and understanding the digital map display, plus the colors used. Responses to all of these questions are mixed. As shown in Figures 2-6 through 2-9 (Section 2.4.1), the majority of respondents answered positively regarding each of the design and legibility features addressed by the 4 questions, but there also were negative responses for each question.

The narrative comments and responses on the survey questionnaire from on-road driving respondents provide more insight into specific user support or concerns regarding particular design and legibility features of the digital map display (Section 2.4.2). Referring to comments in Table 2-4, 3 respondents liked the accuracy of the vehicle indicator on the map (which suggests that the vehicle icon was readily detectable), 2 liked the map being readable and clear, and 1 liked the colors.

Conversely, referring to comments in Table 2-1 and 2-5, 3 respondents said the display/mapped area was too small, 3 said the location of the vehicle indicator was inaccurate, 1 disliked the vehicle indicator blending in with the road colors, 1 disliked the small fonts used for some of the information displayed, and 1 noted that the display was impossible to read with sunglasses. In addition, 3 respondents had difficulty with the zoom in/zoom out feature of the map display.

The most common legibility problem cited by on-road driving respondents pertains to difficulty in reading the display on bright, sunny days. This problem is the focus of a total of 5 negative comments in Tables 2-1 and 2-5. It is likely that viewing problems would be reduced for an IVNS display recessed into the dash. Nevertheless, it is possible that sunny days and use of sunglasses may cause viewing problems with IVNS technology generally, regardless of display placement.

Relative to subjective responses from on-road driving respondents, those from simulated driving Ss are more strongly favorable regarding design and legibility features of the GAINS digital map display. Forced choice questions 12-15 in the modified survey questionnaire (Appendix H) deal respectively with user opinions regarding the ease of seeing, reading, and understanding the digital map display, plus the colors used. Results for these questions summarized in Section 3.5.3 (Figures 3-16 through 3-19, 3-22) indicate that most simulated driving respondents agree or strongly agree with statements that the map display is easy to see, read and understand, and that they like its colors. The disproportionate number of favorable responses for Questions 12, 14 and 15 (Figures 3-16, 3-18 and 3-19) is statistically significant at the $p<.05$ level.

However, narrative responses from the simulated driving Ss (Section 3.5.3, Tables 3-4 and 3-5) are more mixed regarding the design and legibility features of the GAINS digital map display. As summarized in Table 3-4, 6 respondents liked the broad visual perspective that the map provides about vehicle position, 2 liked the vehicle icon, 2 liked the clarity of the display, and 1 liked the display colors. Conversely (Table 3-5), 5 respondents disliked various features of the visual perspective of the map (i.e., changing quadrants, map inaccuracy, perspective not large enough, lack of distance indicators).

Narrative responses in Table 3-5 also indicate that 6 simulated driving respondents disliked the fact that some streets shown on the digital map did not actually exist in the simulated driving environment. These complaints, of course, reflect a deliberate feature of the experimental design and are not relevant to the inherent design features of the digital map. That is, not all streets shown on the digital map were modeled for the simulated driving environment (Section 3.2), and under the test driving condition, some segments of streets that were modeled for the simulated driving environment were removed to make navigation more challenging (Appendix J).

Perhaps the most intriguing series of complaints that emerge from narrative responses of the simulated driving Ss (Table 3-5) pertain to the confusion that a number of Ss experienced in interpreting left-right movements of the vehicle icon on the map with the directions of left and right turns in the simulated driving environment---four respondents registered this complaint. The source of this confusion may stem from the fact that the 'handedness' of the east and west directions changes when a vehicle approaches an intersection from the north versus the south, whereas the 'handedness' of the movement of the vehicle icon on the digital map for turns to the east or west does not similarly vary. For example, east is to the driver's right for a northbound vehicle, but to the driver's left for a southbound vehicle. However, the vehicle icon on the digital map always moves to the driver's right if the vehicle turns east from either the northbound or southbound direction. Similarly, west is to the driver's left for a northbound vehicle, but to the driver's right for a southbound vehicle. However, the vehicle icon on the digital map always moves to the driver's left if the vehicle turns west from either the northbound or southbound direction.

In other words, in terms of the spatial coordinate axes of the driver, visual feedback from the direction of vehicle icon movement on the digital map is reversed 180 deg from that of the vehicle itself for turns to the east of a southbound vehicle, and likewise for turns to the west of a northbound vehicle. Degradative effects on behavioral control of this type of spatial displacement of visual feedback are immediate and profound, and have been extensively studied [10-12]. They very likely account for problems with directional disorientation and confusion reported by some of the simulated driving Ss.

4.2. PLACEMENT AND LEGIBILITY OF GAINS DIGITAL MAP DISPLAY RELATIVE TO PUBLISHED GUIDELINES AND RECOMMENDATIONS

Widespread occupational use of visual display terminals (VDTs) has prompted development and publication of guidelines and standards pertaining to display placement, and to the visibility and legibility of displayed information. This section addresses the degree to which the GAINS display, and features displayed thereon, adhere to these guidelines.

Because of design constraints of the vehicle cab, coupled with the imperative for maintaining a clear field of view for the driver, placement of an IVNS display encounters immediate difficulty relative to general guidelines for VDT placement to enhance legibility. In this study for example, the viewing distance for the GAINS display under both on-road and simulated driving conditions was approximately 0.6 m (2 ft), whereas the recommended viewing distance for a VDT is .41 to .51 m [13, p. 400]. Similarly, the GAINS display screen was placed approximately 45 deg to the driver's right, whereas the recommendation is that the VDT face be perpendicular to the viewer's normal line of sight (IBID). However, the placement of the GAINS display about 15 deg below the driver's line of sight in this study does conform to VDT placement recommendations for seated viewers (IBID).

Table 4-1 compares actual sizes on the display screen of two features on the GAINS digital map display---the vehicle icon and names of major streets---relative to recommended sizes of displayed text for a viewing distance of 0.6 m. Two different sources for VDT design guidelines are cited. One provides recommendations in inches for sizes of displayed text at different viewing distances under average illumination [13, p. 367]. The second recommends that the preferred character height for displayed text is 20-22 min of arc [14, p. 27]. The vehicle icon and names of major streets are selected as features for evaluation because the ability of the driver to visually interpret information

Table 4-1. Sizes of vehicle icon and street names on GAINS digital map display relative to published guidelines and recommendations.

GAINS Display Feature	Viewing Distance	Actual Size on Display Screen	Recommended Size (mm)	Reference
Vehicle Icon	0.6 m	7 mm	5.1 mm*	[13, p. 367]
		41 min arc	20-22 min arc	[14, p. 27]
Names of Major Streets	0.6 m	3.5 mm	5.1 mm*	[13, p. 367]
		21 min arc	20-22 min arc	[14, p. 27]

*Assuming average illumination.

on the digital map display critically depends upon the legibility of these two features.

The analysis in Table 4-1 indicates that the size of the vehicle icon exceeds legibility guidelines specified by both reference sources. Displayed sizes of major street names, however, meet legibility criteria specified by the latter reference [IBID], but not by the former [13, p. 367]. Clearly, the ANSI guidelines [14] for text displayed on VDTs are less stringent than those offered by Woodson and colleagues [13]. The analysis in Table 4-1 suggests that with the GAINS display, most viewers should have little difficulty in detecting the position and movement of the vehicle icon at a viewing distance of 0.6 m, but that reading names of the major streets at the same distance may present difficulty for some viewers.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

This research project is designed to assess how driver interaction with a prototype in-vehicle navigation system, termed GAINS, may influence both objective and subjective measures of driver performance and use of the system under both on-road and simulated driving conditions. The project also addresses HF/E design features of the system. It is anticipated that the project will benefit Mn/DOT, Etak, and the intelligent transportation system (ITS) community generally, through: (1) documentation of effectiveness, safety, and usability qualities of this IVNS technology; (2) identification of possible design improvements that can be made to the system; and (3) possible generalization of the findings to other IVNS applications. The results therefore should improve our understanding of the human and societal implications related to use of IVNS technology, and in a more limited sense to use of other in-vehicle systems designed to provide information to travelers. Implications of the results obtained from the different phases of the research are discussed in the next section; conclusions supported by the findings are itemized in Section 5.3.

5.1. DISCUSSION

Subsections below discuss findings from on-road evaluation of GAINS (Chapter 2), simulation testing (Chapter 3), and HF/E evaluation of system design (Chapter 4).

5.1.1. Implications of Results From On-Road Evaluation of GAINS

Responses to the forced choice questions contained in the survey questionnaire administered to Mn/DOT employees after on-road use of GAINS (Chapter 2) indicate that no attribute of GAINS addressed by these questions attracted the uniform approval or disapproval of most or all respondents (Section 2.4.1, Figures 2-1 through 2-7). Possible insight into this lack of uniformity in respondent opinion about GAINS is provided by comments listed in Table 2-1, which address individual experiences on the part of some of the respondents with GAINS. The comments in Table 2-1 support the following conclusions:(1) some respondents found the system difficult to use (Table 2-1, Comments 1, 3, and 7); (2) the digital map may not be up to date and may not contain information about some features of interest to the user (Table 2-1, Comments 2, 9, and 10); (3) nevertheless, the system can benefit navigation (Table 2-1, Comment 8); (4) reading the map display may be difficult under some conditions (Table 2-1, Comments 5 and 6); and (5) one respondent reports almost having an accident while looking at the display (Table 2-1, Comment 4).

It can be argued that these respondent comments may be applicable to IVNS technology generally, despite evident limitations of the present study (Section 5.2). Thus, although such technology may aid navigation, we may also expect IVNS users to encounter occasional difficulties with reading the digital map, lack of currency and accuracy of the information presented, and general difficulty in using the system, and distraction stemming from visual interaction with the display that may adversely affect driving performance and safety.

These conclusions are supported further by responses to the narrative questions in the survey questionnaire completed by Mn/DOT employees after on-road use of GAINS (Chapter 2, Tables 2-2 through 2-6). Difficulties with using the system cited in Tables 2-2, 2-3, and 2-5 can be grouped into four broad categories: (1) difficulty interacting with GAINS hardware and/or software (18 responses); (2) map inaccurate and/or Skymap information incomplete or not up to date (11 responses); (3) difficulty viewing the display (9 responses); and (4) instructions provided for system use unclear (3 responses).

As suggested in Section 2.3.5, reported difficulties interacting with GAINS hardware and/or software may largely be attributed to the prototype nature of the system. Responses addressing incomplete/ inaccurate system information and viewing difficulties may point to more fundamental shortcomings with the HF design of IVNS technology. Some of the viewing problems may be attributed to the relatively exposed position of the GAINS display (Appendix B, Photograph B-1). It is likely that viewing problems would be reduced for an IVNS display recessed into the dash. Nevertheless, it is possible that use of sunglasses (Table 2-5, Respondent 19) and sunny days may cause viewing problems with IVNS technology generally, regardless of display placement. If so, incorporation of anti-glare technology as a routine feature of in-vehicle information system displays should be carefully considered.

Incomplete/inaccurate information may be attributed to loss of GPS calibration, software errors, and/or the rapidly changing nature of the traffic grid and commercial development in the U.S. One implication of the latter point is that in order to maintain accurate system information, IVNS users may be required to update their system software at regular intervals. It is possible that incomplete/ inaccurate information may prove to be a general problem with IVNS technology.

As tabulated in Table 2-4, despite its evident shortcomings respondents also found a number of things to like about GAINS. Positive responses about the system listed in Table 2-4 can be grouped into 5 categories: (1) map display confirmed vehicle location and aided navigation (11 responses); (2) system is accurate and easy to use (5 responses); (3) address location feature helpful (2 responses); and (4) system is good source for points of interest and general travel information (2 responses). It is likely that the popularity that IVNS technology currently appears to attract may be attributed, at least in part, to sentiments voiced in these responses.

As tabulated in Table 2-6, respondents offer a number of suggestions for improving GAINS. These can be grouped into four broad categories: (1) improve usability of system hardware and/or software (10 responses); (2) expand capabilities of system and scope of information presented (6 responses); (3) improve accuracy of map display and/or information presented; and (4) improve instructions to aid understanding. Recommendations pertaining to improving system usability largely can be linked to the prototype nature of the system. However, recommendations calling for changes/improvements in system capabilities and accuracy, scope of information presented, and system instructions likely are relevant to IVNS technology generally.

The mix of narrative comments about GAINS listed in Tables 2-2 through 2-6 provide some insight into the range of responses provided to the forced-choice questions (Questions 12-23) in the survey questionnaire (Section 2.4.1, Figures 2-1 through 2-5). Some respondents find the system difficult to use; others find it easy. Some respondents find the system inaccurate; others remark on its accuracy. Some respondents are satisfied with the system capabilities; others call for expanding system capabilities and the scope of information presented. Some respondents appear to be highly frustrated with using the system; others appear to be delighted. These seemingly contradictory findings support at least two general observations regarding IVNS technology. First, system usability and reliability are likely to represent major determinants of customer acceptance of such systems. Second, even with highly reliable and useable systems, there is likely to be a wide range of individual differences in relation to customer acceptance.

As with Comment 4 in Table 2-1, one response in Table 2-5 (Respondent 19) calls attention to possible driving safety problems that may occur during interaction with the system. Among all the narrative comments, it may be argued that the two complaints in Tables 2-1 and 2-5 pertaining to how visual interaction with the display interfered with driving are the most critical, in that they suggest the possibility of an adverse effect of driver interaction with a digital map display on driving safety, at least for some drivers. In terms of ultimate acceptance by the driving public, the auto industry and government regulators, the driving safety implications of IVNS technology may prove to be a key consideration governing ultimate acceptance and success of the technology.

5.1.2. Implications of Subjective Responses From Simulated Driving Subjects

Compared with mixed responses of the on-road driving respondents to all of the forced choice questions in the survey questionnaire dealing with GAINS design and usability (Section 5.1.1), the distribution of responses of the simulated driving Ss to comparable forced choice questions contained in the modified survey questionnaire (Section 3.5.3; Appendix H) are more strongly favorable for a number of questions. In particular, for questions dealing with the usability of GAINS, most simulated driving Ss agree or strongly agree with statements that the system is easy to understand and to learn (Figures 3-11, 3-12, 3-17). However, responses of these Ss are more mixed to statements that the system aided navigation, interfered with driving, and was useful (Figures 3-13, 3-15, and 3-20).

Narrative responses from the simulated driving Ss (Section 3.5.3, Tables 3-4 and 3-5) provide insight into why the navigational utility of the system received mixed reviews from these respondents. Specifically, almost half of the simulated driving respondents liked the navigational benefit provided by the broad visual perspective of vehicle position displayed on the map (Table 3-4), but about half of these respondents also disliked the fact that some streets shown on the digital map did not actually exist in the simulated driving environment (Table 3-5). The latter complaints stem from the fact that not all streets shown on the digital map were modeled for the simulated driving environment (Section 3.2), and under the test driving condition, some segments of streets that were modeled for the simulated driving environment were removed to make navigation more challenging (Appendix J). Although lack of correspondence between the digital map and the simulated driving environment represents an artificial feature of this study, these complaints suggest that an on-road IVNS display also may prompt user dissatisfaction if it does not accurately portray the driving environment.

A number of simulated driving Ss complained about confusion in interpreting left-right movements of the vehicle icon on the map with the directions of left and right turns in the simulated driving environment (Table 3-5). As noted in Section 3.5.3, the source of this confusion may stem from the fact that the 'handedness' of the east and west directions changes when a vehicle approaches an intersection from the north versus the south, whereas the 'handedness' of the movement of the vehicle icon on the digital map for turns to the east or west does not similarly vary. As a consequence, with reference to the spatial coordinate axes of the driver, visual feedback from the direction of vehicle icon movement on the digital map is reversed 180 deg from that of the vehicle itself for turns to the east of a southbound vehicle, and likewise for turns to the west of a northbound vehicle. Degradative effects on behavioral control of this type of spatial displacement of visual feedback [10-12] very likely account for problems with directional disorientation and confusion reported by some of the simulated driving Ss.

It is interesting that similar problems with spatial disorientation were not reported by any of the on-road driving respondents (compare narrative responses in Table 2-6 with those in Table 3-5). A possible reason for this discrepancy may be that the simulated driving Ss relied on the digital map to a much greater degree for directional guidance at intersection turns than did the on-road driving respondents.

In a recapitulation of observations by two on-road driving respondents (Tables 2-1 and 2-5), two simulated driving Ss in Table 3-5 (Ss 1 and 4) also call attention to possible driving safety problems that may occur during interaction with the system. Both of these respondents indicate that paying attention to the digital map interfered with their attention to the road and affected their driving. Indeed, based on pooled results from all simulated driving Ss, greater variability under test relative to control conditions was observed for 6 of 7 dependent measures of simulated driving performance (next section).

As with the on-road driving respondents (Table 2-6), simulated driving Ss also offer a number of suggestions for improving GAINS (Table 3-6). These can be grouped into four categories: (1) improve presentation and scope of map perspective (3 responses); (3) improve accuracy of map display (2 responses); (3) provide directional indicators (N,S,E,W) on map (2 responses); and (4) place display closer to driver's line of sight (2 responses). It is interesting that no on-road driving respondent recommended directional indicators. This may reflect the fact that the navigational demands for the simulated driving task were more intense than those for on-road driving.

5.1.3. Implications of Results From Simulation Testing

The simulation testing research reported in Chapter 3 is aimed at addressing the question of how driver interaction with GAINS influences variability in simulated driving performance. Despite limitations of the study (Section 5.2), it can be argued that the findings cited in Chapter 3 have implications for understanding how interaction with IVNS technology may influence driving performance generally, with possible consequent effects on driving safety.

This argument has validity only if it can be shown that the design of the simulation testing research actually addresses the main effect of driver interaction with GAINS on simulated driving performance. In fact, the head turn results reported in Figure 3-3 appear to substantiate a major premise of the experimental design (Section 3.4.2), namely that Ss would be more likely to interact with the GAINS digital map for navigation purposes under the test condition (no verbal turning instructions provided) compared with the control condition (verbal turning instructions provided). The results therefore imbue the study with a degree of ecological validity by suggesting that differences in visual interaction with the GAINS digital map between the control and test conditions may have made a substantial contribution to differences observed in dependent measures of simulated driving performance between the two conditions.

Table 5-1 compares results between the control and test conditions for the key dependent measures of simulated driving performance (Section 3.5.2). For each of the 9 measures itemized in the table, mean, SD, variance, maximum and minimum values are listed for performance under both the control and test driving conditions.

Results in Table 5-1 indicate that simulated driving performance under the test condition consistently differs from that under the control condition. For almost every dependent measure evaluated, simulated driving under the test condition displays greater variability in performance than that under the control condition. Specifically, a higher performance variance during the test compared with the control sessions is observed for the following measures: (1) both unfiltered and filtered measures of overall vehicle speed (Figure 3-4); (2) peak vehicle speed (Figure 3-6); (3) percent braking time (Figure 3-8); (4) number of braking adjustments (Figure 3-9); and (5) vehicle

Table 5-1. Descriptive statistics for dependent measures of simulated driving performance under control versus test conditions.

DEPENDENT MEASURE	UNITS	N	CONTROL CONDITION					TEST CONDITION					STATISTIC	p
			Mean	SD	Variance	MAX	MIN	Mean	SD	Variance	MAX	MIN		
Head Turns	no./min	12	1.1	1.1	1.2	3.1	0	2.8	1.8	3.1	6.1	0.65	t_{11}=-4.88 (2-tailed)	<0.00**
Task Completion Time	min	12	13.8	1.2	1.4	11	15	24.9	5.7	32.5	16	31	N/A	N/A
Overall Vehicle Speed (Unfiltered)	kph	13	62.5	7.7	59.7	75.7	53.0	59.6	10.4	108.2	81.2	46.6	$F_{1,12}$=1.7	0.22
Overall Vehicle Speed (Filtered)	kph	13	66.7	7.6	58.4	80.3	56.9	68.0	10.8	117.6	87.3	50.6	$F_{1,12}$=0.5	0.49
Peak Vehicle Speed	kph	13	93.8	7.8	60.8	107.3	83.9	96.7	12.0	143.5	114.8	74.6	$F_{1,12}$=2.0	0.18
Braking Pressure	V	13	0.24	0.08	0.064	0.35	0.12	0.21	0.06	0.036	0.33	0.10	$F_{1,12}$=3.6	0.08*
Percent Braking Time	%	13	12.8	3.5	12.2	20.6	8.0	16.4	6.7	44.8	30.2	9.0	$F_{1,12}$=2.6	0.14
Number of Braking Adjustments	number	13	1.9	0.3	0.09	2.3	1.3	1.6	0.4	0.2	2.3	1.1	$F_{1,12}$=11.0	0.01**
Vehicle Heading Error	SD	13	69.5	3.3	11.1	78.2	66.1	95.2	11.8	139.9	81.9	111.3	$F_{1,12}$=75.0	<0.00**

*significant at p<.10 level

**significant at p<.05 level

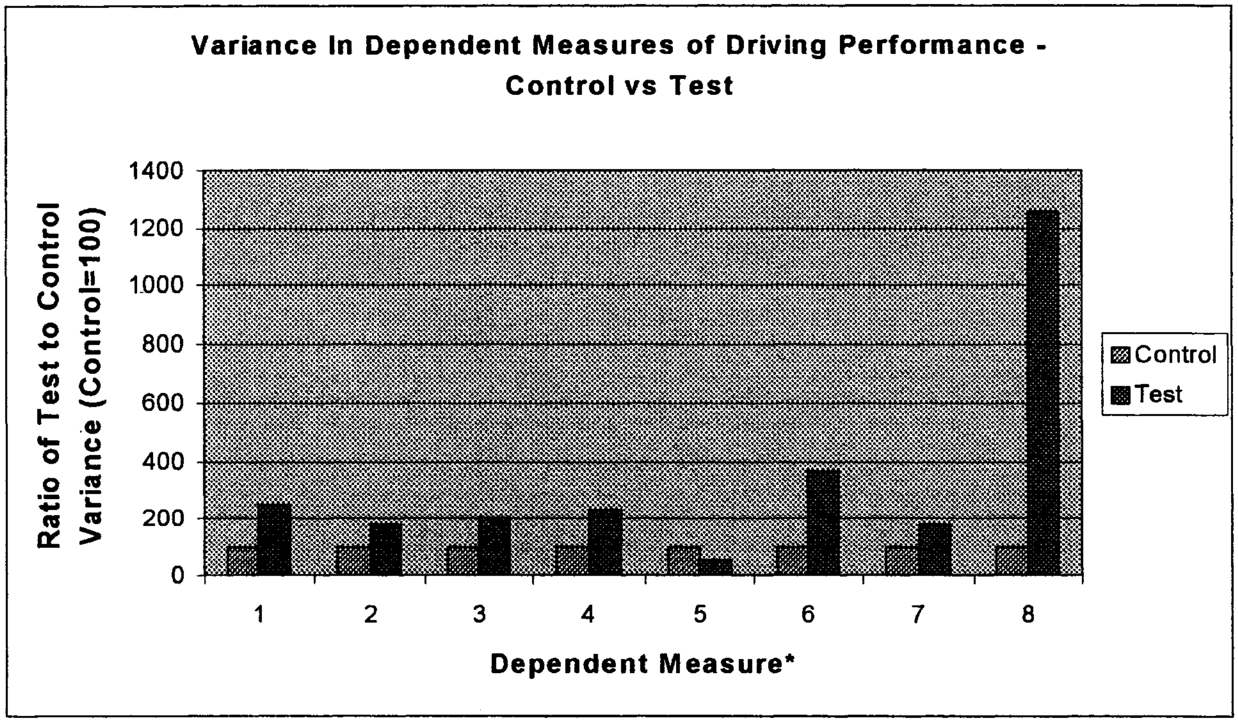


Figure 5-1. Ratio of variance of different dependent measures of simulated driving performance for test relative to control condition, with variance for control condition normalized to a value of 100 for each measure (*dependent measures indicated by numbers on X axis: 1 = head-turns/min; 2 = overall vehicle speed (unfiltered); 3 = overall vehicle speed (filtered); 4 = peak speed; 5 = braking pressure; 6 = percent braking time; 7 = number of braking adjustments; 8 = vehicle heading error).

heading error (Figure 3-10). Only for the measure of braking pressure (Figure 3-7) is performance under the test condition less variable than that under the control condition.

Figure 5-1 graphically illustrates how variability in driving performance is higher under the test relative to the control condition for all but one dependent measure. In the figure, the ratio of variance in eight different dependent measures of simulated driving performance for test relative to control condition is plotted, with the variance for the control condition normalized to a value of 100 for each measure. For all dependent measures except braking pressure, variance under the test condition exceeds that under the control condition by factors ranging from 1.8 (overall vehicle speed (unfiltered) and number of braking adjustments) to 12.6 (heading error).

As shown in Table 5-1, for 3 dependent measures of simulated driving performance---braking pressure, number of braking adjustments, and heading error---differences in mean levels of performance between the control and test conditions are statistically significant. For heading error, performance under the test condition is significantly worse (higher error) than that under the control condition. For braking pressure and number of braking adjustments, levels under the control condition are significantly higher than those under the test condition.

It can be argued that the variance findings may have implications for predicting possible effects of IVNS technology on driving safety. A more variable level of driving performance implies less consistent control of the vehicle by the driver. This in turn may expose the vehicle and the driver to an elevated level of accident risk, in the sense that more pronounced fluctuations in vehicle speed, braking, and/or heading may elevate the risk of such incidents as collisions or departure from the roadway. Indeed, as noted in the previous section, two on-road users of GAINS reported almost having an accident while interacting with the system. The findings from the simulation testing suggest that as usage of in-vehicle information systems becomes more widespread, possible adverse effects of driver interaction with such systems on driving safety should be closely monitored.

