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ADVANCE Safety Evaluation

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13. ABSTRACT (Maximum 200 words)

ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) is an in-vehicle navigation and guidance system for enhancing localized travel. Its automated Mobile Navigation Assistant (MNA) interface, is one of several Intelligent Transportation System (ITS) prototypes of Advanced Traveler Information Systems (ATIS) for highway vehicles. The ADVANCE project included an operational field test to evaluate various ADVANCE system components.

The National Highway Traffic Safety Administration (NHTSA) has sponsored the safety evaluation of the ADVANCE MNA based on the operational field test. The main objectives of the evaluation were to (1) determine whether drivers drive more, or less, safely with the system than without it in ways related to the system, (2) extend the knowledge base of ATIS use for navigation, and (3) gain insight into ATIS design improvements.

The study examined the variable effects of using four navigation scenarios on driving and navigation performance by 60 test subjects, traversing a set of four common routes, using a highly instrumented test vehicle for gathering safety related data. The scenarios were (1) MNA with voice supplement, (2) MNA without voice supplement, (3) a paper map, and (4) a textual paper direction list. The preponderance of evidence suggests drivers drive equally as safe with the MNA as without it, when the MNA is used to navigate to unfamiliar destinations.

ADVANCE users indicated that the voice supplement was easily understood, provided relief from distractions, and enhanced feeling of safety over the direction list or paper map. On the other hand, their eye glance and safety performance suggested that the voice did not appreciably change the visual demands or error rate of navigation. Considering the contrasting results of prior ATIS evaluations, the precision and informational clarity of the MNA voice supplement was called into question. With design improvements, MNA auditory guidance has the potential to further reduce driver workload, yield fewer driver errors, and enhance the safety preference of users.

14. SUBJECT TERMS

ADVANCE, in-vehicle navigation, route guidance, advanced traveler information system, ATIS, intelligent transportation system, ITS, driver performance, hazard indicator, eye glance behavior, turn instruction, voice supplement, auditory guidance

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Preface

This report presents the results of an independent effort to evaluate the safety impacts of an automotive route navigation and guidance system deployed under the auspices of the ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) project in Metropolitan Chicago. The ADVANCE consortium, consisting of the Federal Highway Administration (FHWA), Illinois Department of Transportation (IDOT), the University of Illinois, Northwestern University, the American Automobile Association, and Motorola, Inc., conducted an extensive operational field test of new navigation and guidance technology in 1994-96. The technology was aimed primarily at reducing individual travel times through the provision of real-time traffic information and navigation assistance, a type of Advanced Traveler Information System (ATIS).

The National Highway Traffic Safety Administration (NHTSA) Office of Crash Avoidance Research, provided the direction and funding for the ADVANCE safety evaluation. The evaluation provides the public with a reliable, quantitative safety benchmark for ATIS systems. The main objectives of the evaluation study were to:

- Address NHTSA's primary goal of determining whether drivers drive more, or less, safely with the system than without it in ways related to the system;
- Extend the knowledge base of ATIS use for navigation; and
- Gain insight on ATIS improvements

The US Department of Transportation's Volpe National Transportation Systems Center (Volpe Center) conducted the independent evaluation with the support from Science Applications International Corporation (SAIC) , the University of Iowa, and Virginia Polytechnic Institute and State University (VPI). Completion of this study was facilitated under the leadership of Dr. August Burgett, of the NHTSA Office of Vehicle Safety Research, NRD-51. Dr. Burgett's thoughtful guidance helped the authors solidify the findings and recommendations.

The authors also acknowledge the continual support and supervision of Mr. John Hitz, Chief of the Volpe Center Accident Prevention Division. Another major contributor was Ms. Suzanne Chen, of the Volpe Center Operations Assessment Division. Ms. Chen was invaluable in deciphering numerous test data, and in verifying and performing extended statistical analyses from the test archives.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

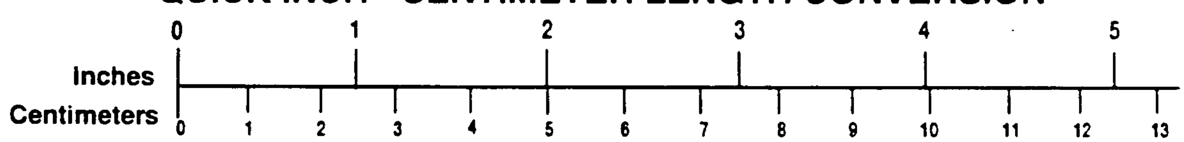
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

Background

ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) is an in-vehicle navigation and guidance system intended to reduce individual travel times through provision of real-time traffic information and navigation assistance. The system is also envisioned to reduce traffic congestion by encouraging better use of the transportation network. ADVANCE, with its automated Mobile Navigation Assistant (MNA) interface, is one of several prototypes of Advanced Traveler Information Systems (ATIS) that have been introduced over the last decade as part of an emerging series of Intelligent Transportation Systems (ITS) for highway travel. The ADVANCE project includes an operational field test that was intended to evaluate various ADVANCE system components.

The ADVANCE safety evaluation is sponsored by the National Highway Traffic Safety Administration (NHTSA) Office of Crash Avoidance Research, which is responsible for ensuring that the safety impacts of such vehicular ITS devices are understood and addressed. The safety evaluation focused on the use of the ADVANCE MNA for navigation guidance purposes on the basis of a planned field operational test. The main objectives of the evaluation were to:

- Address NHTSA's primary goal of determining whether drivers drive more, or less, safely with the system than without it in ways related to the system;
- Extend the knowledge base of ATIS use for navigation; and
- Gain insight on ATIS design improvements.

Conclusions

- The preponderance of evidence suggests drivers drive equally as safe with the MNA as without it, when the MNA is used to navigate to unfamiliar destinations.
- Useful information has been gathered toward understanding how drivers interact with both ATIS displays and conventional navigation methods. Furthermore, in collecting and analyzing the data, innovative techniques were devised that can be employed in future ITS safety studies.
- To realize its full potential (including possible safety benefits), the quality and timing of aural directions in the voice supplement should be enhanced.

Study Approach

In a planned field test the study examined the variable effects of using four navigation scenarios on driving and navigation performance by 60 test subjects. The scenarios were (1) MNA with voice supplement, (2) MNA without voice supplement, (3) a paper map, and (4) a textual paper direction list. The latter two scenarios served as control conditions. In addition to the four navigation scenarios, the study examined the effects of age and experience on safety-related measures of effectiveness (MOE).

Each volunteer driver was directed to traverse the same four origin-destination (O-D) pairs, using a randomly assigned sequence of navigation scenarios – one distinct scenario for each O-D. A 1995 Ford Taurus Station Wagon, to which unobtrusive sensors, cameras, and data-recording instrumentation had been added, was used as the test vehicle. The instrumentation and sensor package included four hidden video cameras that provided time-stamped video images of the following: forward out-of-windshield view, lane-position view from the left rearview mirror, driver's head and eyes, and the MNA display. The package also included a dual-axis accelerometer, steering potentiometer, accelerator and brake pedal sensors, laser rangefinder, audio recording, data collection computer (486 laptop), PC-VCR, and quad-multiplexer. This instrumentation suite, as well as a supplementary driver questionnaire, provided the performance data from which comparative safety measures of effectiveness were analyzed.