Under the test condition, 7 Ss found the end point of the navigation environment (Appendix J) within the 30 min time limit, whereas testing sessions for the remaining 6 Ss were terminated after 30-31 min of simulated driving because they still had not successfully navigated to the end point. The route trajectories for the test sessions plotted in Appendix L indicate distinct differences in navigation strategies between those who completed the task successfully, and those who did not. These observations suggest that there may be a difference in spatial memory skill between the successful and unsuccessful navigators. More broadly, the findings imply that there is likely to be a wide range of individual differences in relation to the degree to which users are able to effectively interact with, and thereby derive benefit from, in-vehicle information systems. As noted in the previous section, this in turn may result in a wide range of individual differences in customer acceptance of such systems.

5.1.4. Implications of Results From HF/E Analysis of GAINS Design Features

Responses to questions on subjective response questionnaires (Appendices A and H) from both on-road and simulated driving users of GAINS (Section 4.1) support two broad conclusions regarding the design and legibility of the GAINS digital map display. First, the need for a small display is a more or less common feature of IVNS technology generally, because of space constraints, but this in turn introduces possible legibility problems plus a need for a zoom in/zoom out feature to provide sufficient map detail under some conditions. Respondent comments suggest that the latter operation should be made as seamless as possible, with minimal requirement for user intervention. Restraining the display to a fixed level of detail represents an alternative approach.

Second, there is a large range of individual differences in likes and dislikes pertaining to design and legibility features of the GAINS digital map. It is highly likely that this is a common feature of IVNS information displays generally. To deal with this issue, system designers should consider two strategies: (1) a priority focus on resolving problems (such as poor legibility on bright days) that attract widespread user concern; and (2) a well-defined program of usability testing to identify and abate problems at an early stage.

At the display viewing distance of about 0.6 m employed in this study for both the on-road and simulated driving analyses, the displayed size of the vehicle icon meets guidelines for the size of features displayed on VDTs recommended by two different sources, whereas the displayed size of names of major streets meets guidelines recommended by one source but not those recommended by the other (Section 4.2). Because of constraints placed on in-cab placement of the display dictated by vehicle cab design coupled with the need for unimpeded vision by the driver, both the viewing distance and the viewing angle relative to driver line-of-sight for the GAINS display exceed recommended guidelines for VDTs.

It is not clear that recommended guidelines for VDT design and feature legibility apply to IVNS displays, given that this technology has been primarily marketed for general public rather than occupational use. We are unaware of any published guidelines pertaining to the legibility and viewability of IVNS displays. However, it can be argued that available guidelines and recommendations pertaining to VDTs offer commonly accepted criteria that could, and perhaps should, serve as a reference for any information display system targeted for public use. In this study, it should be emphasized that GAINS, as a prototype system, made use of a regular computer screen rather than a customized display embedded in the vehicle dashboard. The relevance of the findings and conclusions to commercial IVNS displays therefore remains to be established.

5.2. LIMITATIONS OF STUDY

A number of limitations of this study should be addressed. Methods used to collect survey questionnaire responses from Mn/DOT employees regarding on-road use of GAINS (Chapter 2) likely provided a biased set of responses. For example, there was no control over the age and gender distribution of the respondents. There also is a paucity of responses from older drivers, because most Mn/DOT fleet vehicle users are below retirement age. This represents a distinct shortcoming of the present study, in that other research has shown that relative to younger drivers, older drivers have more difficulty in using IVNS technology [8].

As employees of a state department of transportation, the respondents may have had more familiarity and interest with in-vehicle technological systems than the general population. In addition, it is possible that use of Mn/DOT fleet vehicles containing GAINS attracted Mn/DOT employees interested in and possibly favorably disposed toward IVNS technology, while repelling those who do not share such an interest or who are put off by computer-based technological innovation. The latter point is of particular concern in that, as implemented for this study, the system requires some user interaction with the computer.

There also are a number of limitations to the simulation testing phase of the study (Chapter 3). As with the on-road evaluation of the system, older drivers were not included in the pool of simulation testing Ss. The small number of Ss evaluated (N=13) limits the generalizability of the results. The simulation testing methodology is designed to assess the main effect of visual interaction by drivers with GAINS on variability in the dependent measures collected---the head turn results (Section 3.5.1) indicate that the frequency of this interaction was almost 3 times greater under the test relative to the control condition. Nevertheless, the methodology does not rule out the possibility that other factors may have contributed to the results obtained. For example, driver uncertainty and anxiety associated with navigating through an unknown driving environment without assistance under a perceived time limit may have contributed to differences in driving performance observed in the test relative to the control condition.

An important confounding factor that also may have influenced the simulation testing results is the small delay in visual feedback of driver steering wheel movements that was present throughout both the control and test sessions, and that clearly impaired the ability of Ss to accurately maintain the position and trajectory of their vehicle in the right lane of the roadway. This delay was caused by the complexity of the driving environment model, and resulted in a small temporal discrepancy between the timing of steering wheel adjustments by drivers, and the timing of updates to the projected visual image of the simulated environment to reflect those adjustments. Training sessions prior to both the control and test sessions were designed to help Ss acclimate to the simulated driving task before actual testing was initiated. The steering delay factor was present for both the control and test conditions. Because the control sessions always were scheduled first, it may be argued that lack of S familiarity with the demands of simulated driving, compounded by possible delay effects, should have enhanced variability in simulated driving performance under the control relative to the test condition. The actual results show an opposite effect. Nevertheless, the possible contribution of delay in visual feedback of steering wheel movements on performance differences observed between the two testing conditions cannot be ruled out.

GAINS represents a prototype version of IVNS technology. The interface design features of the system differ substantially from interface design characteristics of commercially available in-vehicle information systems. The latter typically feature recessed dashboard installation of the display, no keyboard, relatively simple control requirements, and no demand on the user to interact with a computer operating system. The interface design differences between GAINS and other commercial in-vehicle information systems, coupled with the limitations of the study outlined above, suggest that applying and generalizing results of this study to other contexts, should be treated cautiously.

5.3. CONCLUSIONS

Major conclusions supported by this study are itemized below.

1. This study evaluated a prototype in-vehicle navigation system termed GAINS, consisting of a commercially available digital map software system, digital map databases of a large area of Minnesota including the Twin Cities metropolitan area, and hardware including a GPS signal receiver, a remote control, and off-the-shelf IBM-compatible notebook and laptop PCs running Windows 95 on which the digital map software and databases were installed.
2. The evaluation comprised three phases: (1) collection of subjective responses from on-road users of the system regarding the utility, usability, appeal, and shortcomings of the system; (2) objective analysis of effects of visual interaction with the system on a series of dependent measures of simulated driving performance, coupled with collection of subjective responses from the simulated driving Ss regarding the utility, usability, appeal and shortcomings of the system; and (3) HF/E analysis of design and legibility of the system display.
3. Subjective responses from both the on-road and simulated driving respondents cite the following positive features of the system: (1) accuracy of the vehicle indicator on the map; (2) map display confirms vehicle location and aids navigation; (3) system is accurate and easy to use; (4) address location feature helpful; and (5) system is good source for points of interest and general travel information; (6) system is easy to understand and to learn; (7) display is readable, clear and easy to see; and (8) display colors are appealing.
4. Subjective responses from both the on-road and simulated driving respondents cite the following negative features of the system: (1) system difficult to use; (2) instructions provided for system use unclear; (3) digital map inaccurate, not up to date, and lacking information about some features of interest to the user; (4) reading the map display difficult under some conditions; (5) confusion and disorientation in relating left-right movements of the vehicle icon on the map with directions of left and right turns in the simulated driving environment; and (6) driving adversely affected because of the distraction of looking at the display while driving.
5. As part of their subjective responses, on-road and simulated driving respondents offer a number of suggestions for system improvement: (1) improve usability of system hardware and/or software; (2) expand capabilities of system and scope of information presented; (3) improve

presentation and scope of map perspective; (4) improve accuracy of map display and information presented; (5) improve instructions to aid understanding; (6) provide directional indicators (N,S,E,W) on map; and (7) place display closer to driver's line of sight.

6. On-road and simulated driving respondents provided a broad and sometimes contradictory mix of subjective responses regarding both the positive and negative attributes of GAINS. This indicates a wide range of individual differences in relation to the degree to which respondents were able to effectively interact with and thereby derive benefit from GAINS. The general implication of this finding is that a wide range of individual differences may exist in customer acceptance of IVNS technology generally. To deal with this issue, IVNS technology designers should consider two strategies: (1) a priority focus on resolving problems (such as poor legibility on bright days) that attract widespread user concern; and (2) a well-defined program of usability testing to identify and abate problems at an early stage.
7. The simulation testing phase of the study required development and implementation of innovative technical methodology entailing: (1) programmatic generation of a data stream of dummy GPS coordinates corresponding to vehicle position in the simulated driving environment; and (2) communication of this data stream to the GAINS digital map software system, such that the digital map display indicated and updated vehicle position in real time as simulated driving Ss traversed the simulated driving environment.
8. The simulated driving environment modeled an actual grid of streets in the southeast quadrant of Minneapolis, MN. During simulation testing, Ss were required to navigate from a start to an end point in the simulated driving environment. At each intersection, instructions regarding which way to turn at successive intersections were either provided (control condition) or not provided (test condition) to Ss. Dependent measures of driver control of vehicle speed, braking and trajectory were collected during each simulated driving trial.
9. Based on observations of head turns by simulated driving Ss, visual interaction with the GAINS digital map for navigation purposes was much frequent under the test condition compared with the control condition. These results imbue the study with a degree of ecological validity by suggesting that differences in visual interaction with the GAINS digital map between the control

and test conditions may have made a substantial contribution to differences observed in dependent measures of simulated driving performance between the two conditions.

10. For all but one dependent measure of simulated driving performance, simulated driving under the test condition displays greater variability in performance than that under the control condition. Specifically, a higher performance variance during the test compared with the control sessions is observed for both unfiltered and filtered measures of overall vehicle speed, peak vehicle speed, percent braking time, number of braking adjustments, and vehicle heading error.
11. For three dependent measures of simulated driving performance---braking pressure, number of braking adjustments, and heading error---differences in mean levels of performance between the control and test conditions are statistically significant. For heading error, performance under the test condition is significantly worse (higher error) than that under the control condition. For braking pressure and number of braking adjustments, levels under the control condition are significantly higher than those under the test condition.
12. Route trajectories for different simulated driving Ss under the test condition indicate distinct differences in navigation strategies between those who found the end point successfully and those who did not. These observations suggest that there may be differences in spatial memory skill between successful and unsuccessful navigators. The findings therefore complement the subjective response results (Point 6) in suggesting that there is likely to be a wide range of individual differences in relation to the degree to which users are able to effectively interact with IVNS technology for navigation purposes, which in turn may result in a wide range of individual differences in customer appeal of such systems.
13. HF/E analysis of legibility of selected GAINS digital map features points to the possibility of legibility problems for some map features under some viewing conditions. This issue could be addressed with a zoom in/zoom out feature. However, respondent comments suggest that this feature should be made as seamless as possible, with minimal requirement for user intervention.
14. A series of limitations of the study may limit the generalizability of the results. These include lack of representative sample population, small number of on-road and simulated driving Ss,

possible bias in responses from on-road driving Ss, presence of small feedback delay between steering wheel movements and update of visual display during simulation testing, and the prototype nature of the system evaluated.

15. Two sets of findings from this study may have implications for predicting possible adverse effects of IVNS technology on driving safety. First, four on-road and simulated driving respondents reported that visual interaction with the GAINS display interfered with and/or adversely affected their driving. Second, the more variable level of simulated driving performance observed under the test condition (Point 10) implies less consistent control of the vehicle by the driver. This in turn may expose the vehicle and the driver to an elevated level of accident risk, in the sense that more pronounced fluctuations in vehicle speed, braking, and/or heading may elevate the risk of such incidents as collisions or departure from the roadway.

16. On the other hand, responses from both on-road and simulated driving respondents indicate that GAINS definitely aided navigation and gave some Ss a comforting sense of situational awareness regarding the position of their vehicle relative to the surroundings. The implication of these observations is that in some contexts, driver interaction with IVNS technology might actually benefit driving safety by reducing hesitancy and uncertainty in driver control of the vehicle (this possibility was not assessed in this study). As usage of in-vehicle information systems becomes more widespread, the challenge therefore is to monitor possible adverse effects of driver interaction with such systems on driving safety, to adopt design improvements to reduce such effects, and to document possible safety benefits related to use of such systems.

REFERENCES

1. Smith, T.J., Human Factors Evaluation Of GAINS, A Prototype In-Vehicle Navigation System, Interim Summary Report For Completion Of Task Number 1, University of Minnesota Division of Kinesiology Human Factors Research Laboratory, Minneapolis, MN, 1997.
2. ---, Human Factors Evaluation Of GAINS, A Prototype In-Vehicle Navigation System, Interim Summary Report For Completion Of Project Work Plan Tasks Numbers 3, 4, and 5, University of Minnesota Division of Kinesiology Human Factors Research Laboratory, Minneapolis, MN, 1998a.
3. ---, 'Human Factors Evaluation of GAINS, a Prototype In-Vehicle Navigation System,' presentation to University of Minnesota Center for Transportation Studies Ninth Annual Transportation Research Conference, University of Minnesota Center for Transportation Studies, Minneapolis, MN (May 20, 1998), 1998b.
4. Stackhouse, S.P., and Burrus, M., Genesis Pilot Human Factors Test. Human Factors Evaluation of Driver Multitasking and Message Formats, Final Report, Minnesota Department of Transportation Office of Research Administration, St. Paul, MN, 1996.
5. Wade, M.G., Stackhouse, S.P., and Burrus, M., Human Factors Aspects of the Genesis Program, Final Report 1, University of Minnesota Division of Kinesiology Human Factors Research Laboratory. Minneapolis, MN, 1993.
6. Inman, V.W., Fleischman, R.N., Dingus, T.A., and Lee, C.H., 'Contribution of controlled field experiments to the evaluation of TravTek,' in Surface Transportation: Mobility, Technology, and Society, Proceedings of the IVHS America 1993 Annual Meeting, U.S. Department of Transportation, Washington, DC, 1993, pp. 659-666.
7. Perez, W.A., Fleischman, R., Golembiewski, G., and Dennard, D., 'TravTek field study results to date,' in Surface Transportation: Mobility, Technology, and Society, Proceedings of the IVHS America 1993 Annual Meeting, U.S. Department of Transportation, Washington, DC, 1993, pp. 667-673.
8. Dingus, T.A., Hulse, M.C., Mollenhauer, M.A., Fleischman, R.N., McGehee, D.V., and Manakkal, N., 'Effects of age, system experience, and navigation technique on driving with an advanced traveler information system,' Human Factors, Vol. 39, No. 2, 1997, pp. 177-199.

9. Srinivasan, R., and Jovanis, P.P., 'Effect of selected in-vehicle route guidance systems on driver reaction times,' Human Factors, Vol. 39, No. 2, 1997, pp. 200-215.
10. Smith, K.U., 'Cybernetic psychology,' in R.N. Singer (Ed.), The Psychomotor Domain, Lea and Febiger, New York, 1972, pp. 285-348.
11. Smith, T.J., and Smith, K.U., 'Feedback-control mechanisms of human behavior,' in G. Salvendy (Ed.), Handbook of Human Factors, Wiley, New York, 1987, pp. 251-293.
12. Smith, T.J., Henning, R.A., and Smith, K.U., 'Sources of performance variability,' in G. Salvendy and W. Karwowski (Eds.), Design of Work and Development of Personnel in Advanced Manufacturing, Wiley, New York, 1994, Chap. 11, pp. 273-330.
13. Woodson, W.E., Tillman, B., and Tillman, P., Human Factors Design Handbook (Second Edition), McGraw-Hill, New York, 1995.
14. American National Standards Institute, American National Standard for Human Factors Engineering of Visual Display Terminal Workstations (ANSI/HFS Standard No. 100-1988), Human Factors Society, Santa Monica, CA, 1988.

APPENDIX A

GAINS PROJECT SURVEY QUESTIONNAIRE

Minnesota
Department of
Transportation

Minnesota Guidestar

Employee Use of Guidestar Advanced In-Vehicle Navigation System (G.A.I.N.S.) Prototype’

Usability Questionnaire

Dear Mn/DOT Employee:

PLEASE COMPLETE THIS QUESTIONNAIRE IMMEDIATELY AFTER YOU RETURN FROM YOUR TRIP.

EVERY PASSENGER USING THE SYSTEM DURING THE TRIP SHOULD COMPLETE A QUESTIONNAIRE.

FOR QUESTIONS 12-23 PLEASE CIRCLE ONE NUMBER FOR EACH QUESTION TO INDICATE HOW MUCH YOU AGREE OR DISAGREE WITH THE STATEMENT.

PLEASE RETURN YOUR COMPLETED QUESTIONNAIRE TO
Farideh Amiri
Minnesota Guidestar, Mailstop 320
117 University Avenue - 2nd Floor
St. Paul, MN 55155
Office: 651-297-5653
Fax: 651-215-0409

1. Today’s Date ________

2. About when did you start your trip? ______ AM PM (circle)

3. About when did you finish your trip? ______ AM PM (circle)

4. Age ____ 5. Sex ____ 6. Your Height _____

7. Which vehicle are you using? ___ Chevrolet Lumina ___ Plymouth Minivan

8. Is this your first time using the system? ___ Yes ___ No
If 'No,' how many times have you used the system? ____

9. Which About how often do you use a computer?
___ Every day ___ 2-3 times per week ___ Hardly ever ___ Never

10. Which Which of the following system functions did you use today?
___ Directions ___ Address/Location ___ Points of Interest

11. This questionnaire is being completed by: ___ Driver ___ Other Passenger

12. The system is easy to understand.	Strongly Disagree	1	2	3	4	5	Strongly Agree
13. The system is easy to learn.	Strongly Disagree	1	2	3	4	5	Strongly Agree
14. The system helped me find my way.	Strongly Disagree	1	2	3	4	5	Strongly Agree
15. The system functioned properly.	Strongly Disagree	1	2	3	4	5	Strongly Agree
16. The system interfered with my driving.	Strongly Disagree	1	2	3	4	5	Strongly Agree
17. It was easy to see the display.	Strongly Disagree	1	2	3	4	5	Strongly Agree
18. The display is easy to read.	Strongly Disagree	1	2	3	4	5	Strongly Agree
19. It was easy to understand the information presented.	Strongly Disagree	1	2	3	4	5	Strongly Agree
20. I like the display colors.	Strongly Disagree	1	2	3	4	5	Strongly Agree
21. The remote control is easy to use.	Strongly Disagree	1	2	3	4	5	Strongly Agree
22. I found the system useful.	Strongly Disagree	1	2	3	4	5	Strongly Agree

23. The electronic map is accurate and complete.

Strongly Disagree	1	2	3	4	5	Strongly Agree

24. What kinds of technical problems, if any, did you experience?

25. What did you use the system for today?

26. Overall, what did you <u>like</u> about the system?

27. Overall, what did you <u>dislike</u> about the system.

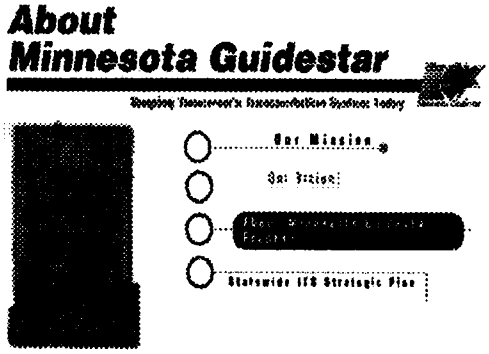
28. Do you have any suggestions for overall system improvement?

Thank you for your help in completing this questionnaire.

Minnesota Department of Transportation

⇛ For detailed information about this project, visit our Internet site at:

www.dot.state.mn.us/guidestar/oats/about.html



APPENDIX B

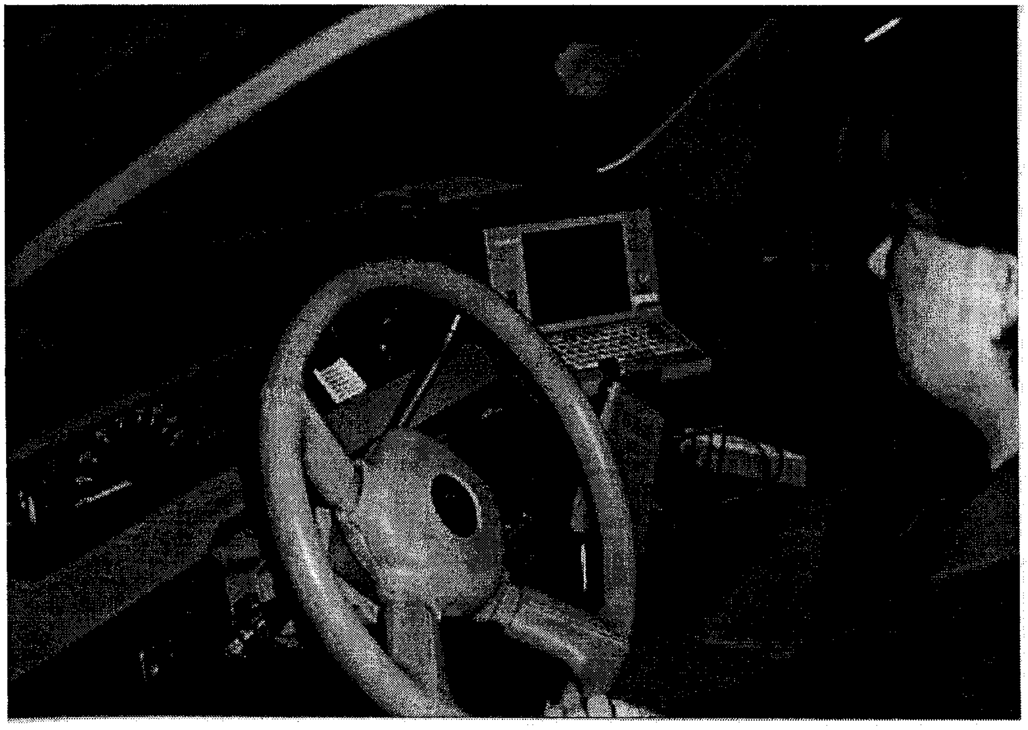
PHOTOGRAPHS ILLUSTRATING IN-VEHICLE PLACEMENT AND VIEWING CONDITIONS FOR GAINS DIGITAL MAP DISPLAY

DESCRIPTIONS OF APPENDIX B PHOTOGRAPHS

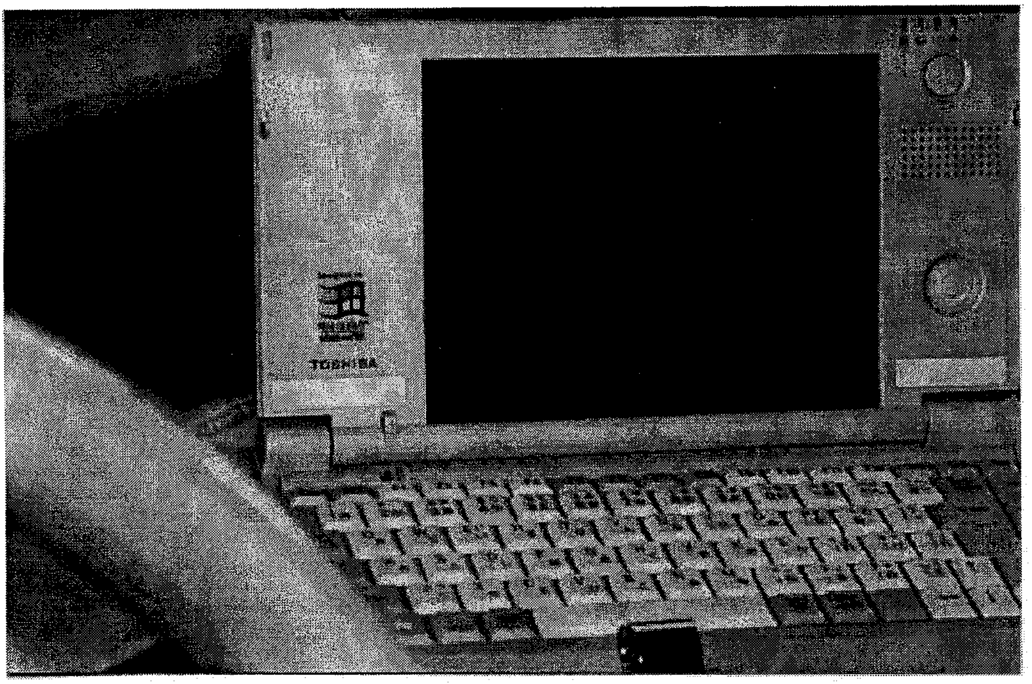
All photographs illustrate GAINS installed on a Libretto 30 PC mounted in Chevrolet Lumina. Photographs were taken in a downtown St. Paul, MN area on Nov. 6, 1997, between 8:45 and 9:00 AM, on a sunny day with the sun located in the southwest fairly low in the sky.

PHOTOGRAPH	DESCRIPTION
B-1	View of mounted Libretto from passenger seat.
B-2	View of mounted Libretto from over driver's left shoulder.
B-3	View of GAINS digital map display from driver's perspective.
B-4	View of GAINS digital map display with vehicle in shade facing west.
B-5	View of GAINS digital map display with vehicle in shade facing east.
B-6	View of GAINS digital map display with vehicle in sun facing northwest.
B-7	View of GAINS digital map display with vehicle in sun facing southeast.

Photograph B-1. View of mounted Libretto from passenger seat.



Photograph B-2. View of mounted Libretto from over driver's left shoulder.

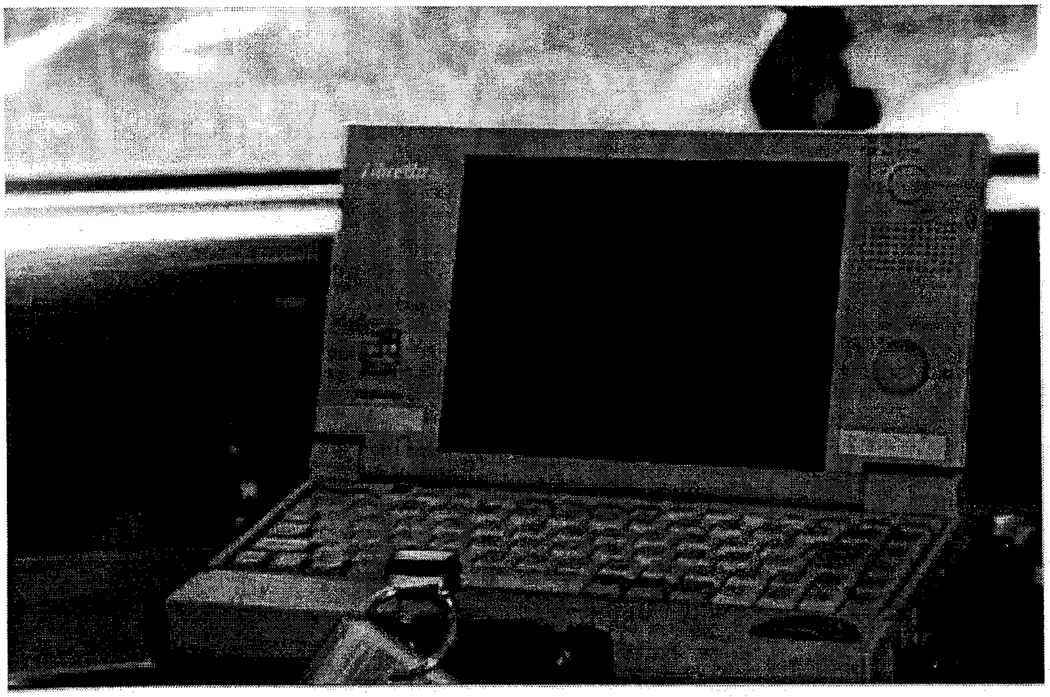


Photograph B-3. View of GAINS digital map display from driver's perspective.

Photograph B-4. View of GAINS digital map display with vehicle in shade facing west.

Photograph B-5. View of GAINS digital map display with vehicle in shade facing east.

Photograph B-6. View of GAINS digital map display with vehicle in sun facing northwest.



Photograph B-7. View of GAINS digital map display with vehicle in sun facing southeast.

APPENDIX C

MAP OF SOUTHEAST QUADRANT OF MINNEAPOLIS SHOWING STREET GRID SELECTED FOR MODELING SIMULATED DRIVING ENVIRONMENT

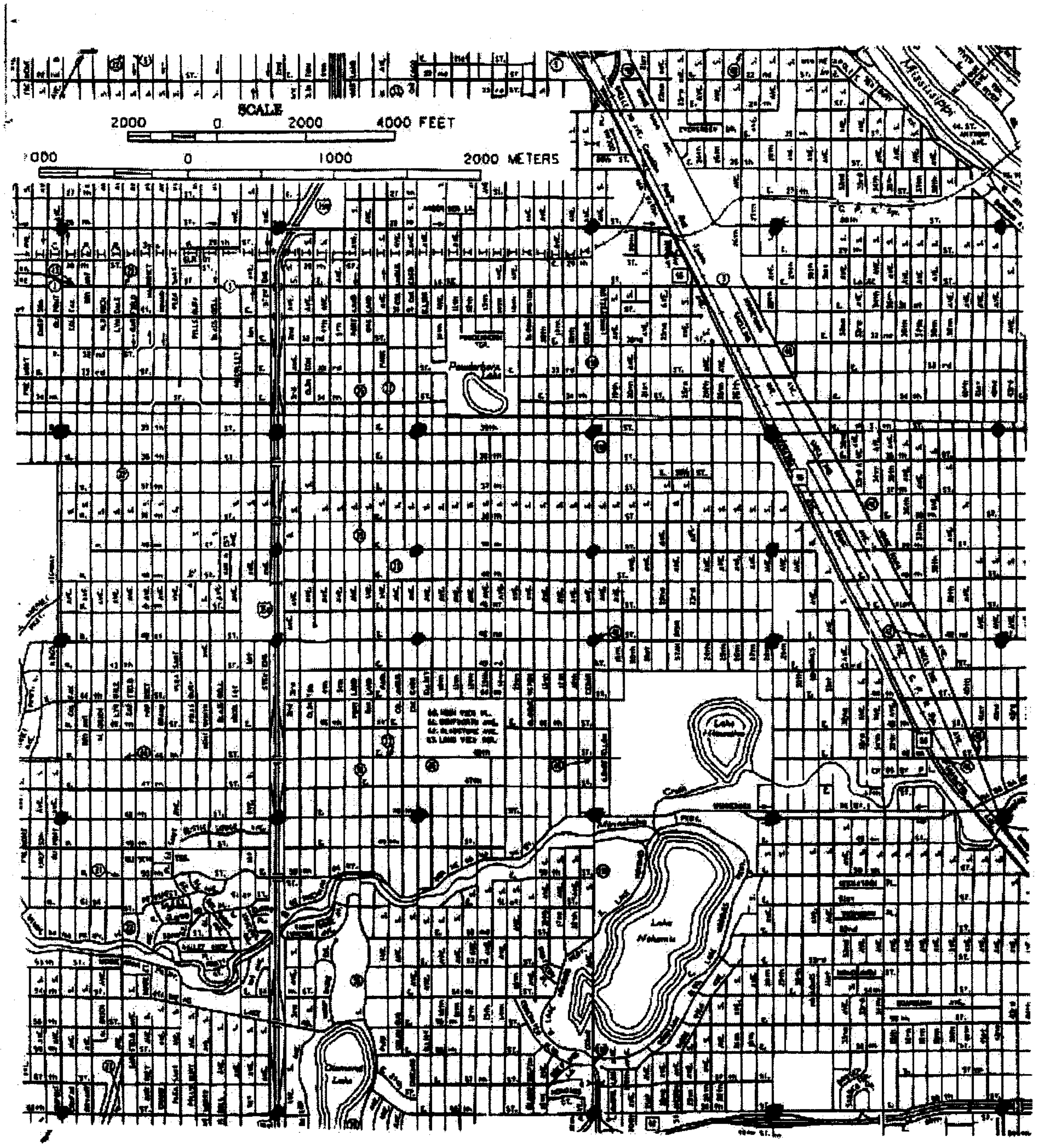


Figure C-1. Map of southeast quadrant of the city of Minneapolis, MN in which selected streets were modeled for simulated driving environment. Black dots demarcate intersections and streets that were modeled.

APPENDIX D

SCHEMATIC DIAGRAMS OF STREET GRID SELECTED FOR MODELING SIMULATED DRIVING ENVIRONMENT, WITH MODELING INSTRUCTIONS AND GRID SEGMENT DISTANCES

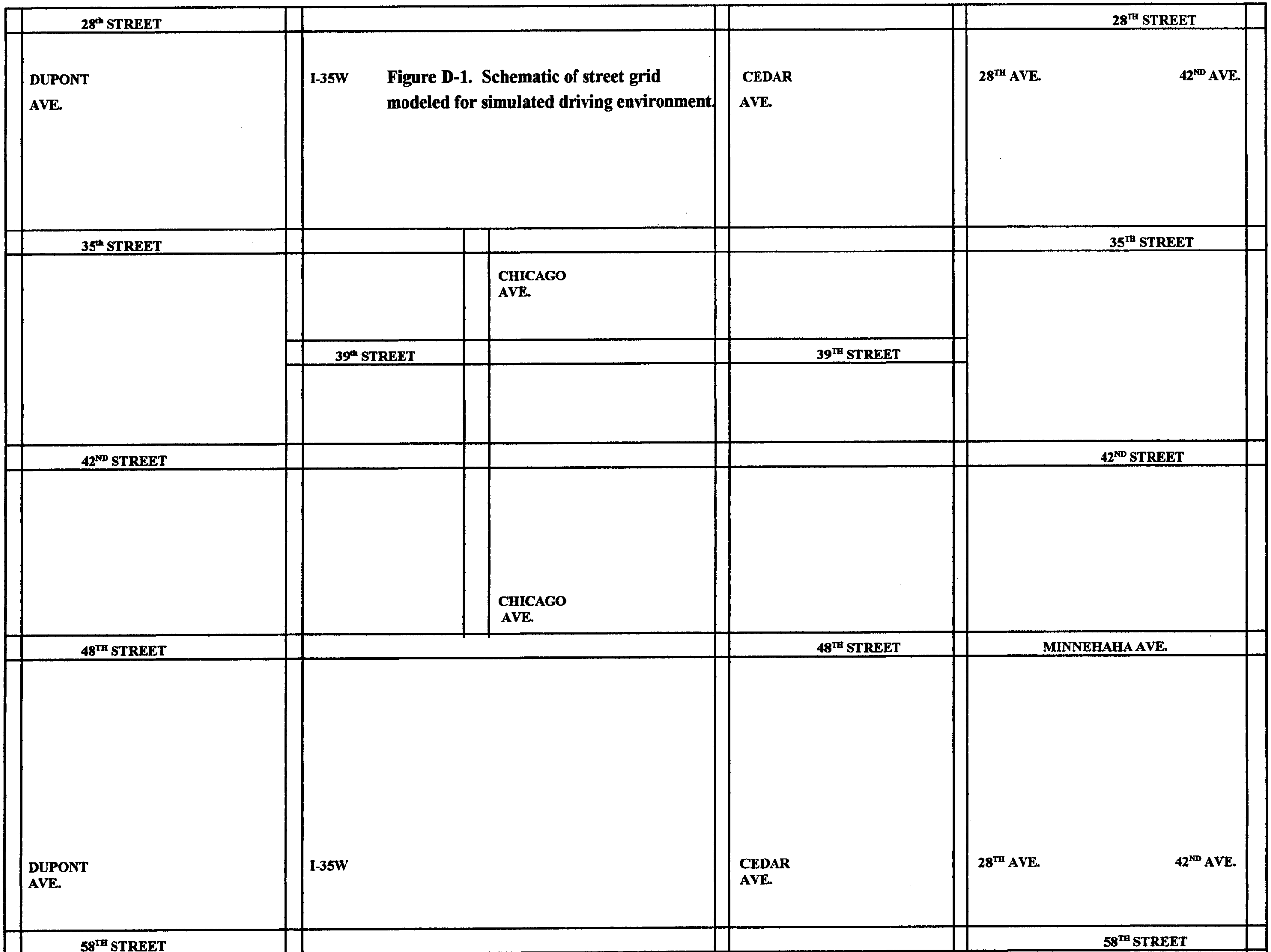


Figure D-1. Schematic of street grid modeled for simulated driving environment.

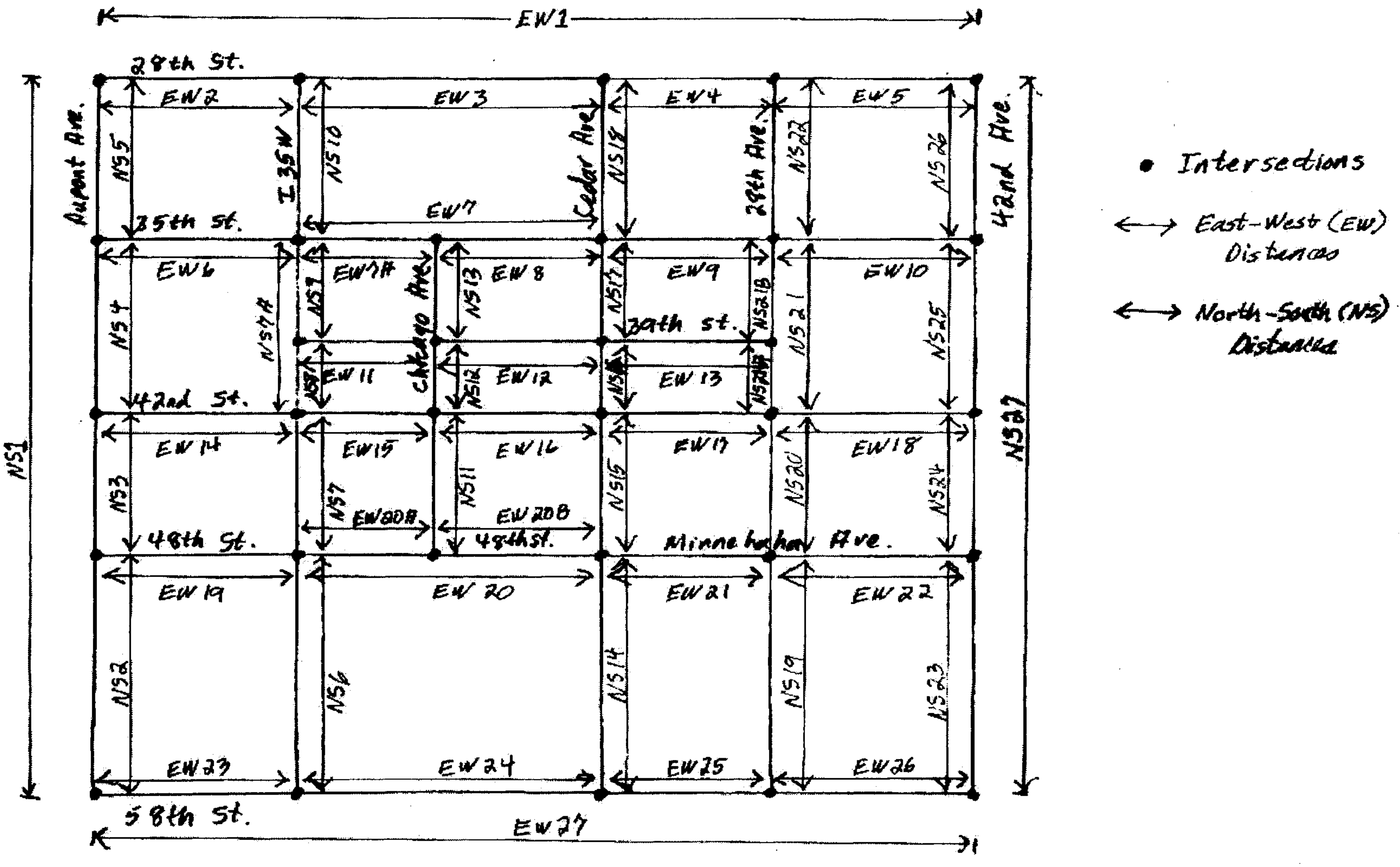


Figure D-2. Labels for segments of streets modeled for simulated driving environment (EW: East-West; NS: North-South). Table D-1 itemizes distances for each of the labeled segments.

Mn/DOT - CTS - UM IVNS RESEARCH PROJECT

INSTRUCTIONS FOR CREATING A SIMULATION MODEL OF EXPERIMENTAL DRIVING ENVIRONMENT

Thomas J. Smith & Paul Cassidy

The model is a rectilinear grid based on an actual grid of streets in the southeast quadrant of the City of Minneapolis (see map Figure C-1, Appendix C). Specifications are as follows.

1. The periphery of the grid is defined by the following Minneapolis streets.

West Edge:	Dupont Ave.
North Edge:	28th Street
East Edge:	42nd Ave.
South Edge:	58th Street

2. There are 3 North-South streets within the grid (see map) connecting 28th St. and 58th St.
   I35W
   Cedar Ave.
   28th Ave.

3. There are 3 East-West streets within the grid (see map) connecting Dupont Ave. and 42nd Ave.
   35th Street
   42nd Street
   48th Street/Minnehaha Ave.

4. There is one shorter, internal North-South street within the grid (see map) connecting 35th St. and 48th St.
   Chicago Ave. from 35th St. to 48th St.

5. There is one shorter, internal East-West street within the grid (see map) connecting I35W and 28th Ave.
   39th Street from I35W to 28th Ave.

6. Collectively, the grid comprises 32 intersections, 30 North-South (NS) road segments, and 30 East-West (EW) road segments. The grid should be modeled on a flat terrain with no roadside features. Each intersection should have stop signs for all applicable directions of traffic entering the intersection. Three maze routes based on the grid are being developed. Once the maze routes are defined, barriers may be required at some intersections, to be specified.

7. Each NS and EW road segment is labeled on the attached schematic map. Distances for each segment are given in the table on the next page. Distances are computed from a MN/DOT map of the area charted from GPS data, with coordinates reputedly accurate to 40 ft. Note that the grid (like the actual street layout) is highly regular. The only (minor) discrepancies are in the southeast corner (NS-19 & NS-23 shortened to bring 58th St. north of I494) and the northeast corner (EW-4 lengthened to bend north end of 28th Ave. slightly to east).

Table D-1. Distances for north-south and east-west segments of street grid modeled for simulated driving environment (see Figure D-2 for locations of specified street segments).

Direction	**Segment**	**Distance (ft)**	**Direction**	**Segment**	**Distance (ft)**
North-South	NS-1	19,608 ft	East-West	EW-1	20,823 ft
	NS-2	6,588		EW-2	4,784
	NS-3	3,922		EW-3	7,098
	NS-4	4,588		EW-4	4,039
	NS-5	4,510		EW-5	4,902
	NS-6	6,588		EW-6	4,784
	NS-7	3,922		EW-7	7,098
	NS-7A	4,588		EW-7A	3,157
	NS-8	1,961		EW-8	3,941
	NS-9	2,627		EW-9	3,961
	NS-10	4,510		EW-10	4,980
	NS-11	3,922		EW-11	3,157
	NS-12	1,961		EW-12	3,941
	NS-13	2,627		EW-13	3,961
	NS-14	6,588		EW-14	4,784
	NS-15	3,922		EW-15	3,157
	NS-16	1,961		EW-16	3,941
	NS-17	2,627		EW-17	3,961
	NS-18	4,510		EW-18	4,980
	NS-19	6,510		EW-19	4,784
	NS-20	3,922		EW-20	7,098
	NS-21	4,588		EW-20A	3,157
	NS-21A	1,961		EW-20B	3,941
	NS-21B	2,627		EW-21	3,961
	NS-22	4,510		EW-22	4,980
	NS-23	6,353		EW-23	4,784
	NS-24	3,922		EW-24	7,098
	NS-25	4,588		EW-25	3,961
	NS-26	4,510		EW-26	4,980
	NS-27	19,373		EW-27	20,823

APPENDIX E

GPS COORDINATES FOR INTERSECTIONS IN STREET GRID MODELED FOR SIMULATED DRIVING ENVIRONMENT

Table E-1.

MN/DOT IVNS Project Longitude and Latitude Coordinates for Street Grid Maze for Simulation Model

Cross Street	North-South	East-West
Dupont Ave. & 28th St.	N 44.951935	W 93.292809
Dupont Ave. & 35th St	N 44.939554	W 93.292851
Dupont Ave & 42nd St	N 44.926808	W 93.293002
Dupont Ave & 48th St	N 44.915950	W 93.292937
Dupont Ave & 58th St	N 44.897926	W 93.292980
I35W & 28th St	N 44.951935	W 93.273132
I35W & 35th St	N 44.939554	W 93.274612
I35W & 39th St	N 44.955540	W 93.269849
I35W & 42nd St	N 44.926894	W 93.274548
I35W & 48th St	N 44.955540	W 93.269849
I35W & 58th St	N 44.955540	W 93.269849
Chicago Ave & 35th St	N 44.939618	W 93.262188
Chicago Ave & 39th St	N 44.939618	W 93.262188
Chicago Ave & 42nd St	N 44.926937	W 93.262124
Chicago Ave & 48th St	N 44.916143	W 93.262231
Cedar Ave & 28th St	N 44.951978	W 93.247061
Cedar Ave & 35th St	N 44.939597	W 93.247039
Cedar Ave & 39th St	N 44.939597	W 93.247039
Cedar Ave & 42nd St	N 44.926915	W 93.247039
Cedar Ave & 48th St	N 44.973779	W 93.248627
Cedar Ave & 58th St	N 44.973779	W 93.248627
28th Ave & 28th St	N 44.951956	W 93.277488
28th Ave & 35th St	N 44.952064	W 93.221376
28th Ave & 39th St	N 44.932323	W 93.231804
28th Ave & 42nd St	N 44.932323	W 93.231804
28th Ave & 48th St	N 44.962792	W 93.231139
28th Ave & 58th St	N 44.898055	W 93.232040
42nd Ave & 28th St	N 44.952021	W 93.212385
42nd Ave & 35th St	N 44.939725	W 93.212450
42nd Ave & 42nd St	N 44.926980	W 93.212450
42nd Ave & 48th St	N 45.031607	W 93.297958
42nd Ave & 58th St	N 44.898655	W 93.212407

APPENDIX F

INFORMATION AND INSTRUCTIONS FOR GENERATING DATA STREAM OF GPS COORDINATES

ETAK EXPLANATION OF HOW A DATA STREAM OF GPS COORDINATES IS TRANSMITTED TO SKYMAP

Skymap sees the GPS as a serial device on a PC COM port. A GPS message is a coded ASCII character string of about 160 characters terminated by a newline. The GPS generates one of these messages once a second regardless of status (in fact, status is part of the message). When it starts, Skymap scans the COM ports looking for one that is receiving messages. Once found, it stops scanning and continues monitoring the GPS on that port.

The program to generate a data stream of dummy GPS coordinates needs to transmit a simulated GPS message once each second (the position therein need not change once a second, but a message should be sent anyway). The message should then be sent out using a serial COM port (9600, N, 8, 1) connected to a COM port of the computer running Skymap via a null modem cable. The actual GPS should not be installed. The simulation program will have to be running before Skymap is started. Skymap then should behave as if a GPS receiver actually is connected.

DETAILS OF THE FORMAT FOR A 160-CHARACTER GPS COORDINATE MESSAGE STRING PROVIDED TO SKYMAP BY THE GPS RECEIVER

GPS MESSAGE FORMAT

```
SONY9112120122321N3537520E13944402+23452342719112120122320A3AAaIABBIIAABIIAA
 A      B           C        D      E   F  G       H     IJ K  L     M    N

BIIAABIIAABIIAABIIAABIIAABIIAABIIAABIIAABIIAAADEFE
  O    P    Q    R    S    T    U    V    W  XY Z a
```

Field Definition

A Program Version

SONY - Sony Mobile Electronics

B Year, Month, Date, Day, Hour, Minute, Second

9112120122321

91: year
12: month (December)
12: date
0: day 0:Sunday 1:Monday ... 6:Saturday
12: hour (24 hr scale) UTC
23: minute UTC
21: second UTC

C Latitude (DMS indication)

N3537520

N: north latitude S: south latitude
35: degree
37: minute
520: second (0.1 second units)

D Longitude (DMS indication)

E13944402

E: east longitude W: west longitude
139: degree
44: minute
402: second (0.1 second units)

E Altitude (meter)

+2345

+ : upper imaginary earth surface - : lower imaginary earth surface
2345: altitude (meter)

Field	Definition (continued)
F	Speed (km/hr) 234: 234 km/hr
G	Bearings (true) 271: 271 degrees 0 degrees: north and increase clockwise to 360 degrees
H	UTC Time (date, day, hour, minute, & second are calculated) 9112120122320: year, month, date, day, hour, minute, second
I	GDOP

Field Indication	GDOP	Field Indication	GDOP
A	1	J	10
B	2	K	11-12
C	3	L	13-15
D	4	M	16-20
E	5	N	21-30
F	6	O	31-50
G	7	P	51-99
H	8	Q	100
I	9		

Field	Definition (continued)
J	Calculation Mode 3: 2 dimension calculation 4: 3 dimension calculation
K	Geodetic System A: WGS-84 Codes for different geodetic systems are in Table F-1
L	Channel 1 Information AaIAB A: satellite number (see Table F-2) a: angle of elevation of satellite (see Table F-3) I: angle of bearing of satellite (see Table F-4)

Field	Definition (continued)
L	Channel 1 Information (continued)

A: information on receiver and satellite

Field Indication	Condition
A	Scanning Satellite (SCAN)
B	Locked Satellite Signal (LOCK)
C	Available Calculation
D	Signal is Interrupted (HOLD)
E	Unable to use Satellite (something is wrong with the satellite)
F	Satellite Being Used for Calculation

B: receive level
A (level low) ... Z (level high)
(When receive level is higher than D, the receiver can receive the signal from the satellite.)

M	Channel 2 Information
N	Channel 3 Information
O	Channel 4 Information
P	Channel 5 Information
Q	Channel 6 Information
R	Channel 7 Information
S	Channel 8 Information
T	Channel 9 Information
U	Channel 10 Information
V	Channel 11 Information
W	Channel 12 Information

X TCXO Offset
a) ... g) ... A) ... G)

Y Filter Mode
D: fixed

Z Value of 0.01 sec unit of Latitude/Longitude
E: Latitude
F: Longitude

a Parity
E or O

Table F-1. Geodetic system definition.