Findings

Objective 1: *Determine whether drivers drive more - or less - safely with ADVANCE*

To test the main safety hypothesis, four MOEs of the impact of the MNA on safety were examined: (1) eye glance behavior, (2) driving performance indicators, (3) hazard indicators, and (4) driver perceptions. Extensive analysis of the MOEs suggest that drivers drive equally as safely with the MNA system as without it. Furthermore, no collisions occurred in over 2,000 miles driven while navigating with the MNA. Specific findings for each MOE are summarize below:

Eye Glance Behavior: The durations of individual glances to the MNA were short compared to driving with a paper map, suggesting an MNA safety benefit. On the other hand, the glance data suggest that the MNA increases total glance time away from the forward roadway – a safety disbenefit. These effects were more pronounced for MNA without voice than with. The MNA without voice yielded the largest proportion of glance time to the display, followed by the MNA with voice, the direction list, and the paper map.

Because average duration of glances is considered a better safety indicator than dwell, the initial results suggested examining the frequency of long glances. In fact, the frequency of glances to the navigation displays longer than 2.5 seconds did not vary with navigation scenario.

The total proportion of time looking at the MNA displays was reduced by having MNA experience. However, this did not alter the relative results between scenarios by experience level.

Older drivers devoted about 2 percent more of their glance time to the navigation aids than did the younger drivers, this age difference was roughly uniform across scenarios.

Driving Performance: Overall, the driving performance measures suggest that drivers drive at least as safely with the MNA as with other navigation scenarios.

There were some indications that navigating with the MNA without voice may have reduced driver workload (e.g., frequency of sharp steering movements and deviation of accelerator input) relative to the paper map, thereby rendering it potentially safer. However, these indications were neither strong, nor consistent across all performance measures. There was no significant reduction in driver workload with the MNA voice supplement. This counterintuitive finding may be explained by design deficiencies addressed in the Objective (3) discussion.

Hazard Analysis: The hazard analysis also showed few differences in the effects of navigation scenarios. The MNA without voice yielded fewer aggregate driver errors than the paper map. The MNA with voice supplement yielded no comparable differences in any error category, and did not improve on the MNA without voice. This reversal from expectation is similar to the finding on driver workload and may also be explained by design deficiencies in the voice supplement.

For the entire test sample, incidence of near misses and driver errors in the vicinity of a hazard did not increase with either MNA scenario. Observations of the limited distribution of errors in certain risk categories, however, suggest that the MNA might help younger drivers more than older drivers, in reducing their overall driving risk.

Driver Perceptions: Whereas the objective measures of performance suggest little safety-related benefit derived from MNA use, the subjective measures suggest a benefit.

When asked to rank the safety of the four navigation scenarios, drivers ranked either MNA scenario as significantly safer than the paper map or direction list. Drivers also reported less distraction, and greater comfort and feelings of safety, with either MNA scenario. Drivers clearly rated MNA with voice as safer than without in a direct preference polling, and ranked both MNA scenarios safer than the paper-based scenarios.

While the differences in assessments between MNA and the control scenarios were predominant, there were also differences between the two MNA scenarios. Drivers stated that they were more aware of their surroundings compared to normal driving, with either MNA scenario than they were with the paper map or direction list, but more so with voice than without. Also, only with the voice supplement did drivers feel they kept their eyes on the road more, and had fewer close calls, than with the paper map. After providing this specific feedback, drivers indicated they felt somewhat safer, relative to the other scenarios, with the voice supplement than without.

Drivers were also asked periodically to rate their workload, in terms of time stress, visual effort, and psychological stress. Subjective workload was rated uniformly low and, unlike objective driver performance measures, did not vary with navigation scenario.

Objective (1) Summary: For the four measures of effectiveness, there is no clear, unifying evidence that drivers drive less safely using ADVANCE MNA than with the paper map. Findings on glance measures are mixed with respect to MNA safety impact. Mean durations are less, whereas the proportion of total glance time is greater, although the frequency of long glances greater than 2.5 seconds are no different between the scenarios. In fact, the workload and hazard analyses indicate that MNA without voice enhances some safety surrogates, particularly for younger drivers. There are indications that the MNA voice supplement has safety advantages for drivers with prior MNA experience, but these benefits are not realized for all users. Also, MNA while providing benefits over the paper map, did not significantly outperform the direction list scenario. Drivers as a whole perceive safety advantages with the MNA and, in particular, the voice supplement.

On the basis of these findings, the evaluators concluded that drivers drive equally as safe with the MNA system, particularly without using the MNA voice supplement, as with the paper map.

Objective 2: *Extend the ITS knowledge base*

The primary contribution to the ITS knowledge base is the information gathered on how drivers interact comparatively with both turn-by-turn graphical guidance displays and conventional navigation methods. Combined with similar information from prior ATIS studies, the information is useful in evaluating the potential of a vehicular navigation system in achieving their primary goals without sacrificing safety. Source (video and digital records) and processed data files of safety performance, as well as questionnaire data, are components for an ATIS safety research database. In particular, the data not only compares performance with varied display devices per se, but also offers insight into how the age of the driver and their experience with the technology affects their performance.

A significant by-product of the evaluation was the development of a new and faster method for reduction of eye glance data. Custom software was developed for this project that enabled analysts to input glance locations at near real-time speed. In addition, glance time and other descriptive measures were extracted automatically with the input of glance location. This development significantly reduced the amount of time and labor required, when compared to earlier efforts in the same laboratory. The tools developed for this study have been utilized in further driver-vehicle interface studies.

Objective 3: *Extract ATIS design recommendations*

The study has provided data on contrasting approaches to the integration of voice supplements to ATIS in-vehicle systems. Unlike prior ATIS prototypes, MNA developers selected digitized voice because it provides higher quality sound than machine-like synthesized voice. Digitized voice technology uses recordings of human speakers. With the technology available at the time of the test, it was impractical to digitize the names of all the roads in the ADVANCE coverage area. Therefore, the MNA did not provide street names when it suggested turns.

ADVANCE users indicated that the voice was easily understood, and ranked MNA with voice - but not without - as safer than the direction list or paper map. On the other hand, their eye glance performance suggested that the voice did not appreciably change the visual demands or error rate of navigation. Considering the contrasting results of TravTek (a previously evaluated ATIS prototype), there was some indication that with more precise directions, the MNA voice supplement has the potential to further reduce driver workload, yield fewer driver errors, and enhance the safety preference of the participants.

Using ADVANCE MNA voice supplement, drivers reported isolated instances where the timing of the instruction was premature or late. If the turn instruction was so mistimed, then the driver sometimes was forced to hesitate and/or respond irregularly to make the turn, if not actually commit a navigational error. Lengthy text messages, intended to clarify brief aural instructions, were judged disconcerting. Added directional labels, to indicate the prefix of a street name, were found similarly confusing.