Field Indication	Geodetic System		Nation
A	WGS-84	WGS-84	U.S.
B	TOKYO	Bessel 1841	Japan, Korea
C	ADINDAN	Clarke 1880	Ethiopia, Mali, Senegal, Sudan
D	ARC 1950	Clarke 1880	Botswana, Lesotho, Malawi, Swaziland, Zaire, Zambia, Zimbabwe
	CAPE	Clarke 1880	South Africa
E	MERCHICH	Clarke 1880	Morocco
F	HONG KONG 1963	International	Hong Kong
G	SOUTH ASIA	Modified Fisher 1960	Singapore
H	LUZON	Clarke 1866	Philippines
I	INDIAN	Everest	Thailand, Vietnam
J	INDIAN	Everest	Bangladesh, India, Nepal
K	KERTAU 1948	Modified Everest	West Malaysia, Singapore
L	NORTH AMERICAN 1927	Clarke 1866	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Mexico
M	EUROPEAN 1950 EUROPEAN 1979	International	Austria, Belgium, Cyprus, Channel Islands, Denmark, England, Finland, France, Germany, Gibraltar, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Scotland, Shetland Islands, Spain, Sweden, Switzerland
N	IRELAND 1965	Modified Airy	Ireland

Field Indication	**Geodetic System**		**Nation**
O	ORDINANCE SURVEY OF GREAT BRITAIN 1936	Airy	England, Isle of Man, Scotland, Shetland Island, Wales
P	NAHRWAN	Clarke 1880	Migirah Island, Oman, United Arab Emirates
Q	NAHRWAN	Clarke 1880	Saudi Arabia
R	OLD EGYPTIAN	Helmert 1906	Egypt
S	NORTH AMERICAN 1927	Clarke 1865	Canada, Newfoundland Island
T	NORTH AMERICAN 1983	GRS 80	Alaska, Canada, Mexico, Central America, U.S.
U	AUSTRALIAN GEODETIC 1984	Australian National	Australia, Tasmania Island
V	GEODETIC DATUM 1949	International	New Zealand
W	PROVISIONAL SOUTH AMERICAN 1956	International	Bolivia, Chile, Colombia, Ecuador, Guyana, Peru, Venezuela
X	SOUTH AMERICAN 1969	South American 1969	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Trinidad and Tobago, Venezuela
Y	CAMPO INCHAUSPE	International	Argentina
Z	CORREGO ALEGRE	International	Brazil

Table F-2. Satellite number definition.

Field Indication	**Satellite Number**	**Field Indication**	**Satellite Number**	**Field Indication**	**Satellite Number**
A	SV 1	L	SV 12	W	SV 23
B	SV 2	M	SV 13	X	SV 24
C	SV 3	N	SV 14	a	SV 25
D	SV 4	O	SV 15	b	SV 26
E	SV 5	P	SV 16	c	SV 27
F	SV 6	Q	SV 17	d	SV 28
G	SV 7	R	SV 18	e	SV 29
H	SV 8	S	SV 19	f	SV 30
I	SV 9	T	SV 20	g	SV 31
J	SV 10	U	SV 21	h	SV 32
K	SV 11	V	SV 22		

Table F-3. Satellite elevation angle definition.

Field Indication	**Satellite Elevation Angle**	**Field Indication**	**Satellite Elevation Angle**
A	0 deg ~ + 5 deg	a	0 deg ~ - 5 deg
B	+ 6 deg ~ +15 deg	b	- 6 deg ~ -15 deg
C	+16 deg ~ +25 deg	c	-16 deg ~ -25 deg
D	+26 deg ~ +35 deg	d	-26 deg ~ -35 deg
E	+36 deg ~ +45 deg	e	-36 deg ~ -45 deg
F	+46 deg ~ +55 deg	f	-46 deg ~ -55 deg
G	+56 deg ~ +65 deg	g	-56 deg ~ -65 deg
H	+66 deg ~ +75 deg	h	-66 deg ~ -75 deg
I	+76 deg ~ +85 deg	i	-76 deg ~ -85 deg
J	+86 deg ~ +90 deg	j	-86 deg ~ -90 deg

Table F-4. Satellite bearing angle definition.

Field Indication	**Satellite Bearing Angle**	**Field Indication**	**Satellite Bearing Angle**
A	0 deg ~ + 5 deg	A	0 deg ~ - 5 deg
B	+ 6 deg ~ + 15 deg	a	- 6 deg ~ - 15 deg
C	+ 16 deg ~ + 25 deg	b	- 16 deg ~ - 25 deg
D	+ 26 deg ~ + 35 deg	c	- 26 deg ~ - 35 deg
E	+ 36 deg ~ + 45 deg	d	- 36 deg ~ - 45 deg
F	+ 46 deg ~ + 55 deg	e	- 46 deg ~ - 55 deg
G	+ 56 deg ~ + 65 deg	f	- 56 deg ~ - 65 deg
H	+ 66 deg ~ + 75 deg	g	- 66 deg ~ - 75 deg
I	+ 76 deg ~ + 85 deg	h	- 76 deg ~ - 85 deg
J	+ 86 deg ~ + 95 deg	i	- 86 deg ~ - 95 deg
K	+ 96 deg ~ +105 deg	j	- 96 deg ~ -105 deg
L	+106 deg ~ +115 deg	k	-106 deg ~ -115 deg
M	+116 deg ~ +125 deg	l	-116 deg ~ -125 deg
N	+126 deg ~ +135 deg	m	-126 deg ~ -135 deg
O	+136 deg ~ +145 deg	n	-136 deg ~ -145 deg
P	+146 deg ~ +155 deg	o	-146 deg ~ -155 deg
Q	+156 deg ~ +165 deg	p	-156 deg ~ -165 deg
R	+166 deg ~ +175 deg	q	-166 deg ~ -175 deg
r	+176 deg ~ +180 deg	r	-176 deg ~ -180 deg

APPENDIX G

SAMPLE DATA STREAM OF DUMMY GPS COORDINATES

```
   incoming string = SMATC09806302000000n4457106W09317344+0290001180980613622O847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000000n4457106W09317344+02900021809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000000n4457105W09317344+02900031809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000001n4457105W09317344+02900041809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000001n4457105W09317344+02900041809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000002n4457104W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000002n4457104W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000002n4457103W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000003n4457103W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000003n4457102W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000004n4457102W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000004n4457101W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000005n4457101W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000005n4457100W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000005n4457099W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000006n4457099W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000006n4457098W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000007n4457098W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000007n4457097W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000008n4457097W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000008n4457096W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000008n4457096W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   incoming string = SMATC09806302000009n4457096W09317344+02900051809806136220847Q3AAHFABeHgABUF
 + NACaEpACHDFABOEfABfDJACECGACAHFABeHgABUFNABaEpACCDFBE
   Terminated
```

Figure G-1. Sample data stream of dummy GPS coordinates.

APPENDIX H

MODIFIED SUBJECTIVE RESPONSE SURVEY QUESTIONNAIRE USED FOR SIMULATION TESTING SUBJECTS

IN-VEHICLE NAVIGATION SYSTEM

USABILITY QUESTIONNAIRE

- **PLEASE ANSWER THE FOLLOWING QUESTIONS ABOUT THE IVNS SYSTEM.**
- **PLEASE COMPLETE THIS QUESTIONNAIRE IMMEDIATELY AFTER YOU COMPLETE THE SECOND TESTING SESSION.**
- **FOR QUESTIONS 7-17, PLEASE CIRCLE THE PREFERRED NUMBER TO INDICATE HOW MUCH YOU AGREE OR DISAGREE WITH THE STATEMENT.**
- **PLEASE RETURN YOUR COMPLETED QUESTIONNAIRE TO THOMAS SMITH OR CURTIS HAMMOND.**

1. AGE ____ 2. SEX __M __F 3. DATE _______ 4. HEIGHT _______

5. ABOUT HOW OFTEN DO YOU USE A COMPUTER?
___EVERY DAY ___1-2 TIMES A WEEK ___INFREQUENTLY ___NEVER

6. HAVE YOU EVER USED AN IN-VEHICLE NAVIGATION SYSTEM BEFORE?
___YES ___NO

IF YES, HOW MANY TIMES? ___

7. THE SYSTEM IS EASY TO UNDERSTAND.

Strongly Disagree	1	2	3	4	5	Strongly Agree

8. THE SYSTEM IS EASY TO LEARN.

Strongly Disagree	1	2	3	4	5	Strongly Agree

9. THE SYSTEM HELPED ME FIND MY WAY.

Strongly Disagree	1	2	3	4	5	Strongly Agree

10. THE SYSTEM FUNCTIONED PROPERLY.

Strongly Disagree	1	2	3	4	5	Strongly Agree

11. THE SYSTEM INTERFERED WITH MY DRIVING.

Strongly Disagree	1	2	3	4	5	Strongly Agree

12.	FROM WHERE I WAS SITTING, IT WAS EASY TO SEE THE DISPLAY.	Strongly Disagree	1	2	3	4	5	Strongly Agree
13.	THE DISPLAY IS EASY TO READ.	Strongly Disagree	1	2	3	4	5	Strongly Agree
14.	IT IS EASY TO UNDERSTAND THE INFORMATION PRESENTED.	Strongly Disagree	1	2	3	4	5	Strongly Agree
15.	I LIKE THE DISPLAY COLORS.	Strongly Disagree	1	2	3	4	5	Strongly Agree
16.	I FOUND THE SYSTEM USEFUL.	Strongly Disagree	1	2	3	4	5	Strongly Agree
17.	THE ELECTRONIC MAP IS ACCURATE AND COMPLETE.	Strongly Disagree	1	2	3	4	5	Strongly Agree

18. HERE IS WHAT I LIKE ABOUT THE SYSTEM.

____
____
____
____

19. HERE IS WHAT I DISLIKE ABOUT THE SYSTEM.

____
____
____
____

20. HERE IS HOW THE SYSTEM COULD BE IMPROVED.

____
____
____
____

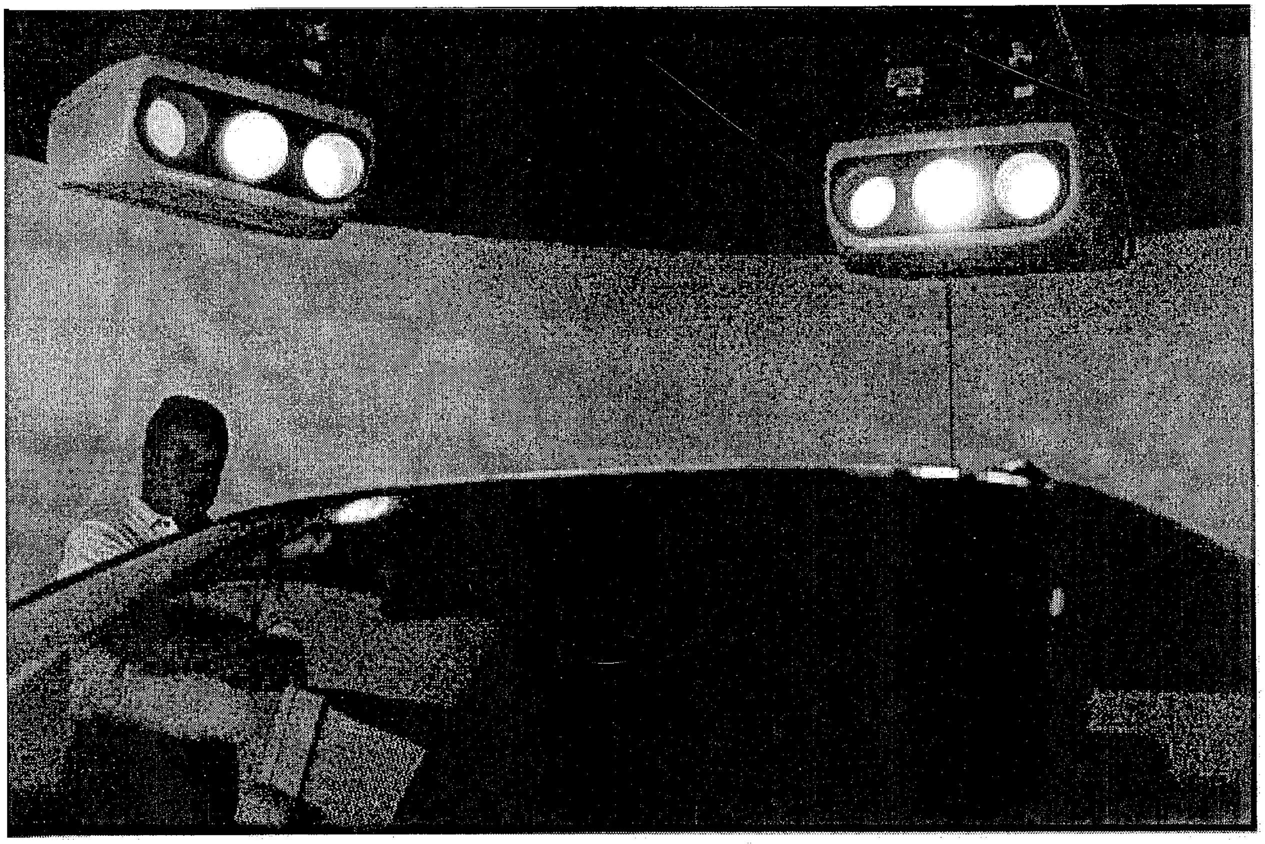
THANK YOU FOR YOUR HELP IN COMPLETING THIS QUESTIONNAIRE.

APPENDIX I

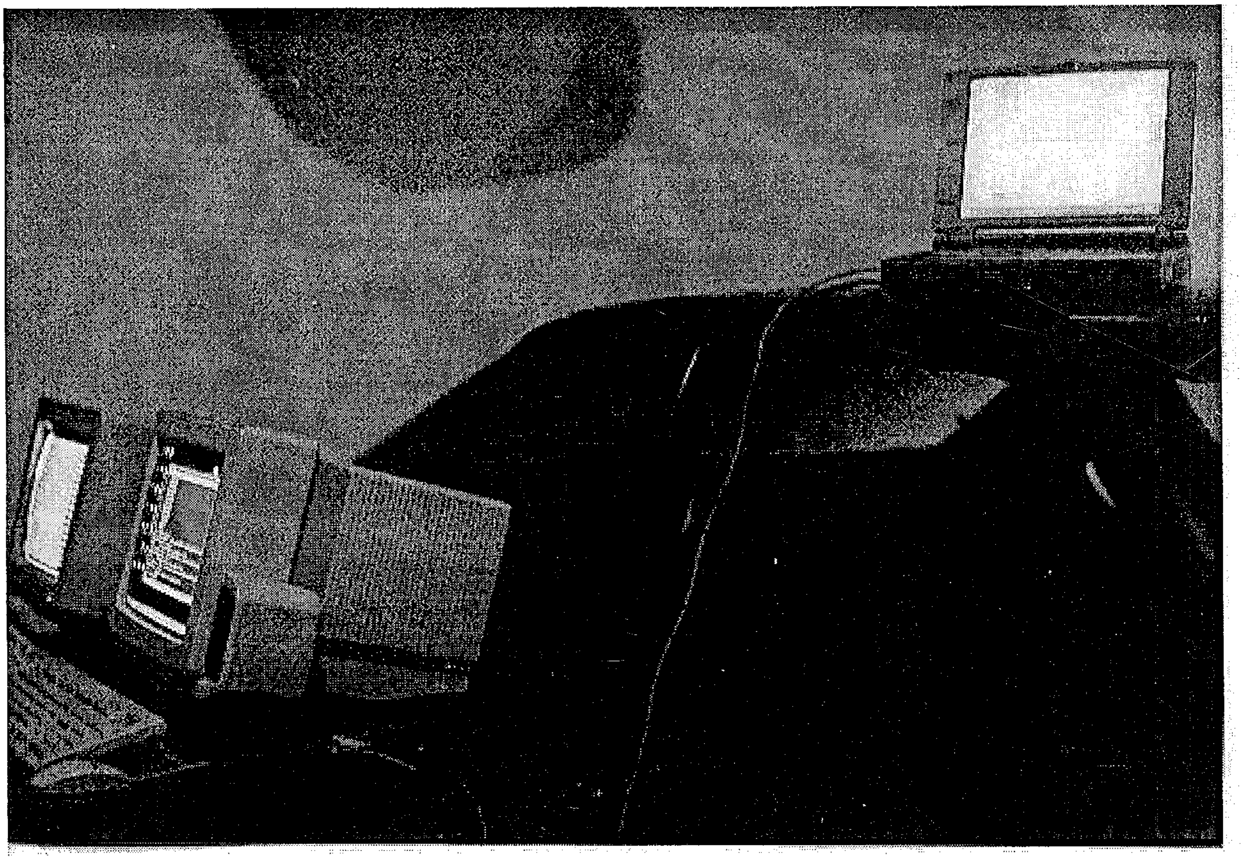
PHOTOGRAPHS ILLUSTRATING FEATURES OF HFRL WRAP AROUND DRIVING SIMULATOR AND IN-VEHICLE PLACEMENT AND VIEWING CONDITIONS FOR GAINS DURING SIMULATION TESTING

DESCRIPTIONS OF APPENDIX I PHOTOGRAPHS

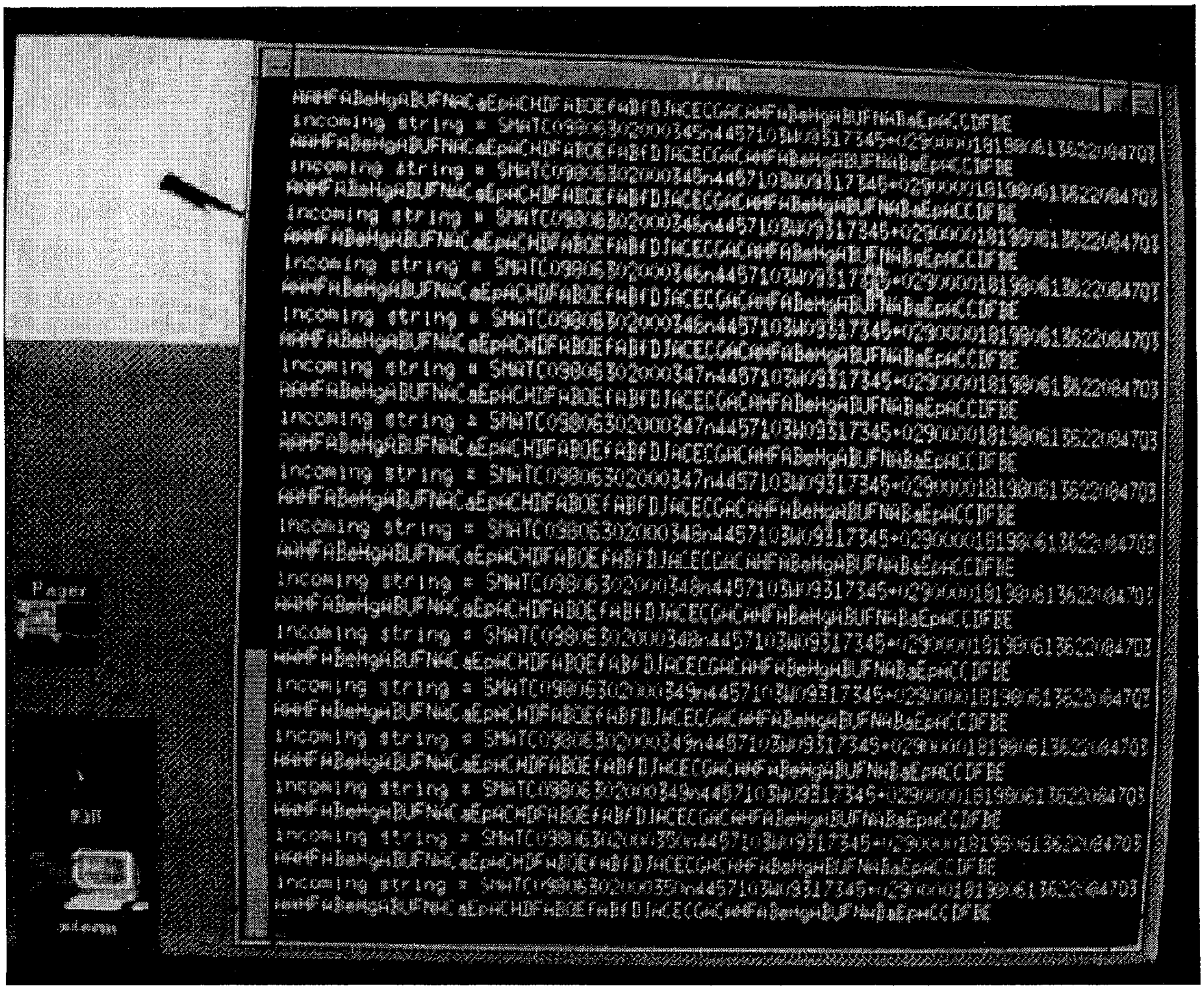
PHOTOGRAPH	DESCRIPTION
I-1	View of two forward projectors used in HFRL fixed-base wrap around driving simulator.
I-2	View of three PCs located within the wrap around simulator during simulation testing: (1) Linux PC (to the left on table); (2) host PC for SGI Onyx (to the right on table), used to control the Onyx from within the wrap around simulator; and (3) GAINS Toshiba Satellite laptop PC on roof of Acura.
I-3	View of representative data stream of formatted message strings containing dummy GPS coordinates displayed on the Linux PC monitor (compare with Appendix G, Figure G-1).
I-4	View of close-up of the Skymap digital map of a portion of the simulated driving environment, displayed on the GAINS Toshiba Satellite laptop PC monitor.
I-5	View of projected image of the starting point in the simulated driving environment for each experimental session, with the vehicle facing south on Dupont Ave. just north of the intersection with 28th Street.



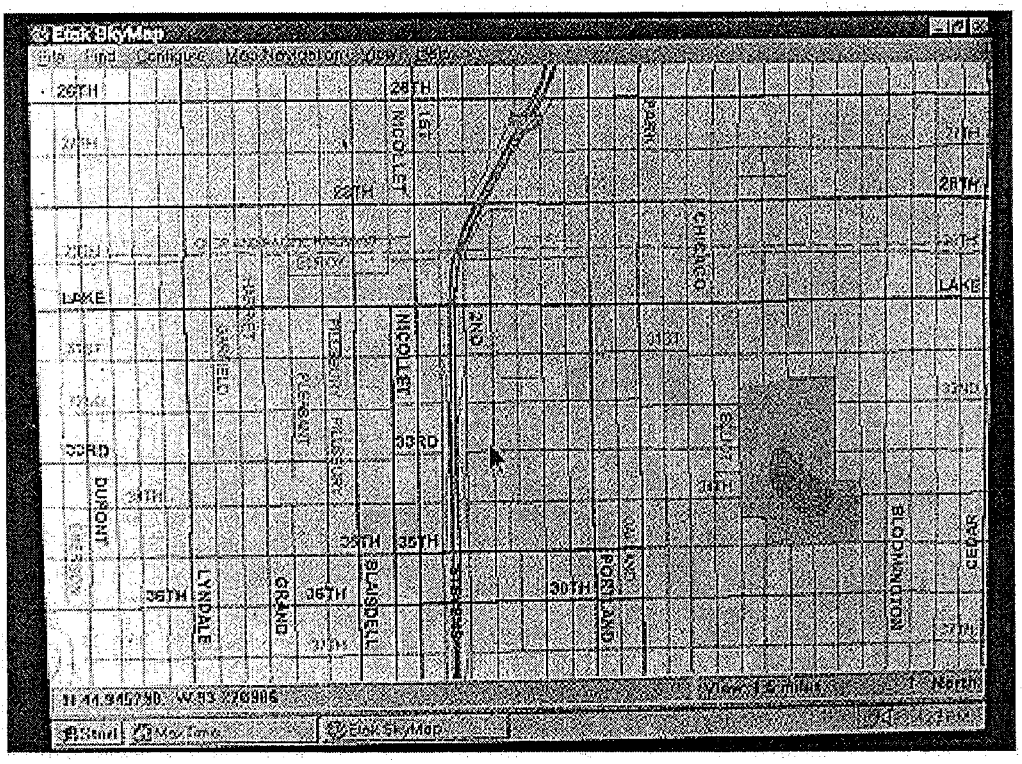
Photograph I-1. View of two forward projectors used in HFRL wrap around driving simulator.



Photograph I-2. View of three PCs within driving simulator used for simulation testing.



Photograph I-3. View of representative data stream of formatted message strings containing dummy GPS coordinates displayed on Linux PC monitor.



Photograph I-4. Close-up of Skymap digital map of a portion of simulated driving environment, showing the starting point (28th Street and Dupont Ave.) in left upper corner of map.

Photograph I-5. View of the projected image of the starting point in the simulated driving environment, with vehicle facing south on Dupont Ave. just north of the intersection with 28th Street.