Timing and directional labels with the TravTek voice supplement were not such a issue. It is reasonable to conclude that replicating the quality of TravTek – in terms of message timing and completeness - would further enhance the performance of the voice supplement relative to the MNA without voice, as well as the other scenarios. The above findings lead to the following recommendations for the design of the ATIS driver interface:

- Include street name information in the voice supplement's directional instructions.
- Enhance the consistency and precision in the timing of voice directional instructions.
- Limit the length of text messages the driver must process while driving.
- Avoid use of directional labels in street names (e.g., North Second Street).

1. Introduction

ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) is an in-vehicle navigation and guidance system intended to reduce individual travel times through provision of real-time traffic information and navigation assistance. The system is also envisioned to reduce traffic congestion by encouraging better use of the transportation network. The ADVANCE project includes an operational field test that was intended to evaluate various ADVANCE system components. This report presents the safety evaluation of the ADVANCE project, conducted under the auspices of the National Highway Traffic Safety Administration (NHTSA) Office of Crash Avoidance Research.

The in-vehicle portion of ADVANCE involved development and testing of a vehicle navigation system that utilized dynamic traffic information for a roadway network in the northwestern portions of Chicago and its suburbs. Seventy-five vehicles were instrumented with in-vehicle computers and radio communications equipment. During the field operational test, data inputs to the system included real-time information from a variety of sources. However, at the time that the safety evaluation was conducted, real-time traffic information was no longer being provided. Therefore, the safety evaluation focused on the use of the in-vehicle device for navigation.

In the remainder of this introduction the ADVANCE in-vehicle navigation device is described, the goals of the safety evaluation of ADVANCE are enumerated, and some previous safety related research on similar navigation devices is reviewed.

1.1 The ADVANCE Mobile Navigation Assistant

The ADVANCE in-vehicle navigation device was called the mobile navigation assistant, or MNA. The MNA had a touch-sensitive display with four primary screens:

- Main menu
- Text entry
- Turn-by-turn guidance
- Heading-up map display.

The screens were presented on a 5.7-inch diagonal, backlighted, color liquid crystal display (LCD). The main menu was used for accessing various system functions but was not available while the vehicle was in motion and was, therefore, not a subject of the safety evaluation. Similarly, the text entry screen was used for entering destinations, but was not intended for use while driving, and was not a subject of this evaluation.

The primary navigation screen was the turn-by-turn display. This display was active when the vehicle is in DRIVE and the user had inputted a destination. The turn-by-turn display, illustrated in Figure 1, presented the driver with the following information:

- Current roadway name
- Distance to next turn (in miles)

- Countdown bars to graphically represent distance to the next turn
- Name of road at next turn
- Graphical depiction of next maneuver in a heading-up format
- Current direction of travel (in compass coordinates).

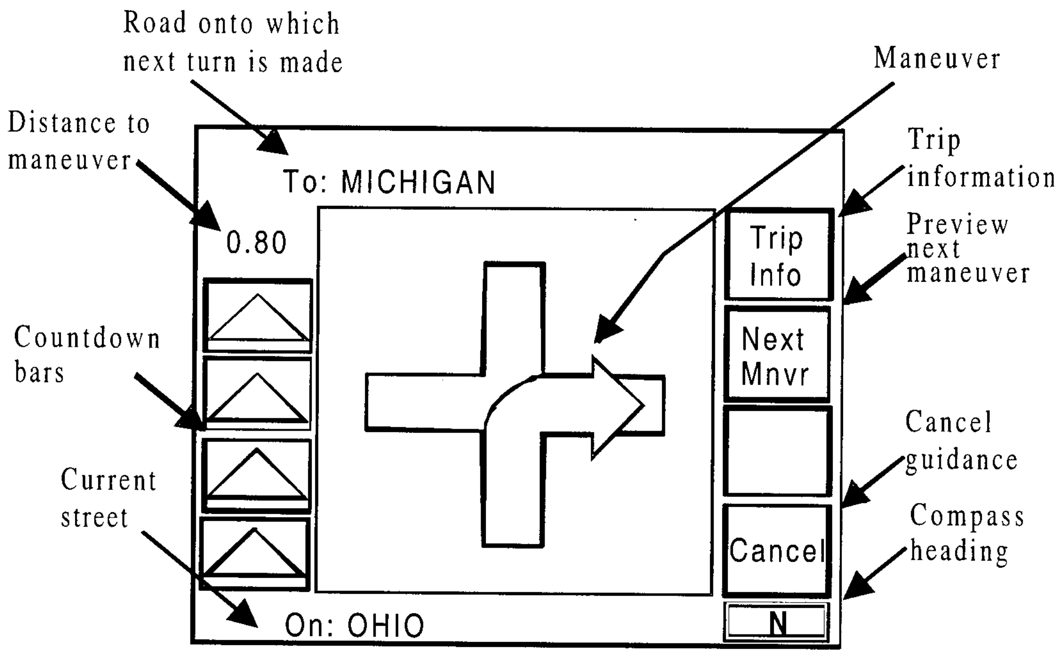

Figure 1. Illustration of MNA Turn-by-Turn Display

When a destination was not input, the MNA presented a simplified map display as illustrated in Figure 2. An arrowhead depicted the vehicle's position on the heading-up map.

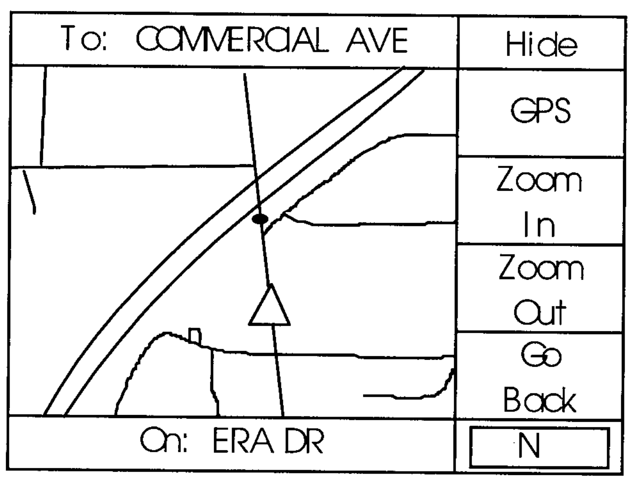

Figure 2. Illustration of the Simplified Map Display

Auditory chime and voice guidance systems were available to supplement the visual turn-by-turn guidance. The voice supplement had the following digitized voice messages in its repertoire:

- "Bear right onto the roadway"
- "Bear left onto the roadway"
- "Right turn ahead"
- "Left turn ahead"
- "Your destination is ahead on right"
- "Your destination is ahead on left"
- "Your destination is nearby."

The auditory chime always preceded voice messages. In a typical example, the voice guidance system announced two-tenths of a mile prior to a turn "right turn ahead." If the voice was turned off, the auditory chime could be enabled to alert the driver to new messages on the screen. However, in the test conducted for this report, the auditory cue was not active when the voice messaging was off. Street name and destination proximity information were not provided via voice messages.

1.2 Goals of the Safety Evaluation of ADVANCE

In carrying out its responsibility for ensuring that the safety impacts of ITS are understood and addressed, NHTSA has developed three standard questions to answer through ITS field operational tests. These are:

1. Do drivers drive more, or less, safely with the system than without it, in ways related to the system?
2. Do vehicles equipped with the system have fewer, or more, collisions than vehicles without the system?
3. If all vehicles were equipped with the system, would there be a decrease, or increase, in the total number of collisions and collision-related injuries?

The Safety Evaluation of the ADVANCE Project addressed only the first question. Because, as tested, the ADVANCE system was primarily a navigation aid, the study was intended to increase the body of scientific knowledge concerning how drivers operate a vehicle while navigating. Whereas, in the absence of crashes, the relationship between driving performance and safety is not clearly defined, it was assumed that such a relationship exists. Therefore special attention was given to measures of driving performance in a navigation environment.

The main objectives of the safety evaluation of the ADVANCE Project were to:

1. Determine whether drivers drive more or less safely with the ADVANCE system than without it, in ways related to the system.
2. Extend the ITS knowledge base with respect to vehicle navigation and in-vehicle navigation aids.

3. Support refinement of Advanced Traveler Information Systems (ATIS) design.

1.2.1 Hypotheses

It was hypothesized that driving performance, driving safety (as reflected by safety-related driving performance), and driver perceptions of driving performance and safety would vary as a function of:

1. Navigation scenario
2. Driver age
3. Driver experience with the MNA.

Four navigation scenarios were defined:

1. MNA turn-by-turn display with voice supplement
2. MNA turn-by-turn display without voice supplement
3. Paper map
4. Typed direction list.

The paper map and direction list scenarios provided baselines against which performance with the MNA was compared. In the paper map scenario, drivers were asked to use the paper map "as they normally would." The paper map scenario provided a comparison with conventional route planning, and followed a route selected by the driver.

Drivers from two age groups were examined:

1. 25 to 45 years of age
2. 65 years of age or older.

Two levels of experience with the MNA were examined:

1. Those with no previous experience with the MNA
2. Drivers who had previously driven MNA-equipped vehicles for at least 2 weeks.

1.3 Previous Research

The Safety Evaluation of ADVANCE is the first published study to examine safety related to use of the MNA. However, navigation devices similar to the MNA have been previously evaluated, and this section summarizes the most relevant of these. Particular attention is given to reviewing the TravTek Camera Car Study (Dingus, McGehee, Hulse, Jahns, Manikkal, Mollenhauer, and Fleischman, 1995), because the present study was patterned after this earlier investigation.

TravTek. In 1993, the Federal Highway Administration sponsored a comprehensive series of evaluation studies of the TravTek system (Inman and Peters, 1996). Like the MNA, the TravTek system included an ATIS-designed system to present drivers with navigation guidance. The TravTek system had two alternative methods for visual navigation instruction: a turn-by-turn guidance display that was similar to the MNA guidance display, and a route-map display that showed planned routes overlaid on a digital map. TravTek had a supplemental voice guidance system that could be turned off or on. The TravTek voice guidance system differed significantly from the MNA voice supplement, in that the TravTek voice system provided street names and distances to upcoming maneuvers. Whereas the TravTek voice system provided significantly more information than the MNA, the TravTek system used synthesized (i.e., machine-generated) speech, rather than digitized (i.e., prerecorded) speech, and the quality of the speech was inferior to that of the MNA.

The TravTek Camera Car Study (Dingus, et al., 1995) provided driving performance and driving behavior measures similar to those obtained in the ADVANCE safety evaluation. Six navigation test conditions were examined:

- TravTek route-map display
- TravTek route-map display with supplementary voice guidance
- TravTek symbolic guidance-map display
- TravTek symbolic guidance-map display with supplementary voice guidance
- Paper map
- Paper textual directions list.

The first four conditions enabled researchers to assess the TravTek configurations with respect to driving performance, system usability, and safety. Because navigation places greater demand on drivers than similar driving under non-navigation conditions, the two most common navigational aids, i.e., a paper map and paper textual direction list, served as baselines for performance with TravTek.

The primary research objectives of the Camera Car Study were similar to those of the safety evaluation of ADVANCE.

By most measures, the TravTek turn-by-turn guidance display, either alone or using supplemented voice, yielded performance superior to the baseline conditions. In comparison to the paper map, TravTek users required about one-half as much time to reach destinations designed to be 20 minutes away.

A primary finding of the TravTek Camera Car Study was that turn-by-turn guidance information (whether presented verbally, in a textual list, or by a symbolic guidance display) enhanced performance, usability, and safety compared to paper or electronic map alternatives.

1.3.1 Other Navigation System Studies

Several navigation systems have been developed in Japan and Europe. Autoguide has been publicly launched as part of a European project concerned with electronic systems (PROMETHEUS). However, because many of these systems are still in their infancy, only limited usability and safety analyses have been performed. Therefore, this body of literature was of limited use in the development of the ADVANCE Safety Evaluation.

A research project in California, Pathfinder, included traffic congestion information on an electronic map display. However, the usability of the system was not a focus of the Pathfinder research. The technology used for Pathfinder did not provide information such as automatic route planning and replanning, and did not provide turn-by-turn guidance.

2. Method

Data collection for the safety evaluation was accomplished by observation of drivers navigating a specially instrumented vehicle. The following sections present the overall approach, driver (participant) recruitment, the test vehicle (equipment), and research design. The objectives, hypotheses, and measures of effectiveness for the safety evaluation are summarized in Table 1.

Table 1. Summary of ADVANCE Safety Evaluation Objectives

Objective	Hypothesis	Measures of Effectiveness	Measures of Performance	Data Sources	Method Of Analysis
Determine effects of MNA use on driving performance and safety	Driving performance will vary as a function of navigation scenario, driver age, and experience with the MNA.	Eye glance behavior	• Glance location • Glance duration as a function of location	• Video analysis	• Glance location mapping • Descriptive Statistics and Inferential Statistics
		Driving performance	• Speed • Speed variability • Lateral acceleration • Longitudinal acceleration • Steering wheel motion • Brake activation • Accelerator pedal motion • Trip distance • Headway	• Video analysis • Camera Car data log	• Descriptive Statistics • Inferential Statistics
	Driving safety will vary as a function of navigation scenario, driver age, and experience with the MNA.	Hazard indicators	• Frequency of single glances > 2.5 s • Turn tracking errors • Close headway • Unsafe intersection behavior • Unsafe stops • Frequency of abrupt lateral maneuvers • Frequency of abrupt braking • Frequency and extent of lane deviations • Frequency of events with high potential for causing crashes • Mean time to complete drive	• Video analysis • Camera Car data log	• Descriptive Statistics • Inferential Statistics
	Driver's perception of driving performance and safety will vary as a function of navigation scenario, driver age, and experience with the MNA.	Driver perceptions	• Perceived safety	• Questionnaire • Subjective Workload	• Descriptive Statistics • Inferential Statistics

2.1 *Objective and Hypotheses*

The primary objective of the study was to determine the effects of MNA use on driving performance and safety.

To accomplish this objective, three hypotheses were addressed:

1. Driver performance would vary as a function of navigation scenario, driver age, and driver experience using the MNA.
2. Driving safety would vary as a function of navigation scenario, driver age, and driver experience using the MNA.
3. Driver perceptions of performance and safety would vary as a function of navigation scenario, driver age, and driver experience using the MNA.