APPENDIX J

MAZE-LIKE STREET GRIDS USED AS NAVIGATION ENVIRONMENTS FOR CONTROL AND TEST CONDITIONS

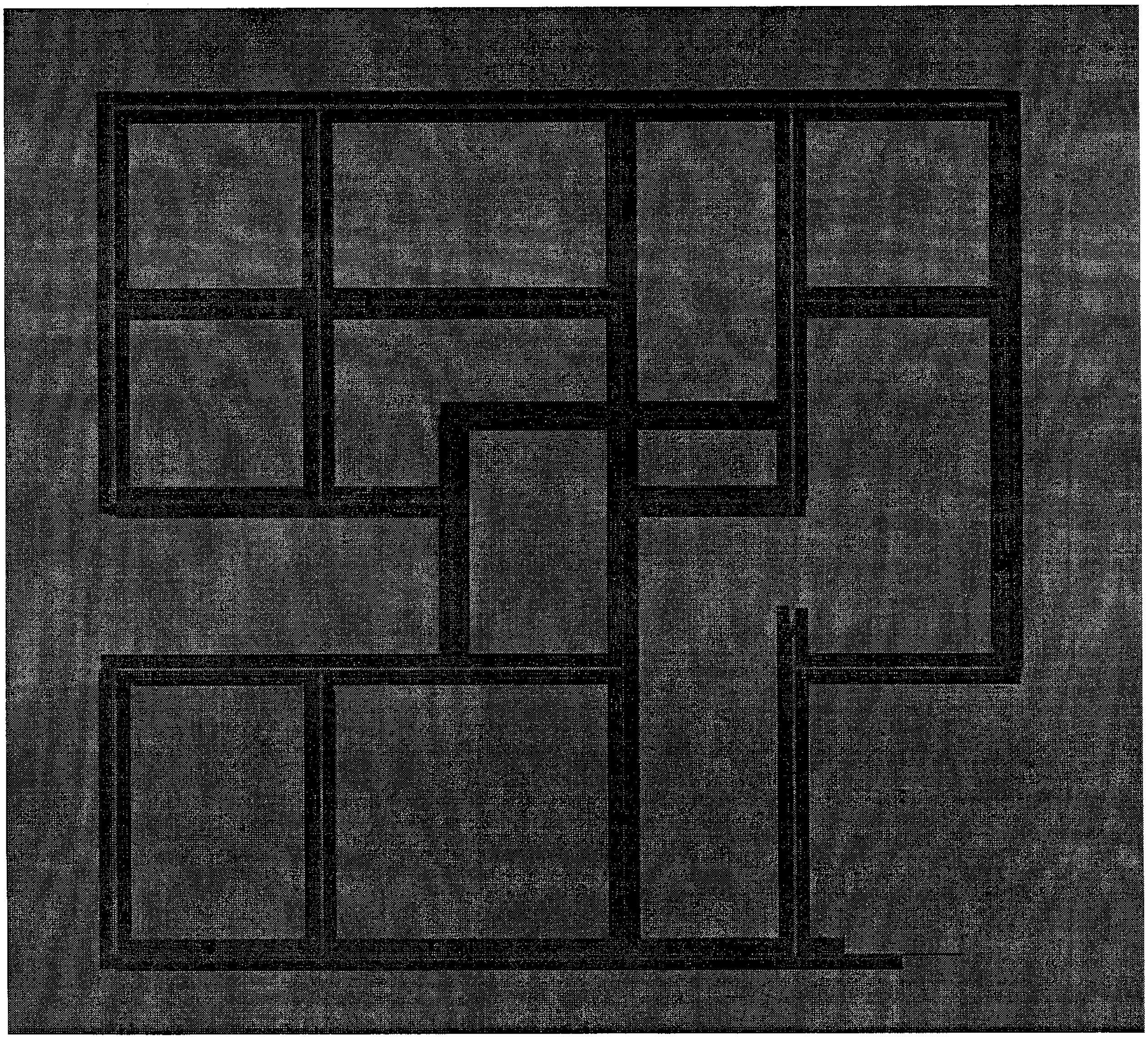


Figure J-1. Maze-like grid of streets in simulated driving environment used during control trials for simulation testing. Only a subset of all streets modeled for the environment are included in the grid (refer to Appendix D, Figure D-1).

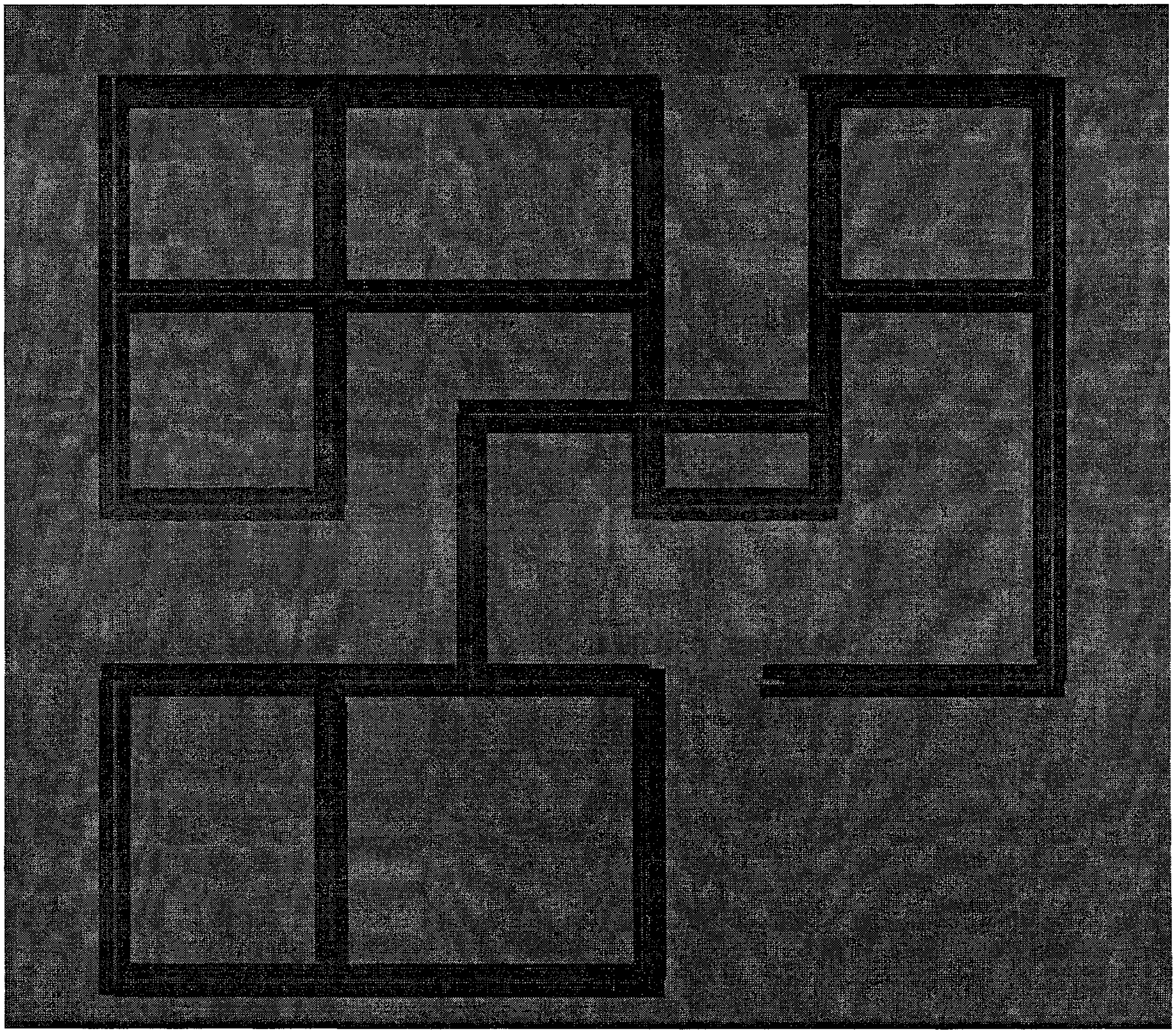


Figure J-2. Maze-like grid of streets in simulated driving environment used during test trials for simulation testing. Only a subset of all streets modeled for the environment are included in the grid (refer to Appendix D, Figure D-1).

APPENDIX K

PRE-TEST QUESTIONNAIRE ADMINISTERED PRIOR TO SIMULATED DRIVING CONTROL SESSION

University of Minnesota Human Factors Driving Simulation Study
Pre-test Survey/Questionnaire

Q1.

Name	
Age	
Gender	**M / F**
Phone Number	

Q2. Do you currently have a valid drivers license? (Circle one.)

1. **Yes**
2. **No**

Q3. Years driving experience (likely to be age-16=_). Number of years __________.

Q4. Do you have any visual impairments?

1. **Yes** If Yes please describe.-______________________________
2. **No**

Q5. Are you currently taking any medications?

1. **Yes** If Yes please describe.-______________________________
2. **No**

Q6. Have you experienced dizziness in the past (circle one.)

	Yes	**No**	(If you answered yes , what caused the dizziness?)
a. 5 years?	1	2	______________________________
b. 1 year?	1	2	______________________________
c. 6 months?	1	2	______________________________

Q7.

Do you experience nausea in any of the following situations?	YES	NO	If YES describe situation (where, how often, etc.).
Driving a car.	1	2	
Riding in a car as a passenger.	1	2	
During plane trips.	1	2	
Carnival rides.	1	2	
Other.(Watching TV, movies, etc.)	1	2	

Q8. Please answer Y or N and the frequency (Circle one response for each item.)

Do you experience-	always	sometimes	rarely	never
Claustrophobia (fear of closed spaces)	1	2	3	4
Acrophobia (fear of heights)	1	2	3	4
Driving fatigue (white line fever)	1	2	3	4
Panic attacks (while driving)	1	2	3	4
Driving aggression. (Anger while driving)	1	2	3	4

Time on Road

How much time do you spend on the road per week (average)?

AS DRIVER			
	In town (About 25-35 mph)	In town highways (50 mph+)	Out of town highways (65 mph+)
Weekdays			
Weekends			
TOTALS			

AS PASSENGER			
	In town (About 25-35 mph)	In town highways (50 mph+)	Out of town highways (65 mph+)
Weekdays			
Weekends			
TOTALS			

Any notable variations (ie. Trips, varying commutes etc.)

Do you have any other concerns you would like to address before continuing?

APPENDIX L

PROFILES OF NAVIGATION ROUTES FOLLOWED BY INDIVIDUAL SUBJECTS UNDER TEST CONDITION

Figure L-1

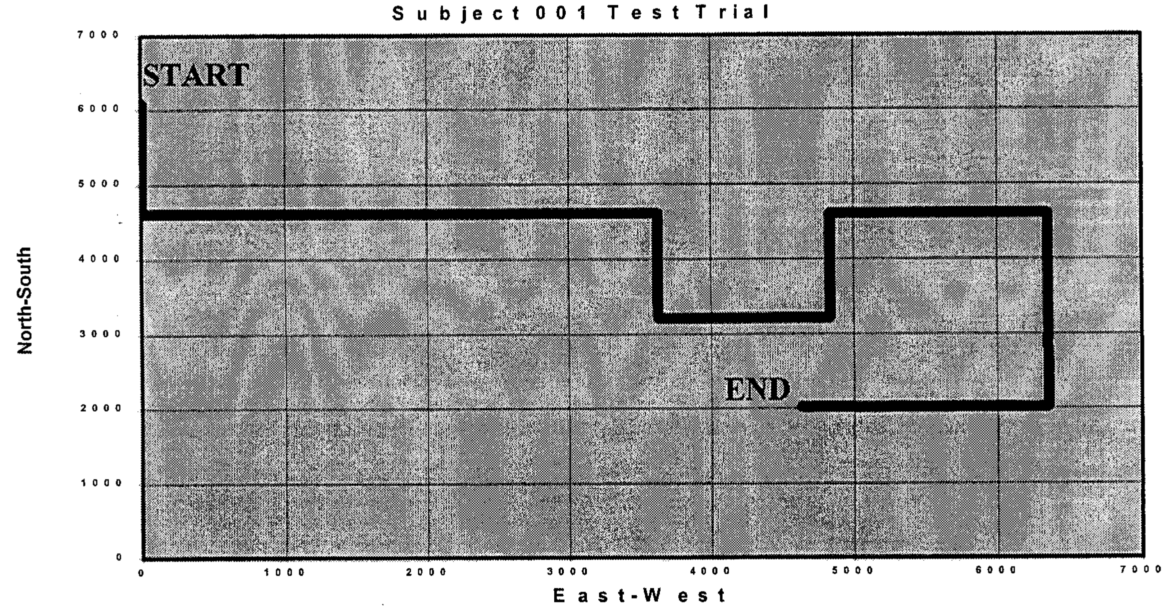
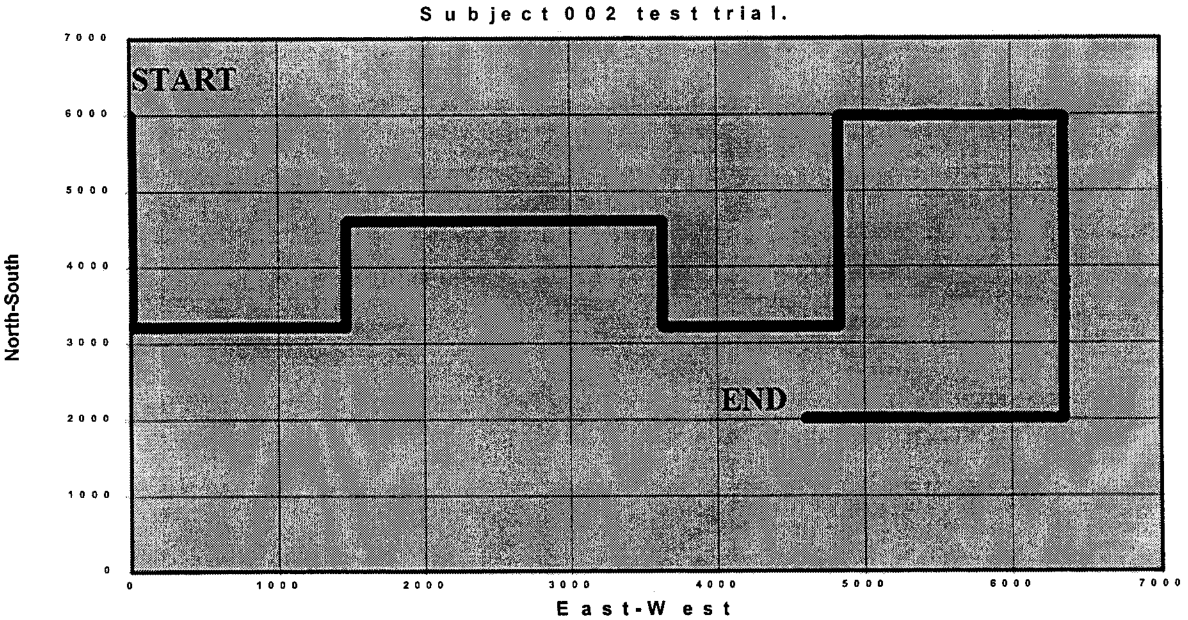


Figure L-2



Figures L-1 and L-2. Route trajectories (solid black lines) for Subjects 001 (top) and 002 (bottom) (Table 3-3, revised ID numbers) in traversing simulated driving environment under test condition. Streets are not labeled in figures. Refer to Appendix D, Figure D-1, for diagram of streets modeled in simulated environment, and to Appendix J, Figure J-2, for diagram of streets accessible under test condition. (**Start**: task starting point, Dupont Ave. & 28th Street; **End**: task end point, 28th Ave. & 48th Street; see Figure 3-2.)

Figure L-3

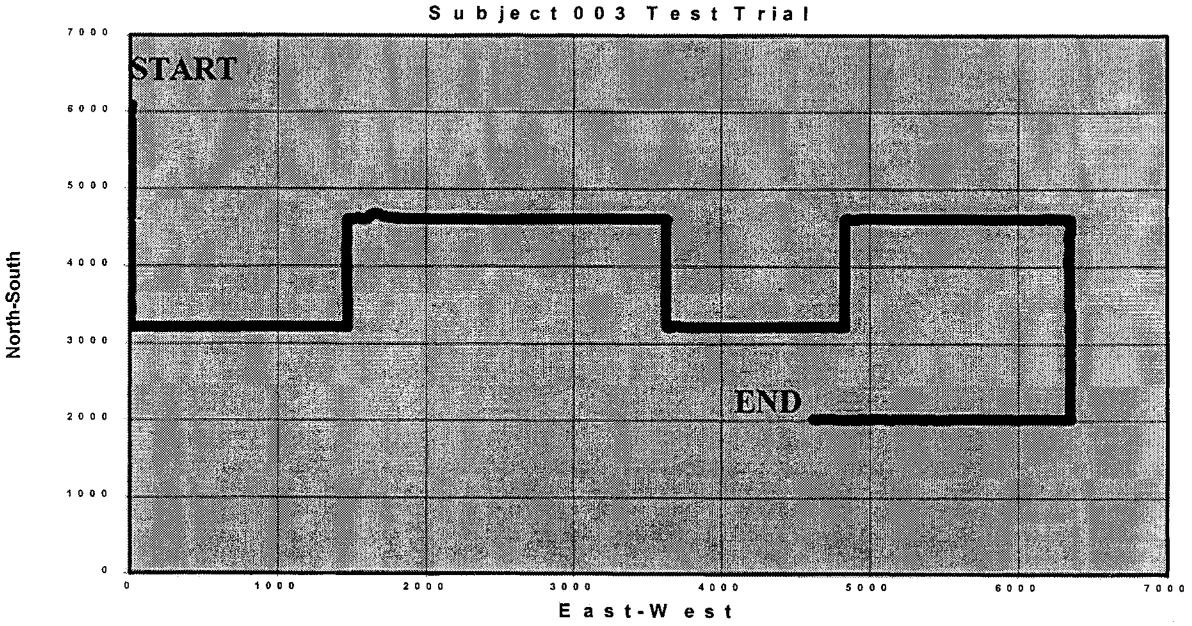
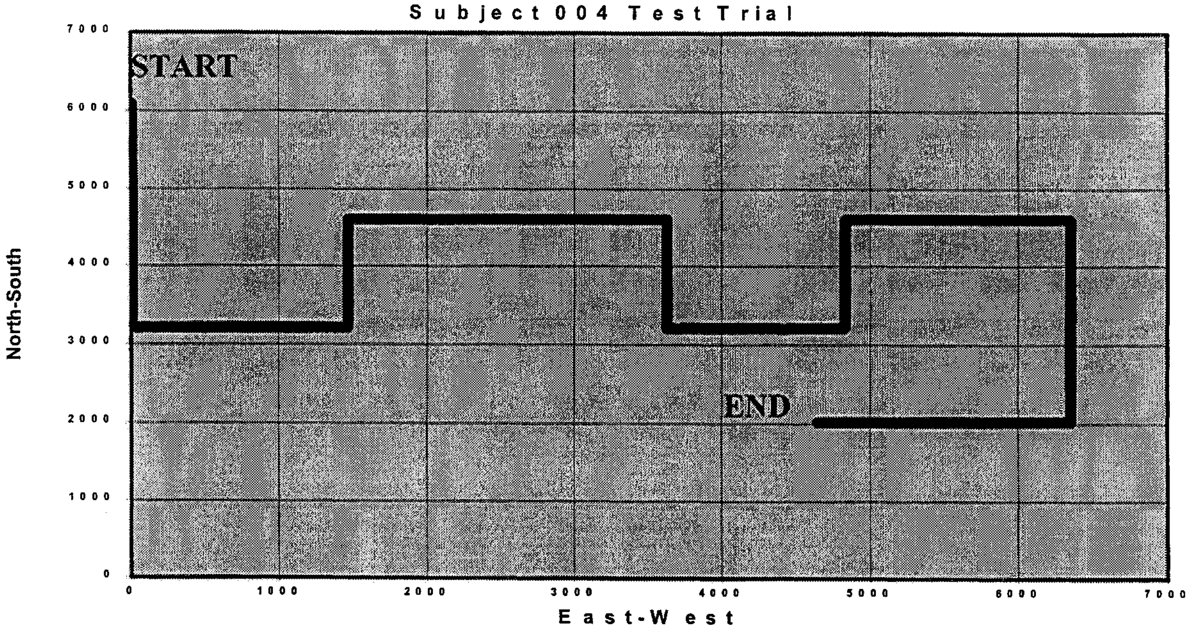


Figure L-4



Figures L-3 and L-4. Route trajectories (solid black lines) for Subjects 003 (top) and 004 (bottom) (Table 3-3, revised ID numbers) in traversing simulated driving environment under test condition. Streets are not labeled in figures. Refer to Appendix D, Figure D-1, for diagram of streets modeled in simulated environment, and to Appendix J, Figure J-2, for diagram of streets accessible under test condition. (**Start**: task starting point, Dupont Ave. & 28th Street; **End**: task end point, 28th Ave. & 48th Street; see Figure 3-2.)

Figure L-5

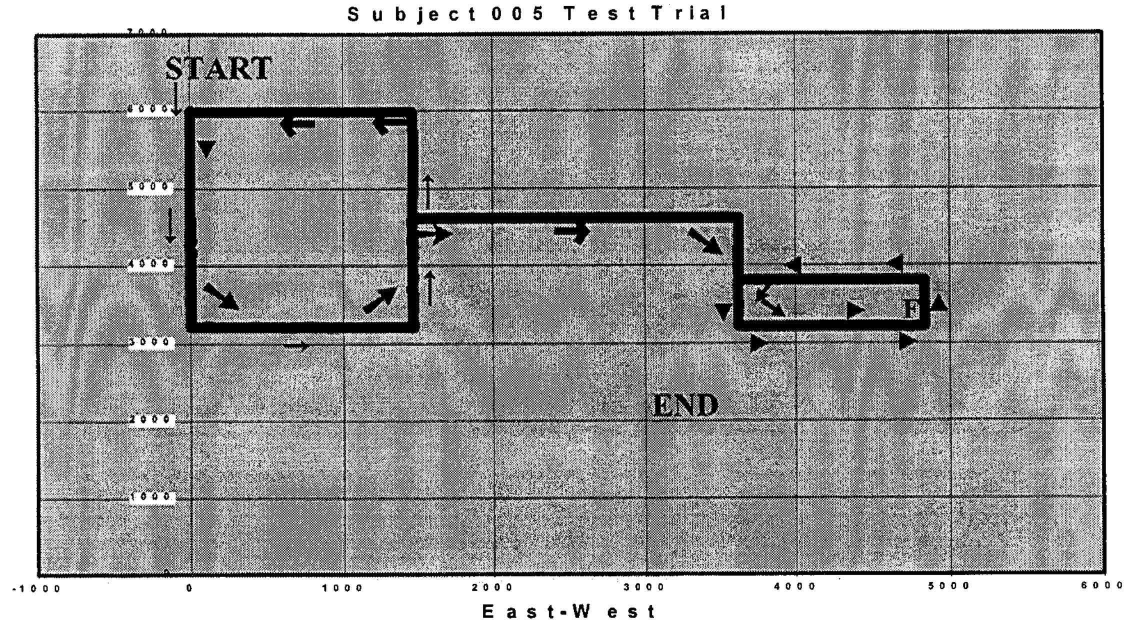
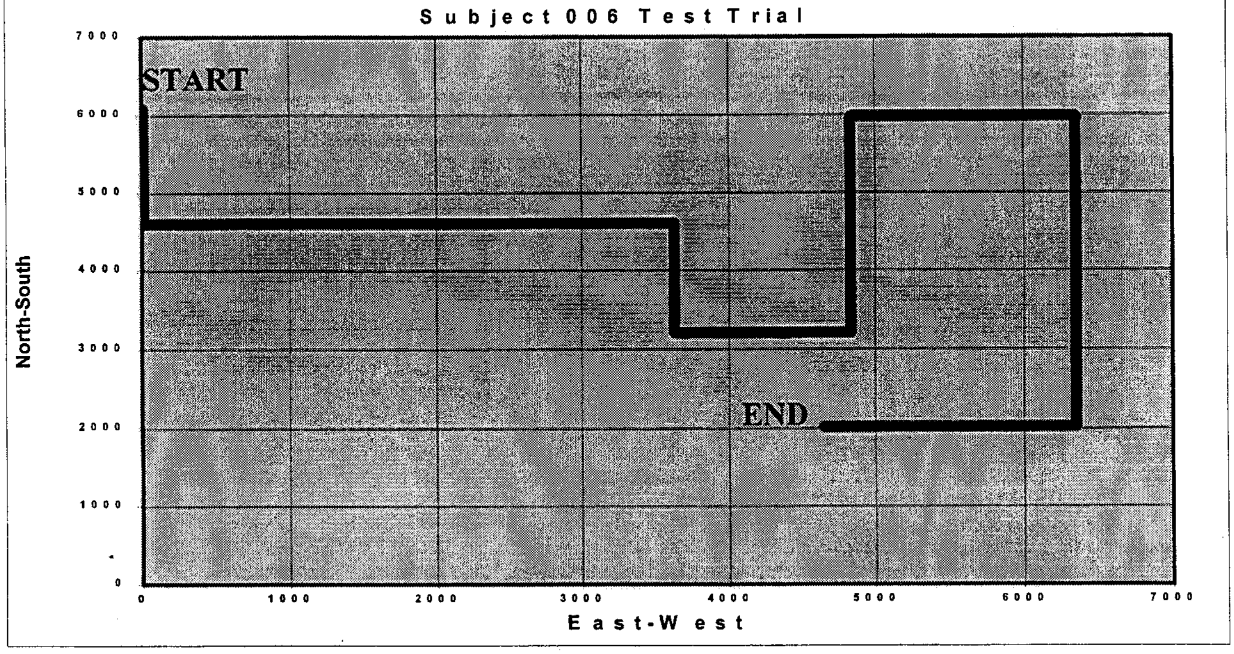


Figure L-6



Figures L-5 and L-6. Route trajectories (solid black lines) for Subjects 005 (top) and 006 (bottom) (Table 3-3, revised ID numbers) in traversing simulated driving environment under test condition. Streets are not labeled in figures. Refer to Appendix D, Figure D-1, for diagram of streets modeled in simulated environment, and to Appendix J, Figure J-2, for diagram of streets accessible under test condition. Arrows in Figure L-5 (Subject 005) show sequence of streets traversed. Subject 005 (Figure L-5) did not find the end point by task termination (30 min). (**Start**: task starting point, Dupont Ave. & 28th Street; **End**: task end point, 28th Ave. & 48th Street; see Figure 3-2; **F**: finish point for subject at task termination.)

Figure L-7

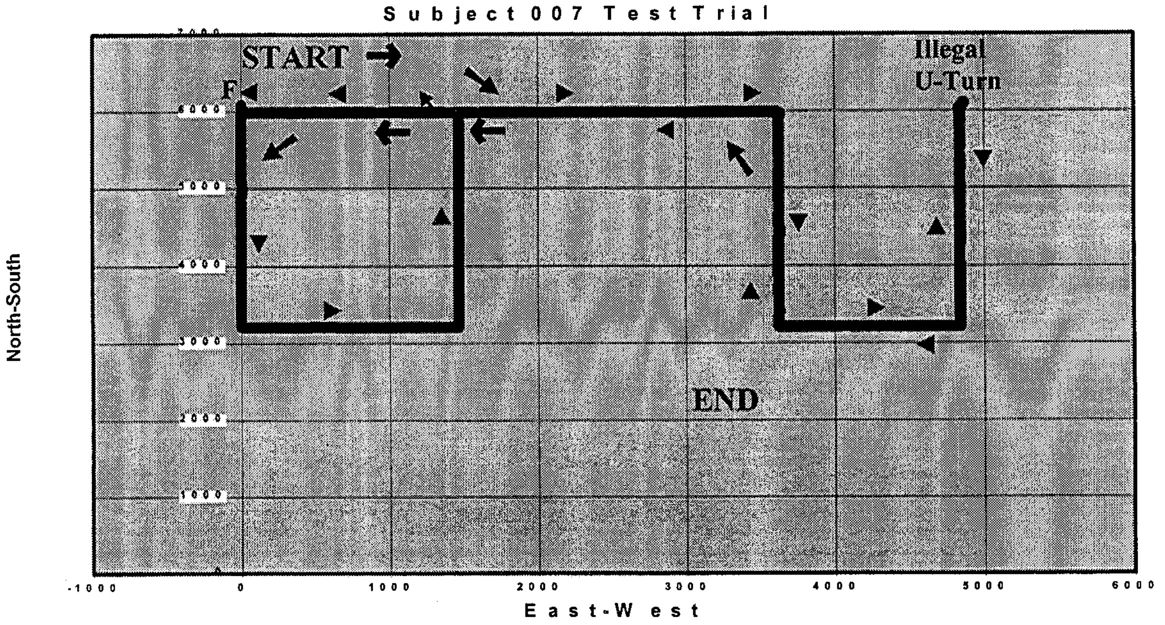
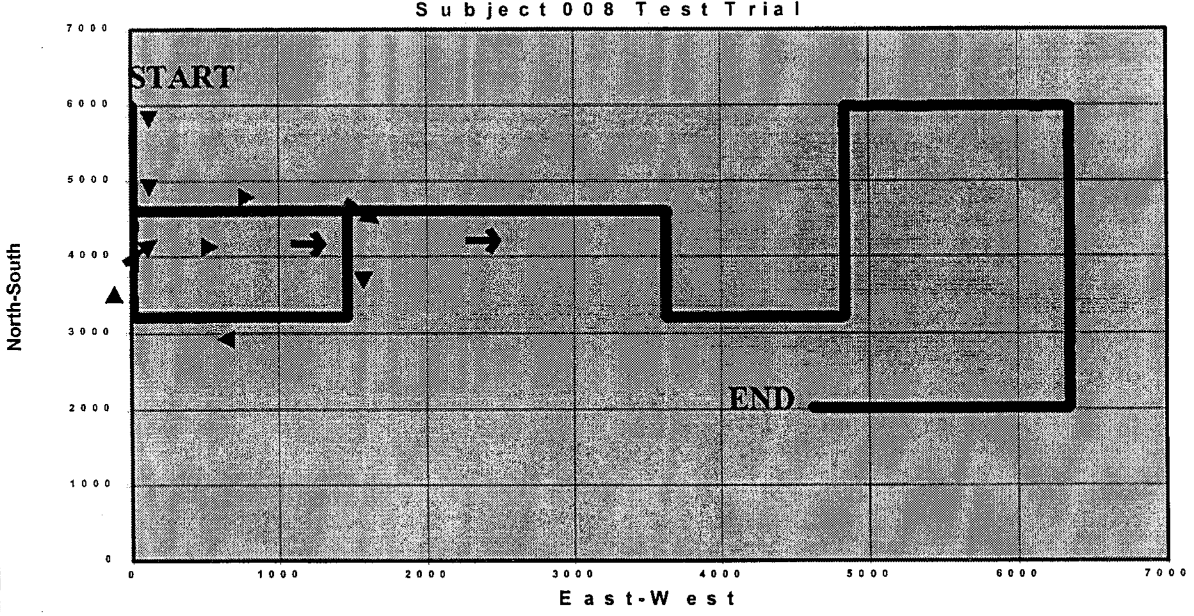


Figure L-8



Figures L-7 and L-8. Route trajectories (solid black lines) for Subjects 007 (top) and 008 (bottom) (Table 3-3, revised ID numbers) in traversing simulated driving environment under test condition. Streets are not labeled in figures. Refer to Appendix D, Figure D-1, for diagram of streets modeled in simulated environment, and to Appendix J, Figure J-2, for diagram of streets accessible under test condition. Arrows in figures show sequence of streets traversed. Subject 007 (Figure L-7) did not find the end point by task termination (30 min)., and made an illegal U-turn. (**Start**: task starting point, Dupont Ave. & 28th Street; **End**: task end point, 28th Ave. & 48th Street; see Figure 3-2; **F**: finish point for subject at task termination.)

Figure L-9

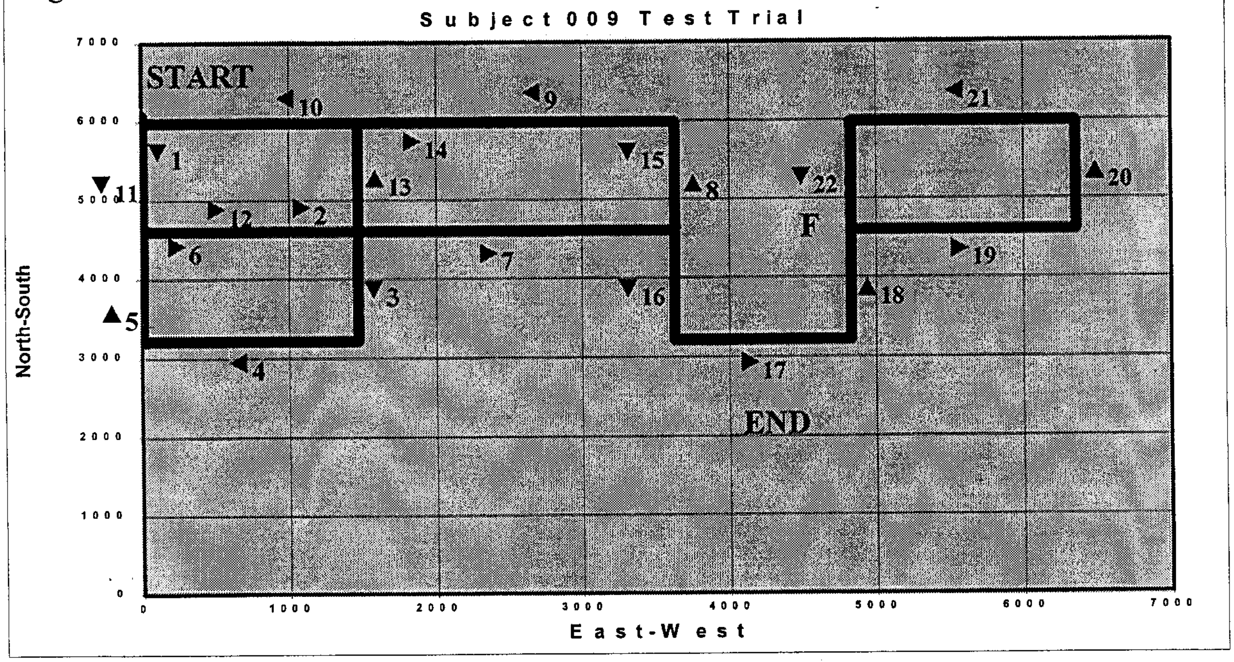
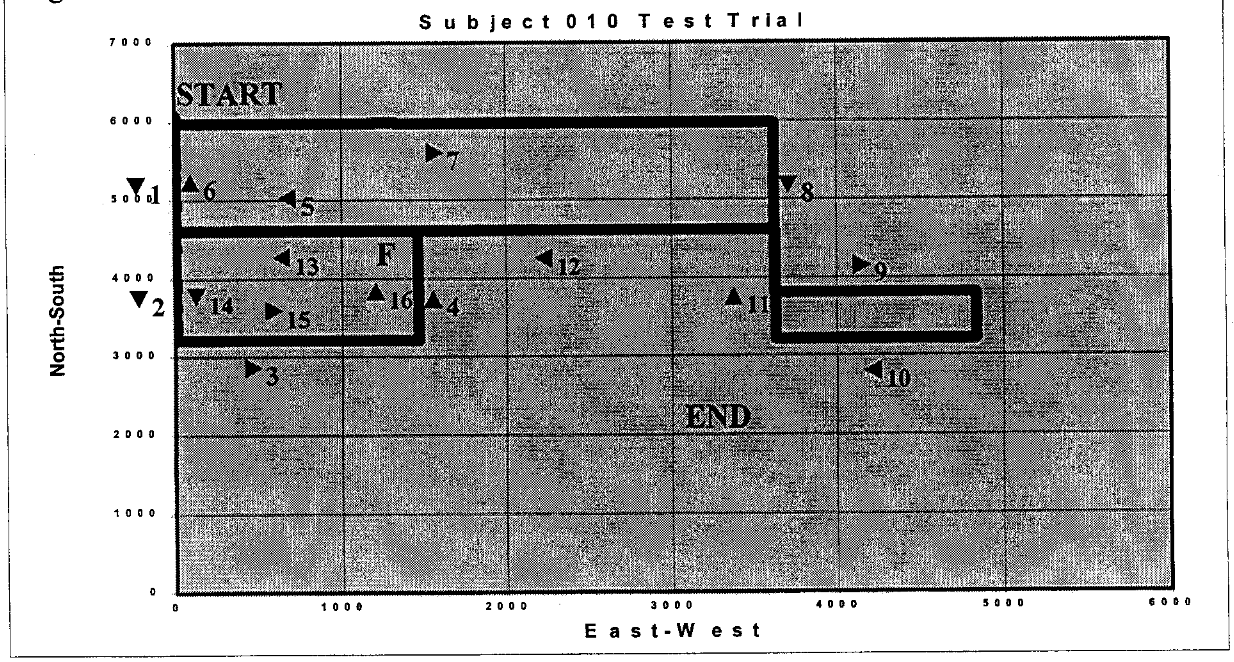


Figure L-10



Figures L-9 and L-10. Route trajectories (solid black lines) for Subjects 009 (top) and 010 (bottom) (Table 3-3, revised ID numbers) in traversing simulated driving environment under test condition. Streets are not labeled in figures. Refer to Appendix D, Figure D-1, for diagram of streets modeled in simulated environment, and to Appendix J, Figure J-2, for diagram of streets accessible under test condition. Arrows in figures show sequence of streets traversed. To clarify trajectories in each figure, arrowheads are numbered sequentially (▸1, ▸2,...▸10, etc.) from start to end points. Both subjects failed to find the end point by task termination (30 min). (**Start**: task starting point, Dupont Ave. & 28th Street; **End**: task end point, 28th Ave. & 48th Street; see Figure 3-2; **F**: finish point for subject at task termination.)

Figure L-11

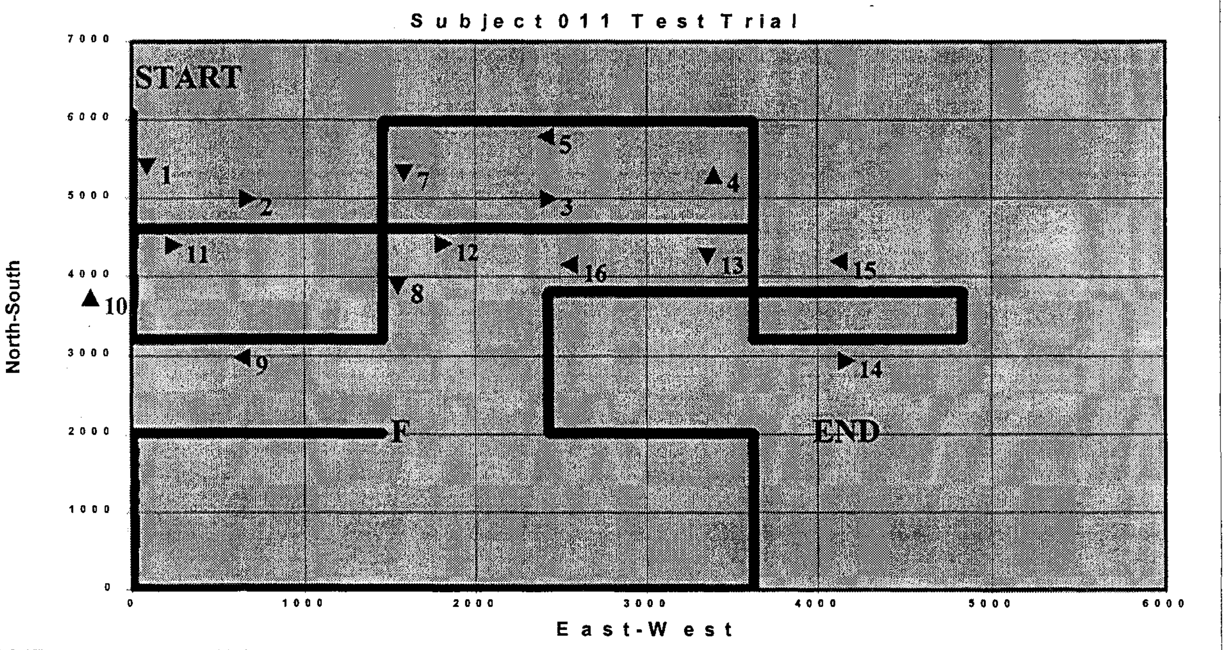
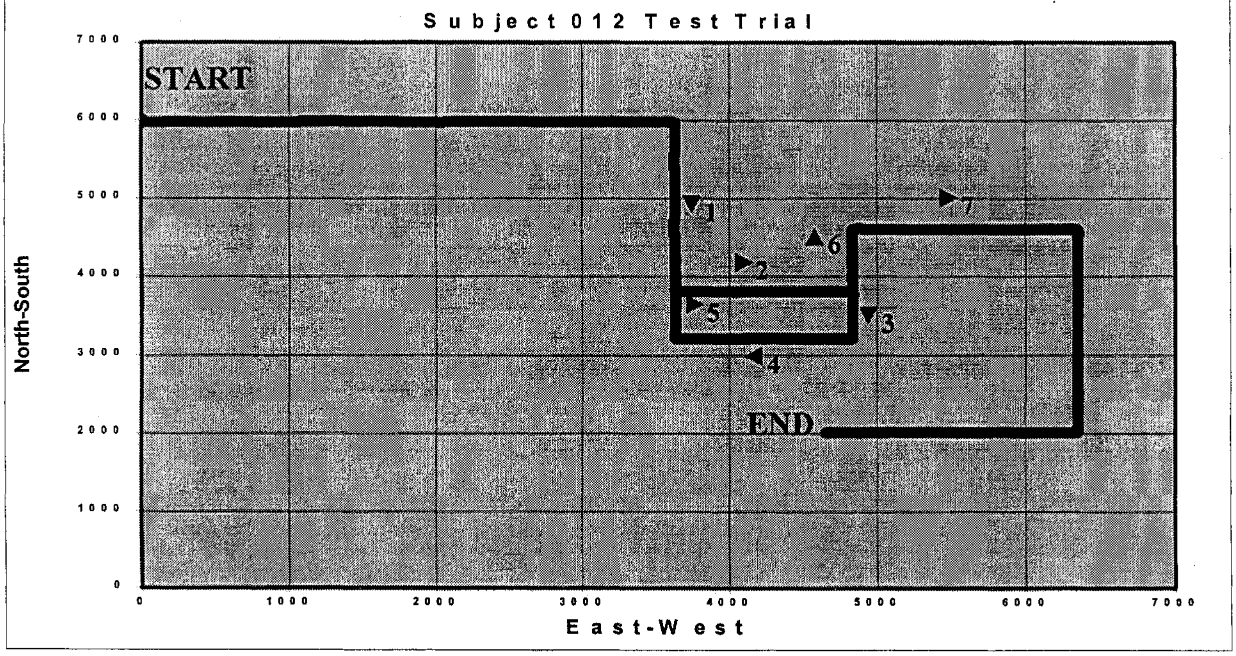


Figure L-12



Figures L-11 and L-12. Route trajectories (solid black lines) for Subjects 011 (top) and 012 (bottom) (Table 3-3, revised ID numbers) in traversing simulated driving environment under test condition. Streets are not labeled in figures. Refer to Appendix D, Figure D-1, for diagram of streets modeled in simulated environment, and to Appendix J, Figure J-2, for diagram of streets accessible under test condition. Arrows in figures show sequence of streets traversed. To clarify trajectories in each figure, arrowheads are numbered sequentially (▸1, ▸2,...▸10, etc.) from start to end points. Subject 015 failed to find the end point by task termination (30 min). (**Start**: task starting point, Dupont Ave. & 28th Street; **End**: task end point, 28th Ave. & 48th Street; see Figure 3-2; **F**: finish point for subject at task termination.)

Figure L-13

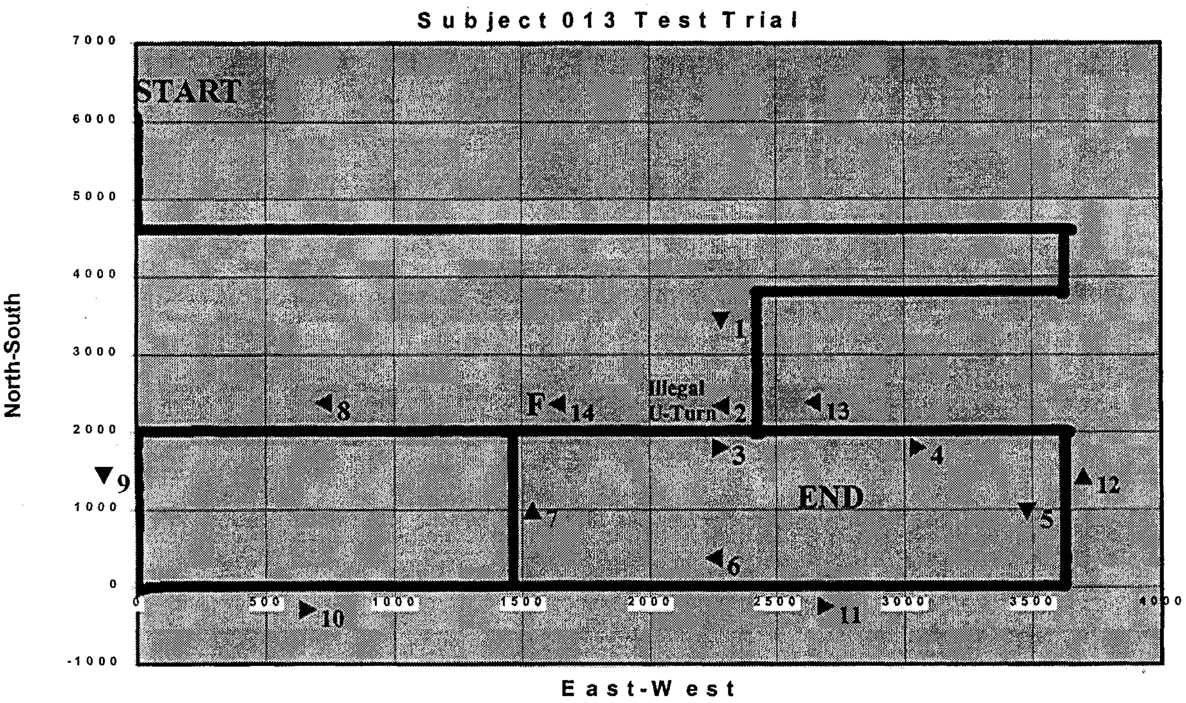


Figure L-13. Route trajectory (solid black line) for Subject 013 (Table 3-3, revised ID numbers) in traversing simulated driving environment under test condition. Streets are not labeled in figure. Refer to Appendix D, Figure D-1, for diagram of streets modeled in simulated environment, and to Appendix J, Figure J-2, for diagram of streets accessible under test condition. Arrows in figure show sequence of streets traversed. To clarify trajectories in each figure, arrowheads are numbered sequentially (▸1, ▸2,...▸10, etc.) from start to end points. Subject failed to find the end point by task termination (30 min), and made an illegal U-turn. (**Start**: task starting point, Dupont Ave. & 28th Street; **End**: task end point, 28th Ave. & 48th Street; see Figure 3-2; **F**: finish point for subject at task termination.)

APPENDIX M

PROFILES OF VEHICLE SPEED AND BRAKING PRESSURE FOR EACH SUBJECT AND EACH TESTING SESSION

Figure M-1A
Superimposed Speed and Braking Profiles - Control Session
Subject 001

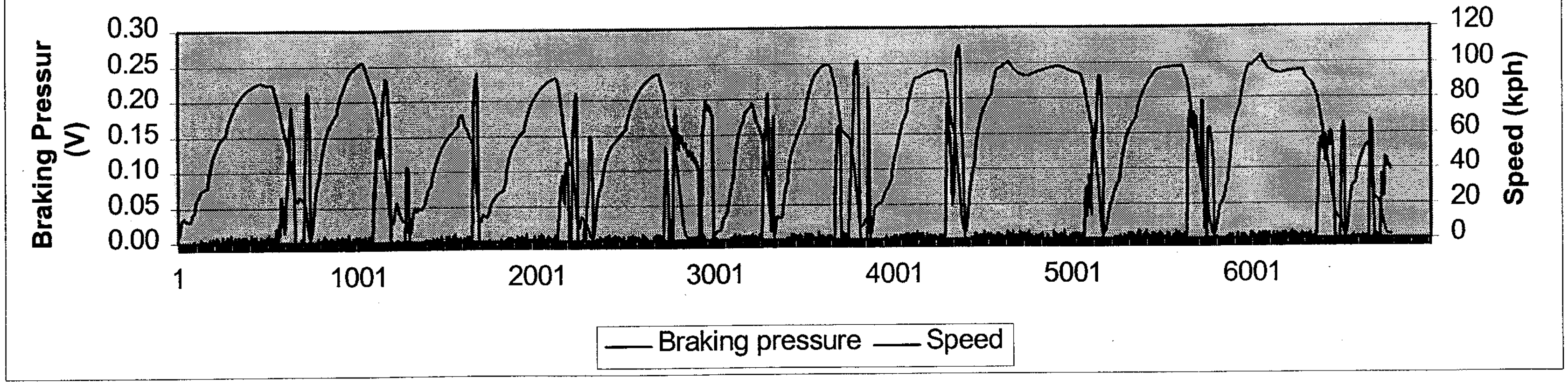


Figure M-1B
Superimposed Speed and Braking Profiles - Test Session
Subject 001

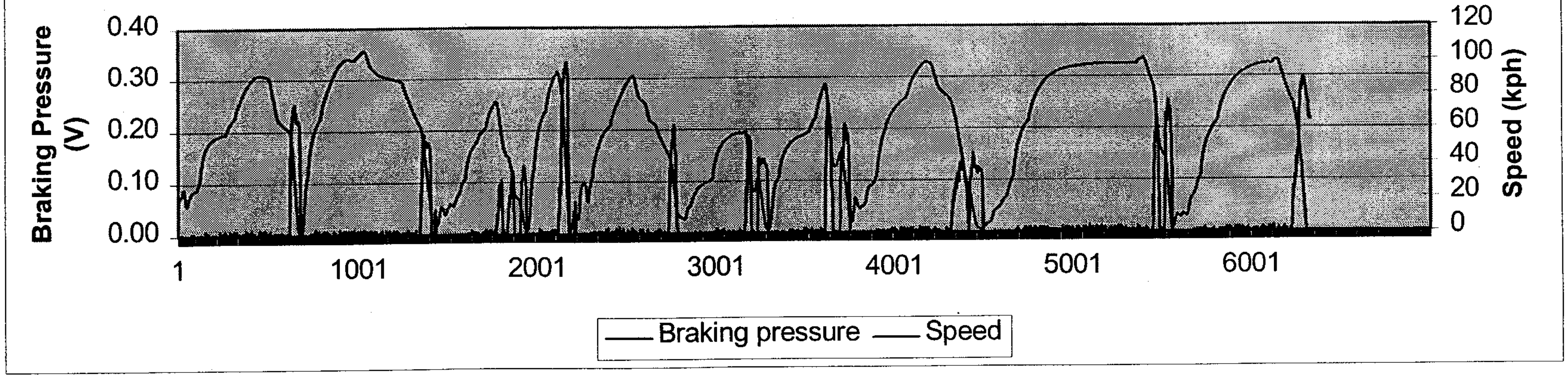


Figure M-1. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-1A, top panel) and test (Figure M-1B, bottom panel) simulated driving sessions for Subject 001 (Table 3-3, revised ID numbers).