2.2 Measures of Effectiveness

The measures of effectiveness (MOE) represent the global categories of dependent variables that are, in turn, defined by specific measures of performance (MOP). The following sections describe the MOP for each of the four MOE:

1. Eye glance behavior
2. Driving performance
3. Hazard indicators
4. Driver perceptions.

2.2.1 Eye Glance Behavior

In-vehicle devices such as the ADVANCE MNA may draw less or more of the driver's attention away from the forward roadway than do conventional navigation aids. Voice supplements, in particular, may free drivers to devote more attention to the roadway. Whether MNA required more or less visual attention than other navigation aids was assessed by comparison of glance behavior among scenarios. The effects of the four navigation scenarios on driver glance patterns were assessed through a frame-by-frame analysis of the video recordings of driver eye glances. It was assumed that attention away from monitoring of the forward roadway detracts, to some degree, from safety.

Two measures of glance behavior were derived: glance transitional probabilities (or frequency) and glance duration. Transitional probabilities are the probabilities for shift of glance from each classification area to each of the other areas. Classification areas were:

- Forward roadway
- Left roadway (left of windshield center)
- Right roadway (right of windshield center)
- Interior rear-view mirror
- Left exterior rear-view mirror
- Right exterior rear-view mirror
- Dashboard
- MNA, map, or direction list

- Left-hand check (outside driver's-side window)
- Right-hand check (outside passenger-side window)
- Steering wheel
- Inside — other
- Outside — other
- Road signs.

Glance probabilities show how often drivers switch their gaze between areas. These data are useful for determining how the use of navigation aids changes the visual demands (in terms of frequency) of the driving and navigation tasks, and may assist designers in refining ATIS driver interfaces.

Glance duration was reduced in the laboratory to the nearest tenth of a second. The combination of transitional probability and glance duration gives a rather complete picture of the visual activity associated with driving and navigation. Long duration glances away from the forward roadway were assumed to be relatively unsafe. Glances away from the forward roadway greater than 2.5 seconds triggered a detailed examination of the video and digital data for other signs of hazardous driving.

2.2.2 Driving Performance

Measures of driving performance were:

- Speed
- Speed variability
- Lateral acceleration
- Longitudinal acceleration
- Steering wheel motion
- Brake activation
- Accelerator pedal position
- Headway.

In describing differences in performance, direct attributions to safety were not made. Rather, analyses of these variables were performed to characterize driving performance during the occurrence of safety-related incidents. These variables were used to identify conditions that were thought to be more likely than others to be associated with high crash risk. These conditions, or *hazard indicators*, are discussed next.

2.2.3 Hazard Indicators

Glance data may raise safety concerns. However, if the glance behavior is not accompanied by changes in driving performance, then there may be little evidence to support those concerns. Although crash data would provide the most persuasive safety data, small studies, such as this one, do not compile sufficient mileage to enable a crash-based evaluation of any but the most unsafe systems. Therefore, events that might *reasonably* be expected to co-vary with crash probability, and occur with greater frequency than crashes, are used as surrogates for crashes. There are no empirical data that demonstrate a relationship between these surrogates and crashes. The analysis of hazard indicators relies on the acceptance of *hazardous driving* as a surrogate for crashes, and as a reasonable predictor of increased crash risk.

Hazardous driving was identified and quantified from analysis of the video data. The following performance data values were used as triggers for a detailed analysis of videos of the driver and roadway.

Driver eye glances away from the forward roadway greater than 2.5 seconds. Of particular interest to the safety of each scenario was the length of single glances to the navigation aid. Bhise, Forbes, and Farber (1986) hypothesized, based on speed and travel distances, that any single display glance greater that 2.5 seconds is inherently dangerous. Therefore, glance durations to locations other than the forward roadway that exceeded 2.5 seconds were examined to determine if they occurred more frequently in some scenarios than in others.

More than two glances to navigation aid to extract an information element. When using navigation systems, drivers tend to glance back and forth between the display and the forward roadway. The total time spent looking at the display and the number of display glances may reflect the demand for visual attention imposed by the system. As a rule of thumb, to avoid disrupting visual scan patterns for long periods of time, a display configuration should not require more than two glances to obtain an information element (Dingus and Hulse, in press). Therefore, a criterion of three or more glances to extract a single information element was a flag for detailed video analysis.

Lane deviation. An unplanned lane deviation is a face valid indicator of driver inattention and crash potential. An unplanned lane deviation was defined as a lane excursion that was not associated with a lane change. Lane excursions were classified and timed in the laboratory from a lane-tracking camera record. Each unplanned excursion was also marked in a data log by the in-vehicle experimenter.

Lateral acceleration greater than $|\pm 0.4|$ g. A lateral acceleration greater than $|\pm 0.4|$ g indicates an extremely rapid change in the vehicle's direction, and is likely to be associated with an unsafe maneuver or recovery from an unsafe situation. Therefore, all instances of values of lateral acceleration greater than $|\pm 0.4|$ g were subjected to close video analysis and hazard classification.

Longitudinal acceleration greater than $|\pm 0.3|$ g. Abrupt longitudinal accelerations may follow lapses in driver attention. Therefore, accelerations at or beyond this criterion level served as a trigger for video analysis.

Steering wheel reversal greater than 12 degrees. Wierwille and Gutmann (1978) demonstrated a relationship between the level of distraction of driver attention away from the roadway and the nature of steering wheel corrections. When drivers are not distracted from monitoring the forward roadway, they make many fine movements of the steering wheel to keep on course. When the level of distraction increases, drivers tend to make fewer, but larger, steering corrections or *steering reversals*. Increasing frequency of steering reversals greater than 12 degrees, with decreased frequency of small reversals, has been associated in the laboratory with increased levels of distraction. Large reversals in steering wheel movement may indicate increased driver workload induced by the navigation scenario. Therefore, where large steering reversals occurred in association with decreased small reversals, detailed analysis of the video data for the presence of hazardous driving was initiated. The frequency of this pattern of steering wheel behavior was also analyzed as a surrogate for driver workload.

Stopping in unsafe circumstances (i.e., stopping in a traffic lane). The in-vehicle experimenter logged stops that unnecessarily increased the potential for a crash. "Unsafe" was operationally defined as any circumstance where slowing, stopping, or acceleration not associated with normal driving, increased potential for a crash.

Close headway. Any time that the in-vehicle experimenter felt uncomfortable with the vehicle headway, an unsafe headway event was logged. The video around these events was subjected to the hazard analysis.

Very high subjective workload ratings. Subjective workload ratings are discussed in Section 2.2.4 - Driver Perceptions. Simultaneous ratings of high time stress, high visual stress, and high psychological stress are rare in practice. Where "high, high, high" ratings occurred, they triggered a hazard analysis for the period that preceded the rating.

Late/inappropriate reaction to an external event. Driver reactions that the in-vehicle experimenter judged as inappropriate triggered a hazard analysis. Inappropriate reactions included: inadvertent failure to observe related safety signs and traffic signals; "closeness of approach" to other vehicles; and actions that caused another driver to take evasive action. The experimenter was instructed to use the event key somewhat liberally to minimize the probability of missing important safety data.

Speed variability. Speed variability may indicate inattention to driving. The in-vehicle experimenter logged deviations from the speed limit greater than 10.61 km/h. Average speed variability was also compared across navigation scenarios. Although average speed variability of an entire trip is influenced by many factors besides driver performance, especially traffic, past research has indicated that it can be sensitive to driver workload when other factors are controlled statistically.