Figure M-2A

Superimposed Speed and Braking Profiles - Control Session

Subject 002

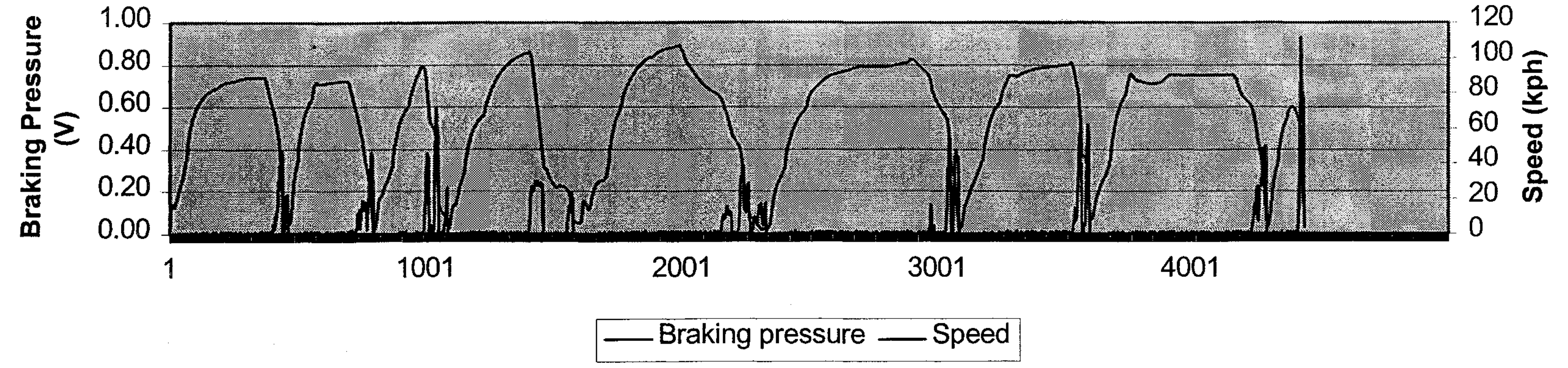


Figure M-2B

Superimposed Speed and Braking Profiles - Test Session

Subject 002

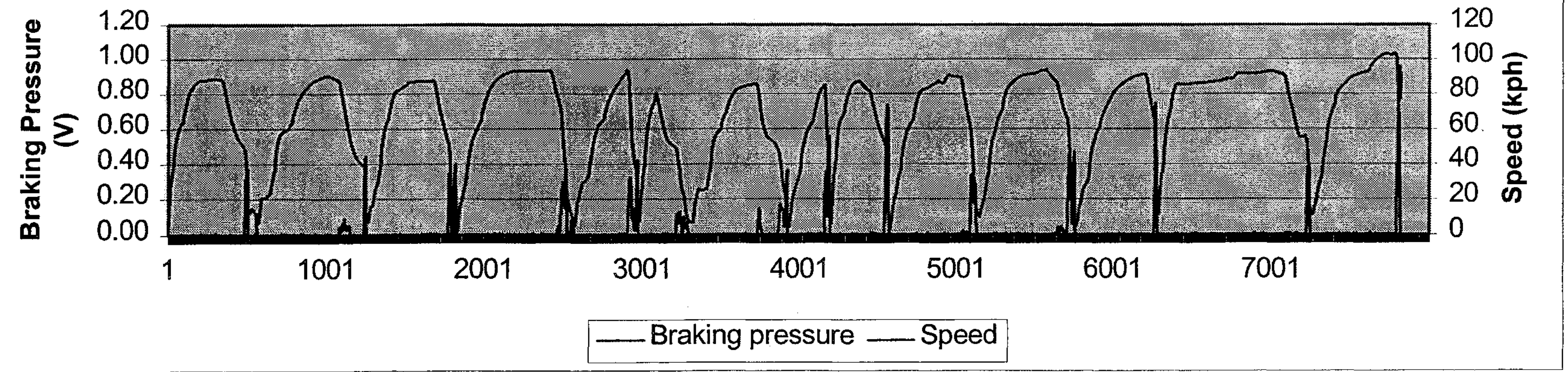


Figure M-2. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-2A, top panel) and test (Figure M-2B, bottom panel) simulated driving sessions for Subject 002 (Table 3-3, revised ID numbers).

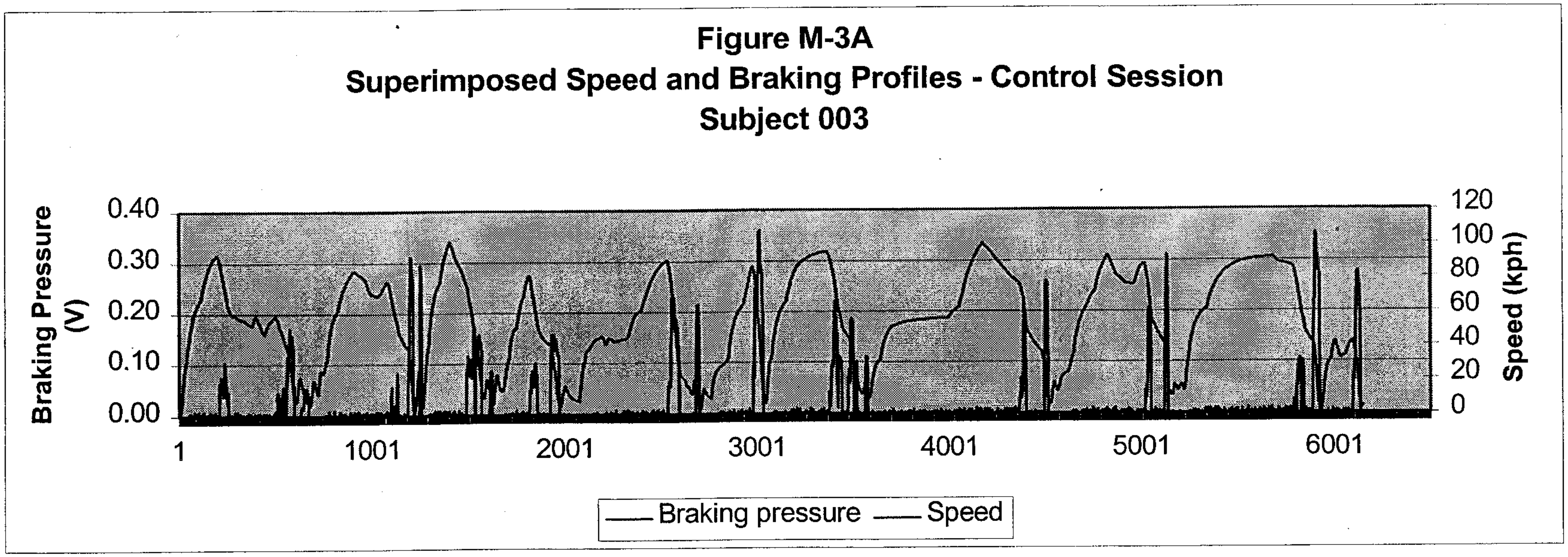


Figure M-3A
Superimposed Speed and Braking Profiles - Control Session
Subject 003

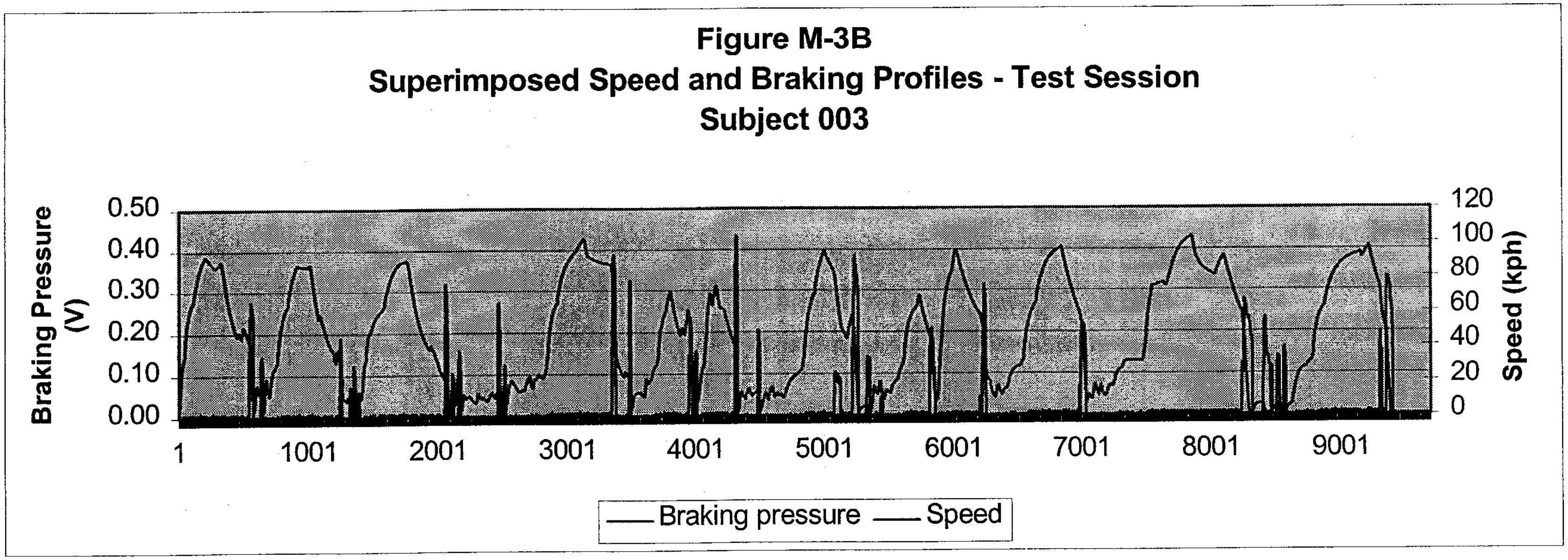


Figure M-3B
Superimposed Speed and Braking Profiles - Test Session
Subject 003

Figure M-3. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-3A, top panel) and test (Figure M-3B, bottom panel) simulated driving sessions for Subject 003 (Table 3-3, revised ID numbers).

Figure M-4A
Superimposed Speed and Braking Profiles - Control Session
Subject 004

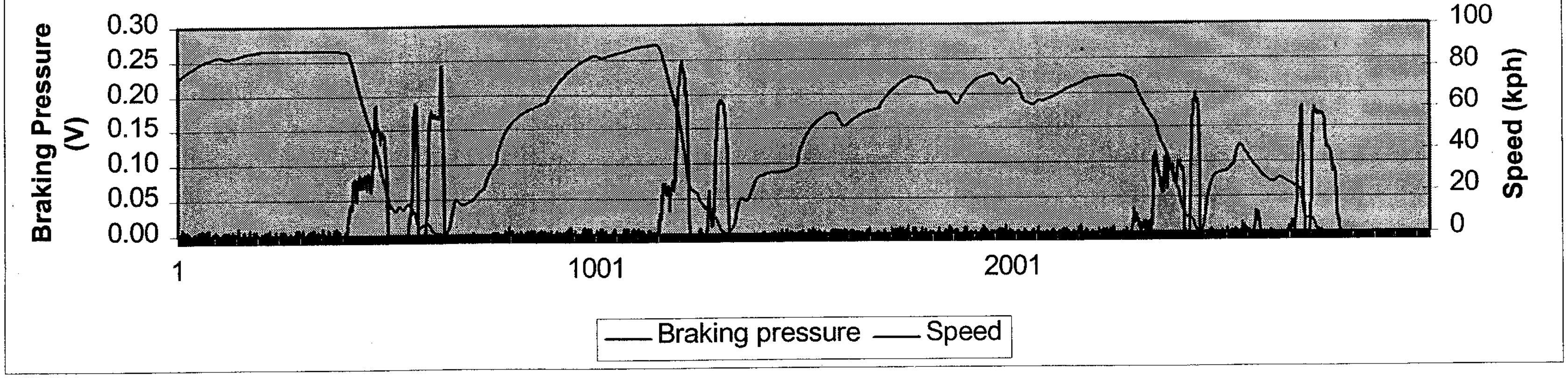


Figure M-4B
Superimposed Speed and Braking Profile - Test Session
Subject 004

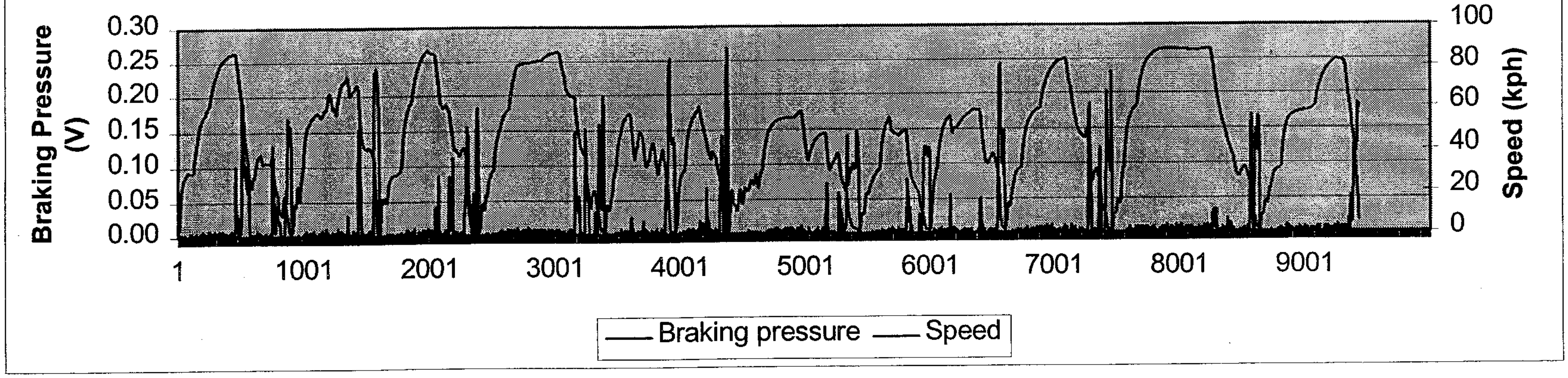


Figure M-4. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-4A, top panel) and test (Figure M-4B, bottom panel) simulated driving sessions for Subject 004 (Table 3-3, revised ID numbers).

Figure M-5A
Superimposed Speed and Braking Profiles - Control Session
Subject 005

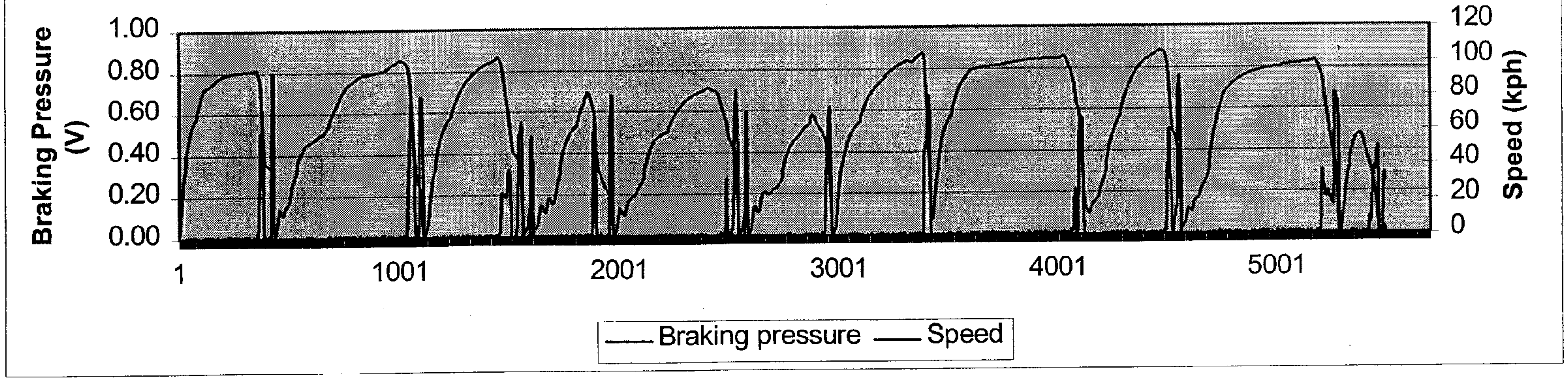


Figure M-5B
Superimposed Speed and Braking Profiles - Test Session
Subject 005

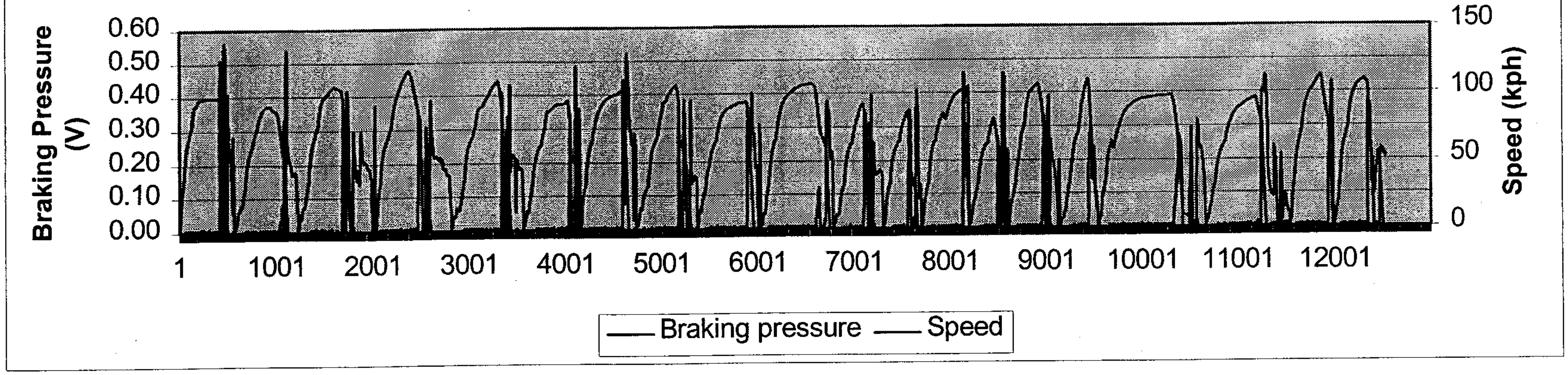


Figure M-5. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-5A, top panel) and test (Figure M-5B, bottom panel) simulated driving sessions for Subject 005 (Table 3-3, revised ID numbers).

Figure M-6A
Superimposed Speed and Braking Profiles - Control Session
Subject 006

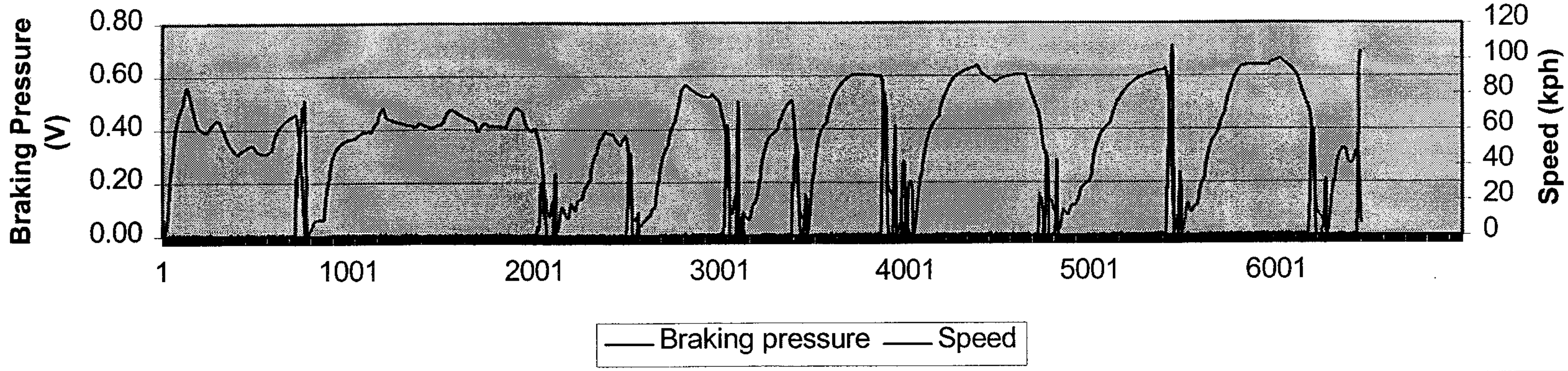


Figure M-6B
Superimposed Speed and Braking Profiles - Test Session
Subject 006

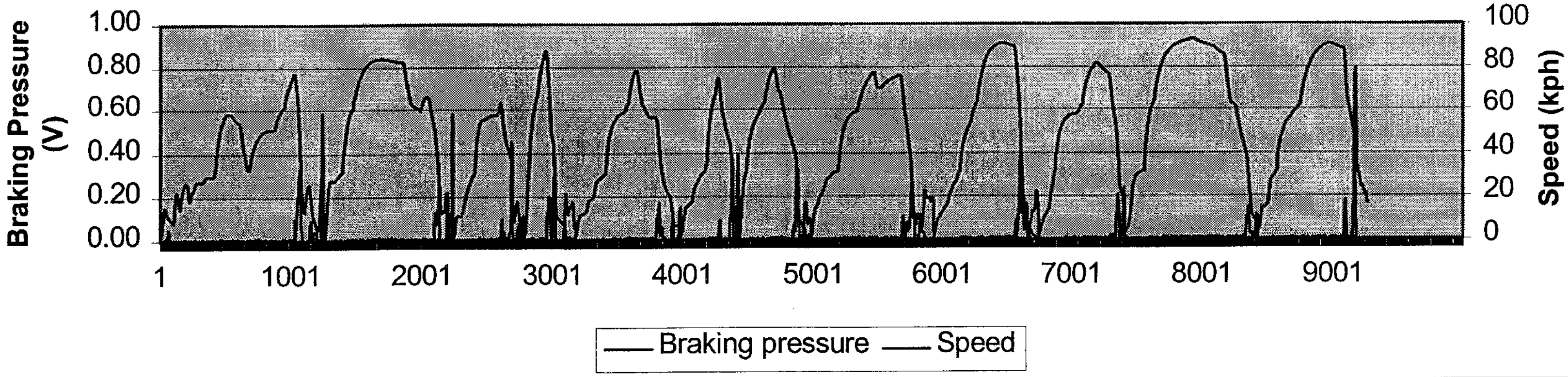


Figure M-6. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-6A, top panel) and test (Figure M-6B, bottom panel) simulated driving sessions for Subject 006 (Table 3-3, revised ID numbers).

Figure M-7A
Superimposed Speed and Braking Profiles - Control Session
Subject 007

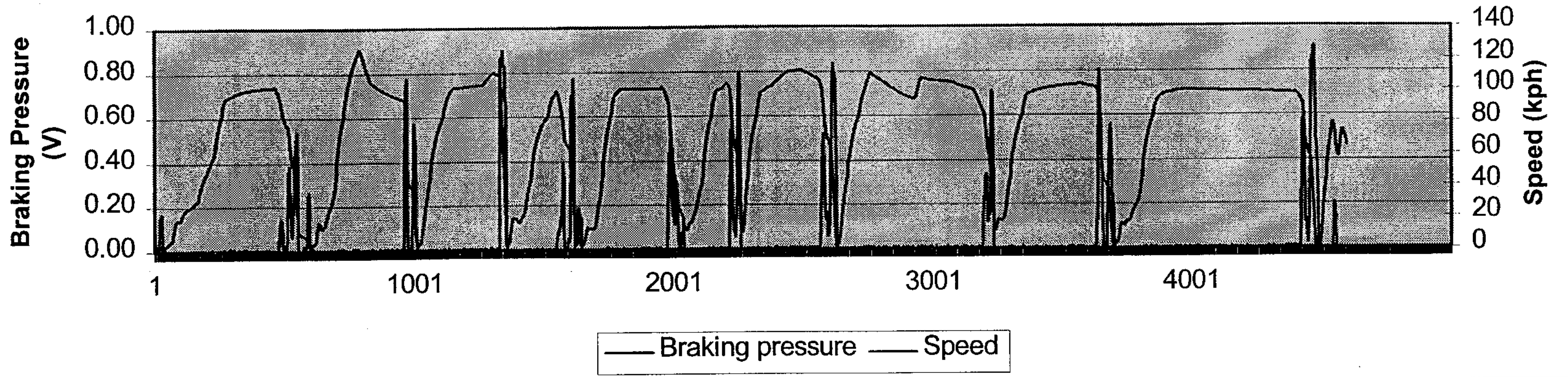


Figure M-7B
Superimposed Speed and Braking Profiles - Test Session
Subject 007

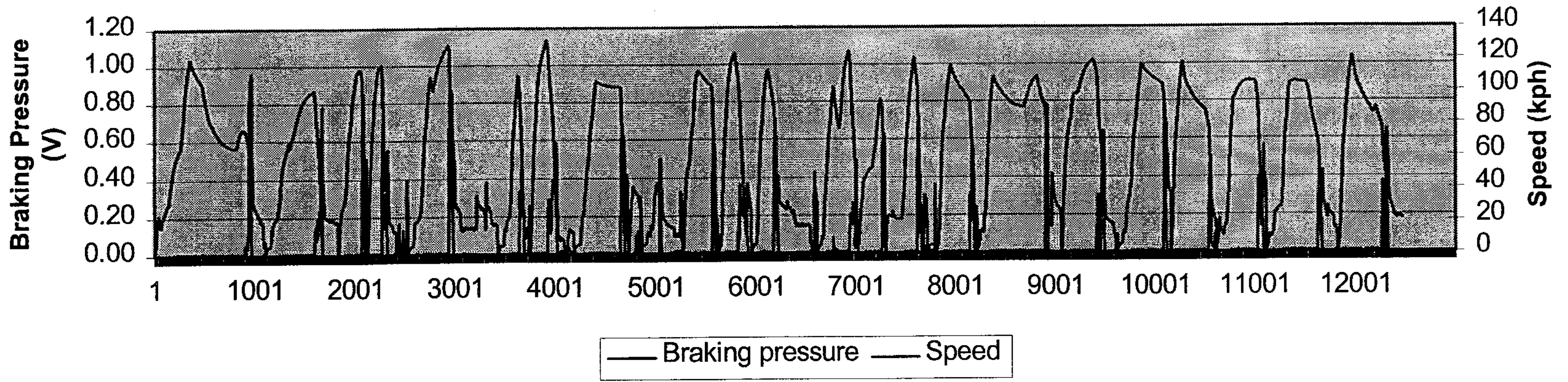


Figure M-7. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-7A, top panel) and test (Figure M-7B, bottom panel) simulated driving sessions for Subject 007 (Table 3-3, revised ID numbers).