Hazardous driving served as a surrogate for crash risk. The operational definition of a hazardous driving was *a driving-related unsafe act that appeared to increase the potential for a crash.* The *potential* for a crash is weighted differently depending on whether an obstacle or other vehicle was present. For instance, a deviation into an on-coming traffic lane was considered hazardous driving, even when there was no traffic in the on-coming lane. However, this hazardous driving was considered more severe when on-coming traffic was nearby.

Quantified estimates of crash risk were derived from the hazardous driving analysis used. It has been shown in other domains, such as industrial crashes, that surrogates can be used to estimate the likelihood of industrial accidents (Hienrick, Peterson, and Roos, 1980). Whereas there are no empirical data that ties the probability of hazardous driving to automobile crashes, there is also no reason to believe the Hienrick methodology does not apply to hazardous driving.

To quantify hazardous driving, a classification number was given to each type of driving error. This number was determined by referring to a flow chart and associated table. The flow chart, a tool developed for the TravTek evaluation (Dingus, et al., 1995), enabled analysts to consistently classify events based on the circumstances. Close to 200 different combinations of circumstances were considered.

After evaluating a hazardous driving event using the flow chart, the analyst was referred to a table to obtain the event type. The frequency of each event type formed the basis of the risk quantification. Data from the NHTSA General Estimates System (National Highway Traffic Safety Administration, 1991) were used to assign severity values to the events. The flow charts and tables used for assigning severity values may be found in the appendix of the Dingus, et al. (1995) report.

Three risk factors were analyzed independently:

1. Potential severity
2. Environmental proximity
3. Whether the navigation aid may have been a ***contributory factor*** to the hazardous driving.

Potential severity. Four elements were considered in assessing the severity of errors. These elements were:

1. Potential crash type and associated injury potential
2. Roadway, intersection type, and likely speed of other vehicles
3. The subject vehicle's speed
4. The presence of traffic or other hazards.

In determining potential severity, a worst-case crash was assumed. Worst-case was defined as the most severe crash that might have resulted from the error. The potential severity rating assumed elements that were not necessarily present. For example, in the case where a driver was traveling at 55 mph on a two-lane road and deviated across the lane boundary into the oncoming traffic lane, the worst-case crash would be a head-on collision. Whether another vehicle was actually in the oncoming lane was factored separately under environmental proximity. In the case of a deviation into the on-coming traffic lane, potential severity would be high because the speed of an assumed oncoming vehicle would be high and striking angles would produce extreme deformation of the vehicle structure.

The worst-case severity was classified into one of four categories:

Minor. Potential for a crash in which only property damage was likely, e.g., hitting a curb at 40 km/h (25 mi/h) and damaging a rim, but not causing physical harm to the driver.

Marginal. Potential for a crash where minor injuries were likely, but where hospitalization was unlikely, e.g., side-swiping a car at 56 km/h (35 mi/h).

Critical. Potential for a crash where injuries were likely to require overnight (or longer) hospitalization. Permanent disabling injuries would be unlikely. For example, running two-way stop signs in a residential area where the speed limit is 56 km/h (35 mi/h).

Catastrophic. Potential for a crash where a fatality or permanent disabling injury was likely, e.g., head-on collision or running a red light on a multi-lane road with a 72 km/h (45 mi/h) speed limit.

Environmental proximity. Operational definitions for the environmental proximity categories were:

Near Miss. The driver needed to take immediate evasive action to prevent a crash. A near miss included the situation where the experimenter felt impelled to give an imperative verbal warning. An example of this might be when the experimenter called out "Red light!" because it appeared that the driver would proceed through the light if not warned. Although the driver may have stopped prior to entering the intersection, an apparent startle response by the driver or experimenter was sufficient to warrant a near miss classification.

Hazard Present. The driver committed a safety-related error when an object (e.g., another vehicle, a pedestrian, or a guardrail) was near. "Hazard present" required that the object was close enough to present a hazard, but not close enough that immediate evasive action was needed.

No Hazard Present. The driver committed a safety-related error, but no obstacle was proximal. An example of this is a lane deviation where there were no objects near the test vehicle that constitute a hazard. The lane deviation was considered a safety-related error, but if no obstacle were nearby, there was no imminent danger.

Contributory factor. Determination of whether the navigation aid may have contributed to causing the error required careful review of the video and audio records. The analyst repeatedly reviewed where the driver was looking prior to the event, and listened to the audio track to determine if an MNA voice prompt occurred just prior to the error. Unsolicited driver commentary sometimes aided in the determination. The operational definitions for categorization of levels of the contributory factor were:

Navigation-caused. The cause of the error appeared likely to be associated with navigation. That is, the error occurred immediately following visual or aural attention to the navigation aid (whether MNA, typed list, or paper map), or was associated with a visual search for navigation-related information outside the vehicle (e.g., road signs).

Other. There was no apparent association between the error and attention to navigation or navigation aids.

The hazard analysis quantified the crash risk associated with each of the four navigation scenarios.

2.2.4 Driver Perceptions

For each navigation scenario, driver perceptions of safety were assessed with subjective workload assessments and a questionnaire.

Subjective workload assessment. Whether a system such as the ADVANCE MNA makes driving easier or harder may, or may not, be reflected in observable changes in driving performance. Changes in performance might only be observable during rare emergency situations or when the driver becomes fatigued (Gopher and Donchine, 1986). Subjective measures of workload are used to reflect differences in effort before the point at which performance is reliably degraded. Thus, subjective workload measures may be sensitive to task demands when performance measures are not. Drivers were asked to rate their level of effort (i.e., workload) while navigating. In this context, effort referred to mental effort, not physical effort.

Drivers rated their subjective workload on three dimensions: time stress, visual effort, and psychological stress. Ratings on each dimension were given on a three-point scale: "low," "moderate," or "high." During training, the drivers were given examples of the low, moderate, and high workload for each effort dimension. The following paragraphs describe the definitions provided to anchor the ratings.

> **Time stress.** Time stress was defined in terms of the amount of time available for driving and navigation relative to the amount of time the driver perceived as needed. It was suggested that under low time stress there might be time to spare, such as for carrying on conversation or tuning the radio. Under moderate time stress, it was suggested that there might be just enough time to drive and navigate, but not enough time to attend to anything else. With moderate time stress, the driver would avoid distractions such as conversation. It was suggested that under high time stress there would be insufficient time to fully attend to both driving and navigation. Examples for high time stress were feeling that it was necessary to delay a lane change or merge, or ignoring an MNA voice message, because of the need to attend to driving safely.
>
> **Visual effort**. Visual effort was defined in terms of the amount of visual scanning that could be accomplished relative to the perceived need to scan the environment. An example of low visual workload was feeling comfortable looking about, such as at scenery or billboards. It was suggested that under moderate visual effort, the visual scanning necessary for driving and navigating could be accomplished comfortably, but that there would be no spare visual capacity. Under high visual effort, it was suggested that the driver would delay looking at things necessary for driving or navigation. A suggested example of high visual effort was when the driver might ignore signs to concentrate solely on the forward roadway.
>
> **Psychological stress**. Psychological stress was defined in terms of perceptions of confusion, frustration, physical danger, and anxiety. Low psychological stress was defined as feeling confident and secure. Moderate psychological stress was defined as mildly con-

fused or frustrated, such as not being sure of being on the planned route or feeling anxious about the actions of other drivers. High psychological stress was defined as feeling extremely stressed, as one might feel after a near crash or when totally lost and confused as to how to get home.

Subjective workload ratings were requested entering each new street. Additional workload ratings were requested when the driver was off route: at the time the driver first went off-route, and again at the point where the driver was first back on-route. Workload ratings that indicated overload on all three dimensions served as triggers for a hazard analysis. This subjective workload technique was previously used in three of the TravTek Evaluation studies (Dingus, et al., 1995, Inman et al., 1995, Inman, Sanchez, et al., 1996).

Questionnaire. Following the completion of their test drive, drivers filled out a questionnaire. The questionnaire focused on impressions of the relative safety of the navigation scenarios. The questionnaire also addressed perceptions of comfort and ease of use.

2.3 Participants

Three groups of drivers were recruited to participate in the safety evaluation:

- 20 younger drivers (25 to 45 years of age) who had previous MNA experience
- 20 younger drivers (25 to 45 years of age) who had not previously used the MNA
- 20 older drivers (at least 65 years of age) who had not previously used the MNA.

Volunteers for the younger groups were recruited from among individuals listed in a database maintained by the ADVANCE Project Office. These individuals had either participated in a previous ADVANCE study, or had expressed an interest in participating in the MNA evaluation but had not previously been selected.

Because the ADVANCE Project Office database did not included drivers over 65, volunteers in the older group were recruited from senior centers. There were no older driver participants who had previous MNA experience.

2.4 Equipment

An ADVANCE MNA, as described in Section 1.1, was installed in a 1995 Ford Taurus Station Wagon. The station wagon was equipped with additional data collection sensors and instrumentation. The sensor package consisted of four video cameras, a multi-plane accelerometer, steering potentiometer, accelerator and brake pedal sensors, audio recording, data collection computer (486 laptop), PC-VCR, and quad-multiplexer. A conceptual schematic of the equipment layout is provided in Figure 3.

The cameras provided NTSC video of:

- 60-degree field-of-view forward through the windshield
- Lane position viewed forward from left rear-view mirror enclosure

- Driver's head and eyes viewed from a small camera mounted on the inside rear view mirror
- Driver interaction with the MNA viewed from above the driver's right shoulder.

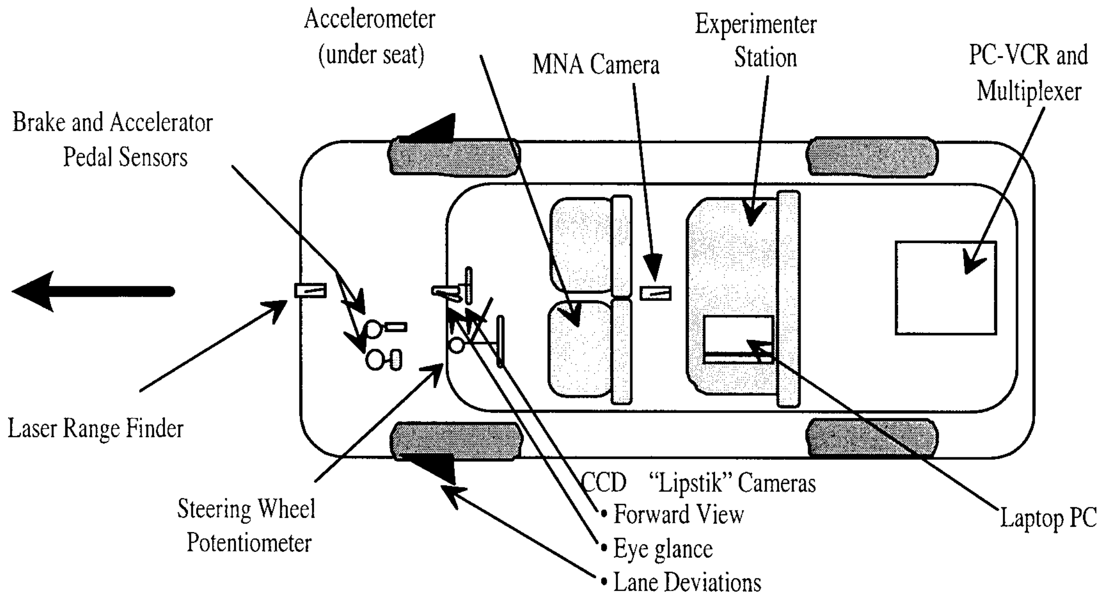

Figure 3. Conceptual Schematic of the Camera Car

The forward field-of-view camera was used in analysis to provided information on vehicle track, headway, lane-position, traffic, roadway conditions, weather, and signs. The lane position camera was mounted to provide a view of the left front tire and lane markings so that lane tracking could be scored in the laboratory. The view of the driver's head and eyes was used to score eye glance location and duration.

The video was time stamped by the PC-VCR so that the images could be matched with time stamped data from the other sensors. The in-vehicle experimenter recorded additional information on the laptop computer, mounted in the back seat directly behind the driver.

The multi-plane accelerometer, and inputs from the speedometer and brake pedal potentiometer, provided lateral and longitudinal acceleration, velocity trends (speed and speed variability), brake actuation, and braking severity. Sensor signals were read by an analog/digital interface at a 10 Hz rate. The steering potentiometer provided driver steering movements at 10 Hz. Audio recording captured MNA voice system messages, driver comments, and experimenter commentary. PC-VCR-generated time stamps for the data collection computer were also displayed on the video record. In the laboratory, the PC-VCR performed high-speed searches for event markers entered by the experimenter on the data acquisition computer. The PC-VCR recorded in S-VHS format. Views of each multiplexed image provided approximately 200 lines of horizontal resolution.

A monitor was mounted in the experimenter station so that real-time data collection stream could be previewed.

2.5 Origins and Destinations

To ensure comparability of trials across drivers and navigation scenarios, four similar Origin-Destination (O-D) pairs were selected. These O-D pairs are summarized in Table 2. The O-D pairs were adapted from those used for previous ADVANCE evaluation studies. For the safety evaluation, the origins and destinations were relocated away from major intersections to nearby intersections or addresses on local roads. This modification ensured that the drivers, who were generally familiar with the area, would require navigation aids to locate the destinations.

Under free-flow traffic conditions, each O-D required approximately 20 minutes to complete. With the usual routing, each O-D traversed similar distances of two-lane, multi-lane, and divided highway, but not interstate highway. The interstate access ramps in the area were located such that they did not support short commutes.

The O-D pairs were assigned in the same order to all drivers. To control for O-D specific effects, the order in which the scenarios were driven was balanced across O-D pairs. That is, each O-D pair was driven equally often in each scenario, and each scenario preceded each of the other scenarios equally often.