Figure M-8A
Superimposed Speed and Braking Profiles - Control Session
Subject 008

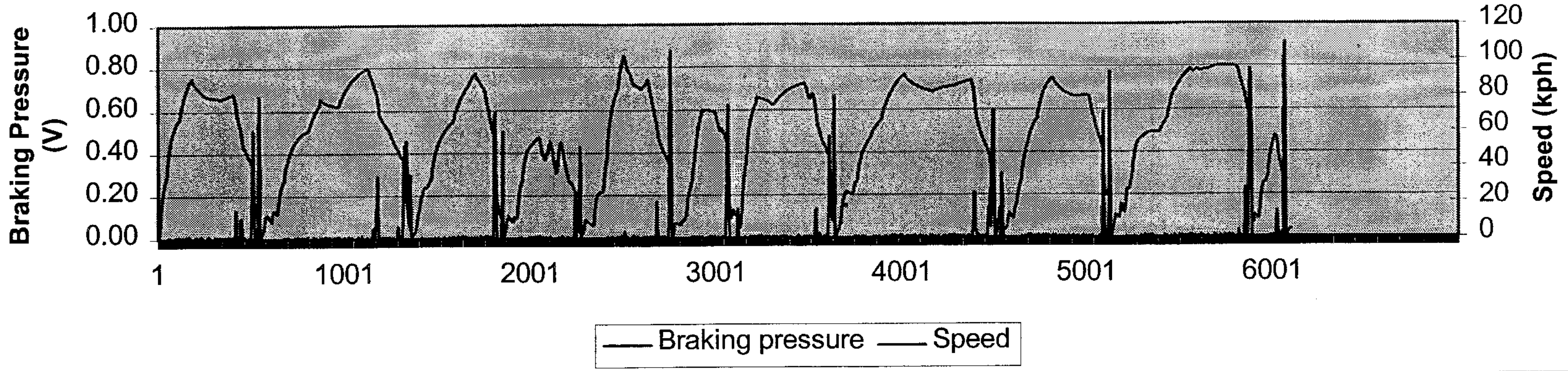


Figure M-8B
Superimposed Speed and Braking Profiles - Test Session
Subject 008

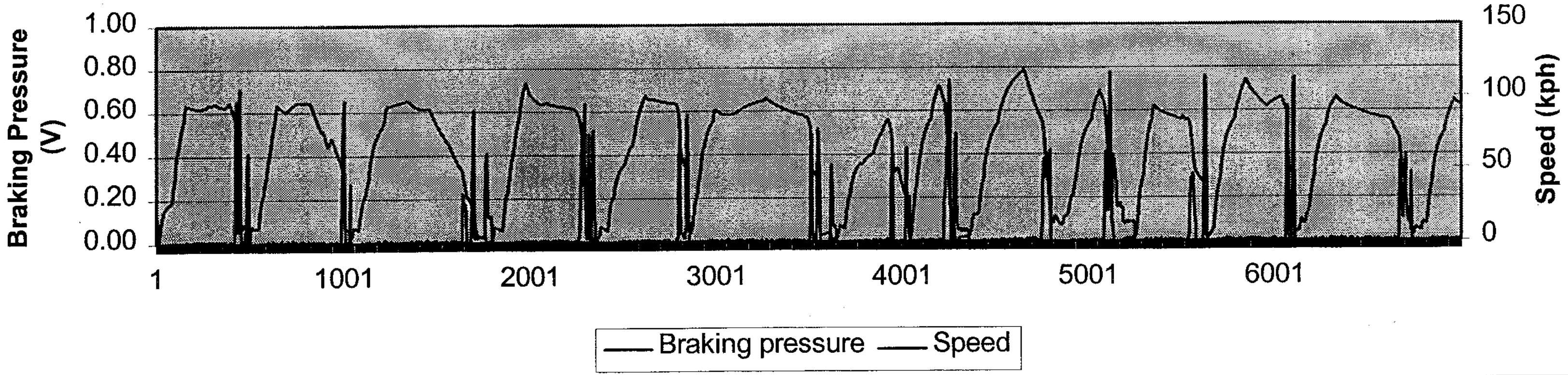


Figure M-8. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-8A, top panel) and test (Figure M-8B, bottom panel) simulated driving sessions for Subject 008 (Table 3-3, revised ID numbers).

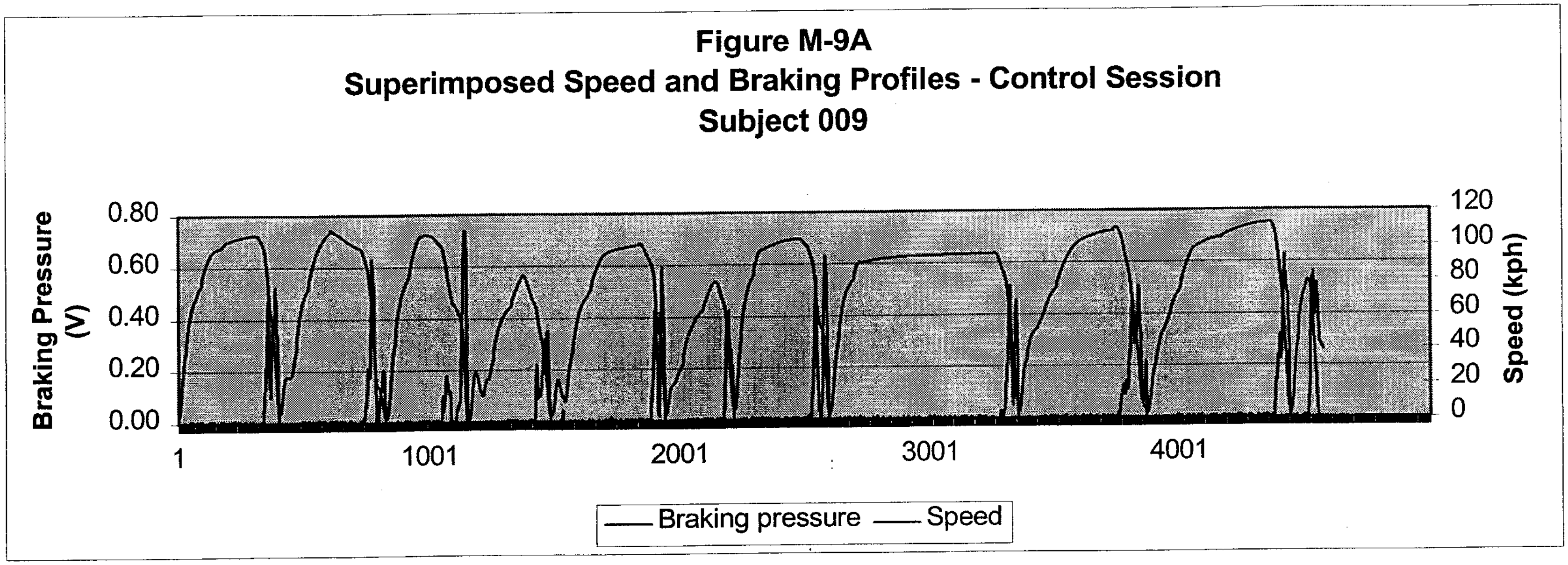


Figure M-9A
Superimposed Speed and Braking Profiles - Control Session
Subject 009

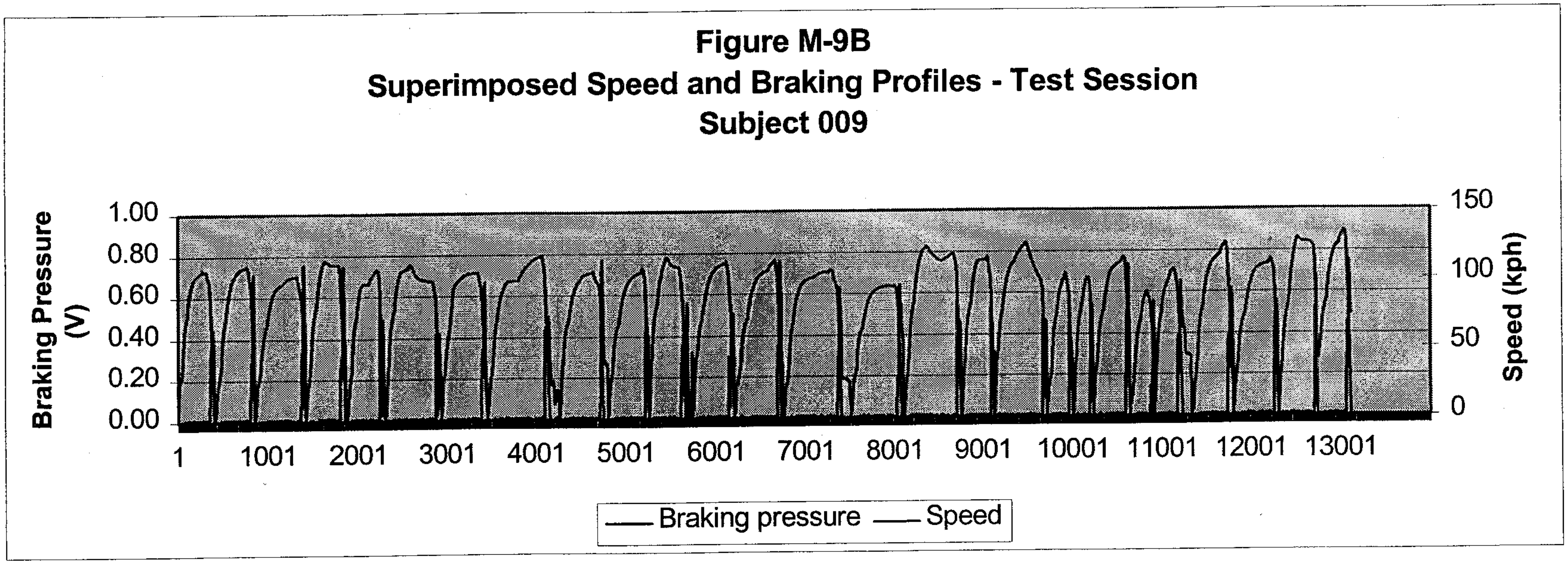


Figure M-9B
Superimposed Speed and Braking Profiles - Test Session
Subject 009

Figure M-9. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-9A, top panel) and test (Figure M-9B, bottom panel) simulated driving sessions for Subject 009 (Table 3-3, revised ID numbers).

Figure M-10A
Superimposed Speed and Braking Profiles - Control Session
Subject 010

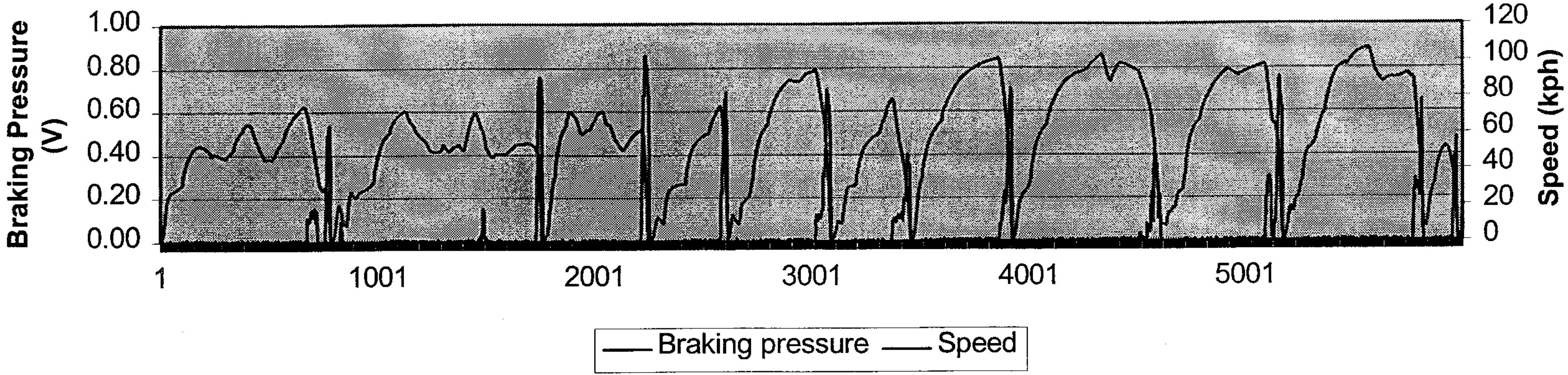


Figure M-10B
Superimposed Speed and Braking Profiles - Test Session
Subject 010

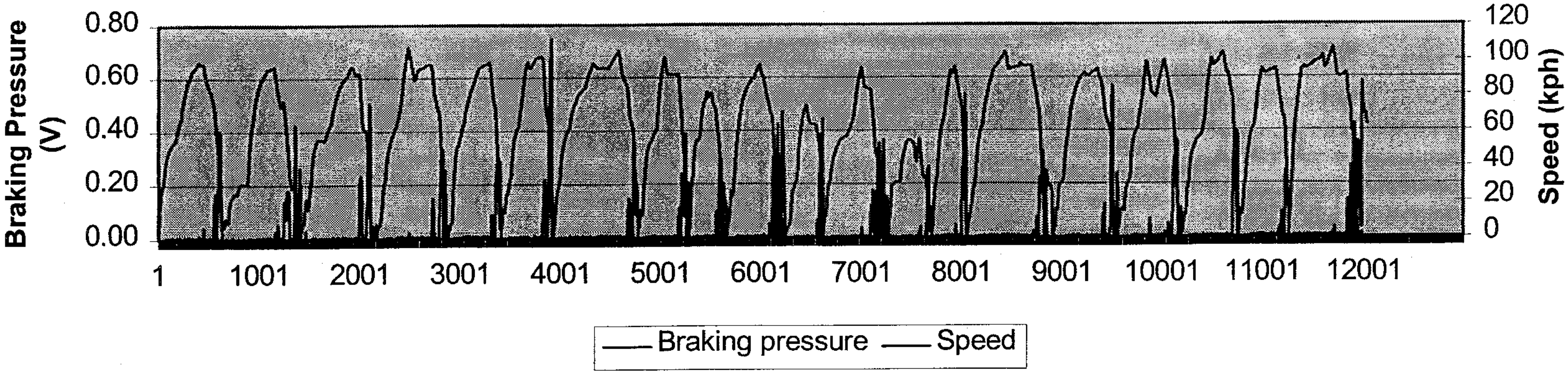


Figure M-10. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-10A, top panel) and test (Figure M-10B, bottom panel) simulated driving sessions for Subject 010 (Table 3-3, revised ID numbers).

Figure M-11A
Superimposed Speed and Braking Profiles - Control Session
Subject 011

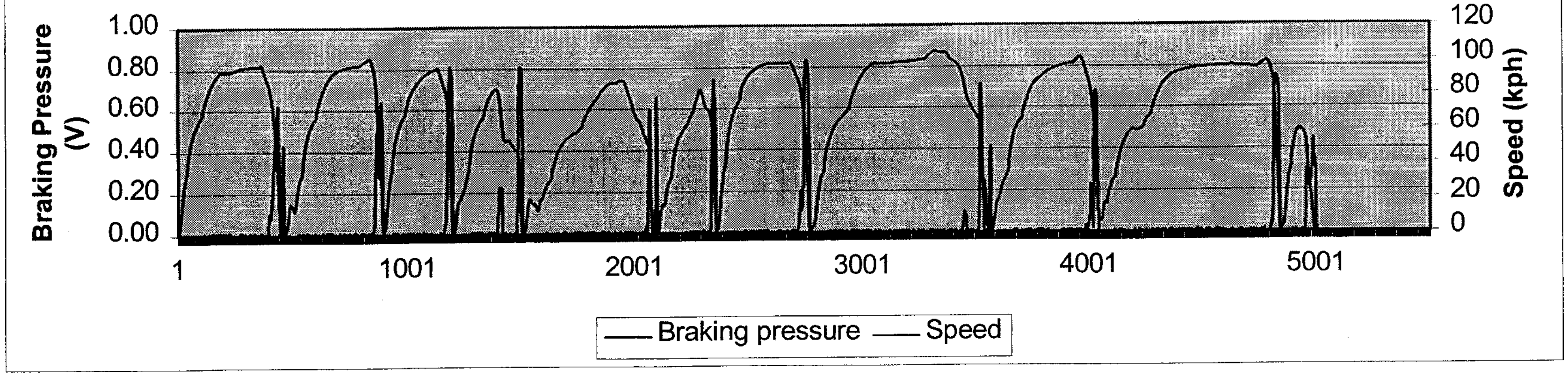


Figure M-11B
Superimposed Speed and Braking Profiles - Test Session
Subject 011

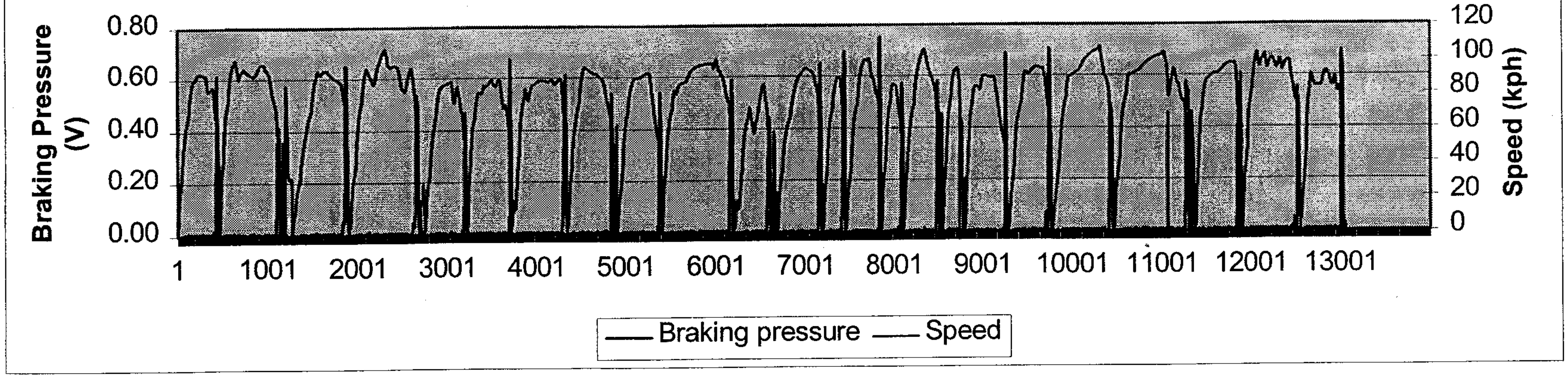


Figure M-11. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-11A, top panel) and test (Figure M-11B, bottom panel) simulated driving sessions for Subject 011 (Table 3-3, revised ID numbers).

Figure M-12A
Superimposed Speed and Braking Profiles - Control Session
Subject 012

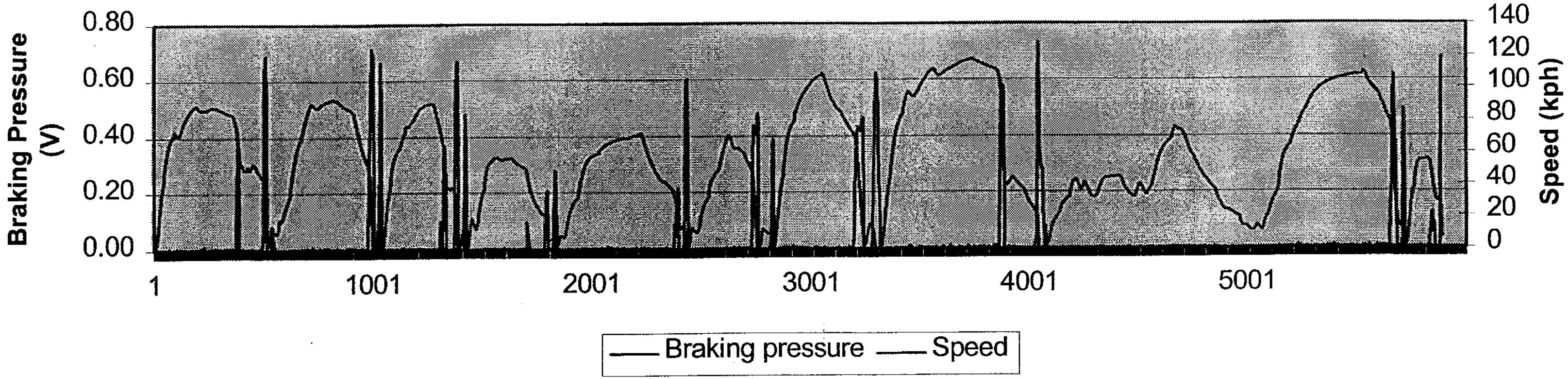


Figure M-12B
Superimposed Speed and Braking Profiles - Test Session
Subject 016.

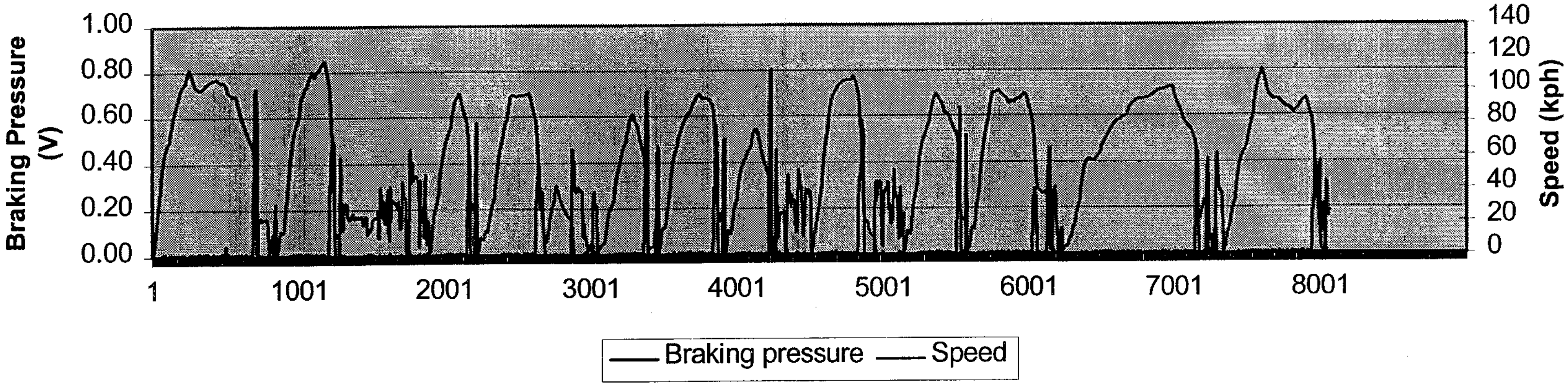


Figure M-12. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-12A, top panel) and test (Figure M-12B, bottom panel) simulated driving sessions for Subject 012 (Table 3-3, revised ID numbers).

Figure M-13A
Superimposed Speed and Braking Profiles - Control Session
Subject 013

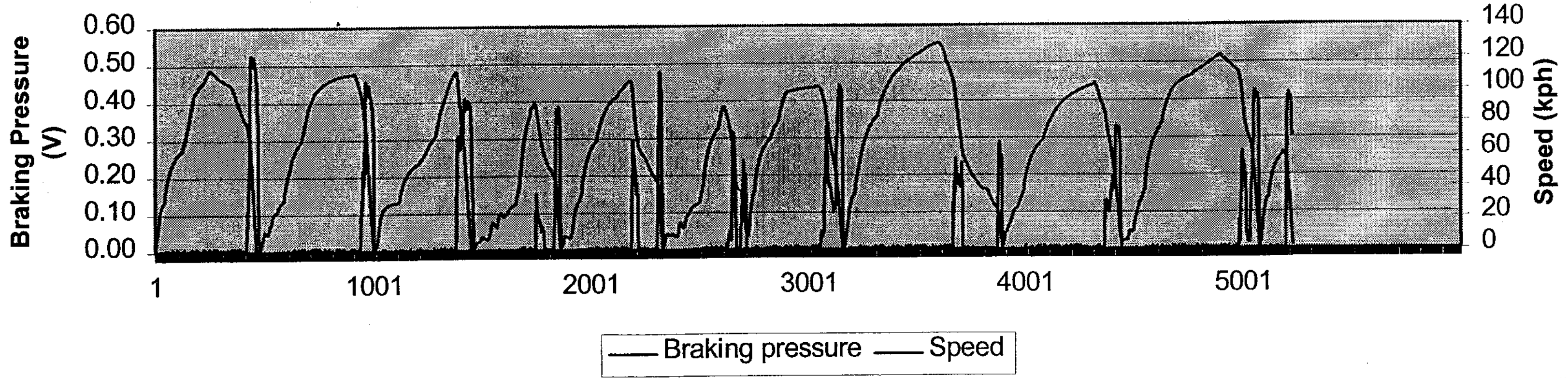


Figure M-13B
Superimposed Speed and Braking Profiles - Test Session
Subject 013

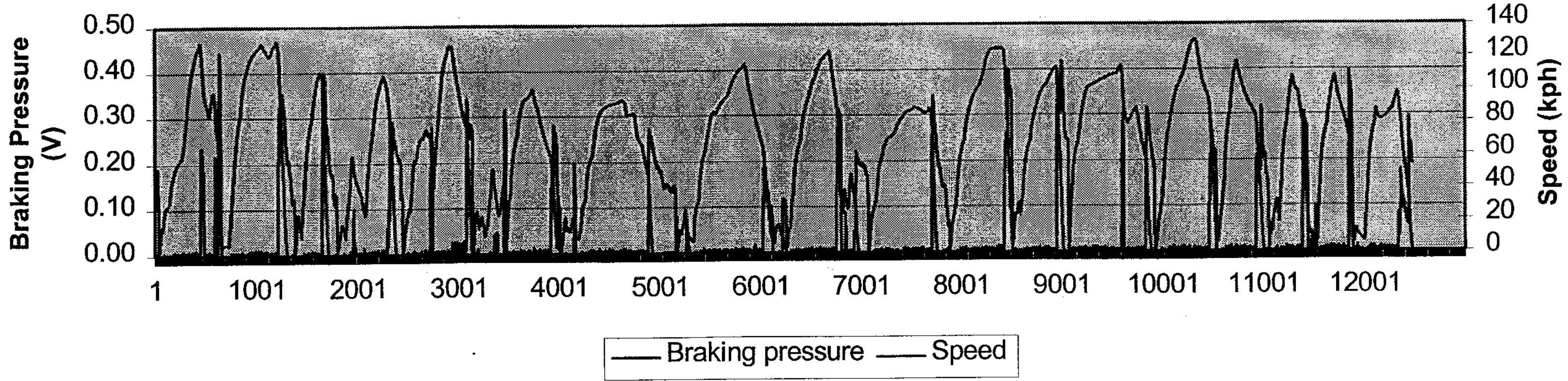


Figure M-13. Superimposed profiles of vehicle speed (hump-like peaks) and braking pressure (spike-like peaks) for control (Figure M-13A, top panel) and test (Figure M-13B, bottom panel) simulated driving sessions for Subject 013 (Table 3-3, revised ID numbers).