Table 2. Origins and Destinations

O-D	Origin	Destination
1	Kasper and Lynnwood, Arlington Heights	Basswood Dr. and Arrowood Dr., Deerfield
2	Wheeling & Portwine, Lake Cook	Thurston Drive and Sanborn Drive, Palatine
3	Intersection of Thurston and Sanborn, Mount Prospect	2010 Ivy, Buffalo Grove
4	2010 Ivy, Buffalo Grove	360 Arborgate, Buffalo Grove

2.6 Procedure

Participants were met at a pre-arranged starting point. Information summary and informed consent forms were provided. One older subject opted not to continue upon learning that the study required having to drive on roadways with high traffic volumes. Participants were informed that their data would remain confidential and that their names would be removed from all data sets. An audiotape with a detailed description of the activities was played over the test vehicle's sound system. Several pauses in the taped instructions facilitated questions and answers. The experimenter encouraged subjects to pause the tape when they desired additional explanation. Note cards with bullet points corresponding to the taped information were provided. A demonstration of the MNA was provided. The same instructions were given to all participants.

When the instructions were completed, the experimenter moved to the rear seat of the vehicle and prepared for the practice drives. One practice drive, of approximately 7 minutes, was conducted for each of the navigation scenarios. The practice drives gave participants opportunities to ask questions and to become familiar with the experimental procedures. After the last practice

O-D, the participants were asked if they were ready to continue with the rest of the study. All participants who took part in the practice drives elected to continue. Verbal navigation directions were provided as participants drove approximately 10 minutes to the starting point of the first O-D.

At the first origin, participants were instructed that the experimenter would no longer answer questions about the navigation or the correctness of turns. They were also told that they were permitted to stop to review navigation materials or displays, but that they should choose a safe place to stop.

For the paper map scenario, participants were provided with a Rand-McNally road map of the Northwestern Chicago suburbs. The beginning and end points of the O-D were marked with red arrows. The experimenter pointed out the current location of the test vehicle (the O-D starting point) and the direction the vehicle was facing. Participants were given a clipboard and a blank sheet of paper, and told that they could make notes if they desired. The participants told the experimenter when they were ready to begin. Once en route, if they felt it was necessary, the participants were allowed to give up and request verbal directions or hints. Only three participants gave up during the experiment: in each case this occurred in the paper map scenario.

In the direction list scenario, the participant was given a 6- by 8-inch laminated card with printed turn-by-turn directions. A numbered list provided distance to the turn, name of the street to turn onto, and the direction of the turn. The distances were given to the nearest tenth of a mile. Participants were reminded that they could use the trip odometer.

For the MNA scenarios, the experimenter provided the name of the destination. To install the route, the participant chose the destination from a list displayed on the MNA.

The four O-D's were completed one after another. The end of one O-D served as the beginning of the next. After completing the final O-D, the participant drove to the starting point of the experiment and the questionnaire was administered. Participants were paid $70.00 for their participation, which took about 3 hours. The tests were conducted between 9 AM and noon.

2.7 Research Design

The statistical model used for most of the analyses reported here consisted of three parts:

- A test for the effect of navigation scenario
- A test for the effect of experience
- A test for the effect of age.

The navigation scenario test was a repeated measures, main-effects analysis of variance (ANOVA) with four factors:

- MNA with voice
- MNA without voice

- Paper map
- Typed direction list.

The sample size for this test was 60.

The test for the effect of experience was a between-groups analysis of variance. The sample size for this test was 40, with 20 experienced drivers and 20 drivers with no previous MNA experience. Interactions with the repeated measure, navigation scenario, were performed using error terms computed using only the 40 drivers included in the analysis.

The test for the effect of age was a between-groups analysis of variance, with a sample size of 40. As with the experience effect, unique error terms were computed for use in testing interactions with the repeated measure, navigation scenario.

The three analyses were performed because a factorial design that crossed age and experience could not be performed, there being no older group with MNA experience. Whereas more sophisticated statistical models are available for partial factorial designs, they require assumptions that were deemed inappropriate.

For each analysis where there was a significant difference in the measured effect amongst the factors, a "post hoc" comparison was performed, using a Student-Newman-Keuls multiple range test. This allowed pinpointing of the differential effects of each primary factor on the target measure. (Displayed as a bar chart in the Results section that follows, "post-hoc" results are shown as a series of letters above the bar for each factor. Factors having different letters are significantly different; those with the same letters are not significantly different.)

3. Results

Crashes and fatalities are the ultimate measures of traffic safety. There were neither crashes nor fatalities involving participants in the ADVANCE safety evaluation. Therefore, the findings presented here should be viewed as surrogates for the ultimate safety measures. Although most of the measures we report are, at least intuitively, related to safety, there are no validated studies that demonstrate how, or whether, these measures are related to crashes and fatalities.

The results are grouped into four sections: Eye Glance, Driver Performance, Hazard Analysis, and Driver Perceptions. Together, these findings are intended to address the primary purpose of the study, i.e. to answer the question: "Do drivers drive more safely with the ADVANCE MNA than without it, in ways related to the system?" Numerous tests are reported in each section that are intended to address this question. A summary table is provided at the end of each section that shows, for each test, differences in dependent measures with respect to the baseline, paper map scenario. That is, where a dependent measure suggests that a scenario is safer than the paper map scenario, a plus (+) sign is shown in the table. Where no statistically reliable difference between baseline and alternative scenarios was found, a zero (0) is shown in the tables. Where a dependent measure suggests that one of the alternative scenarios is less safe than the paper map, a minus (-) sign is shown.

The summary tables have been included to provide a method for making comparisons between scenarios and between dependent measures. Listing of the measures together in a single table is not intended to imply that all the measures are equally good safety surrogates. However, the summary tables do provide a good overview, and facilitate checks for agreement and consistency across measures.

3.1 Eye Glance

A customized software and hardware package was developed to assist in reduction of eye glance data. In previous efforts in the same laboratory (Dingus et al., 1995), data reduction took about six hours for every hour of tape. In that effort, the analysts monitored driver eye movements on a video monitor, controlled the video tape via a remote control, and manually noted starting points, ending points, glance duration, and glance location. For the present study, custom software reduced the number of data entry operations and controlled the video playback. Analysts controlled the speed, position, and direction of the video with right-hand keystrokes. Each of the fourteen individual glance locations was marked with left-hand keystrokes. By positioning the tape at the beginning and end of each glance and by indicating glance location, the tape position, start time, stop time, duration, and location were automatically written to a data file. The end of each glance was automatically marked as the beginning of the next glance. With practice, analysts were able to catalog glances in about the same time it took to play the tapes at normal speed.

The eye glance measures reported here are:

- Mean duration of glances to the navigation displays
- Proportion of glance time to the navigation displays
- Proportion of glance time to the forward roadway

- Number of glances to the navigation displays greater than 2.5 seconds/minute (i.e., corrected for differences in travel time).

3.1.1 Duration and Frequency of Glances

Figure 4 shows that the average duration of a glance to the paper map was 1.8 s, significantly longer than navigation aid glances in the other scenarios, where glances averaged 1 to 1.2 s. Glance duration to the navigation display varied significantly between scenarios, $F\,(3{,}176) = 25.03$ ($p < 0.05$). This analysis included only glances when the vehicle was traveling more than 8.05 km/h. Glance duration did not vary significantly as a function of either age or experience with the MNA.

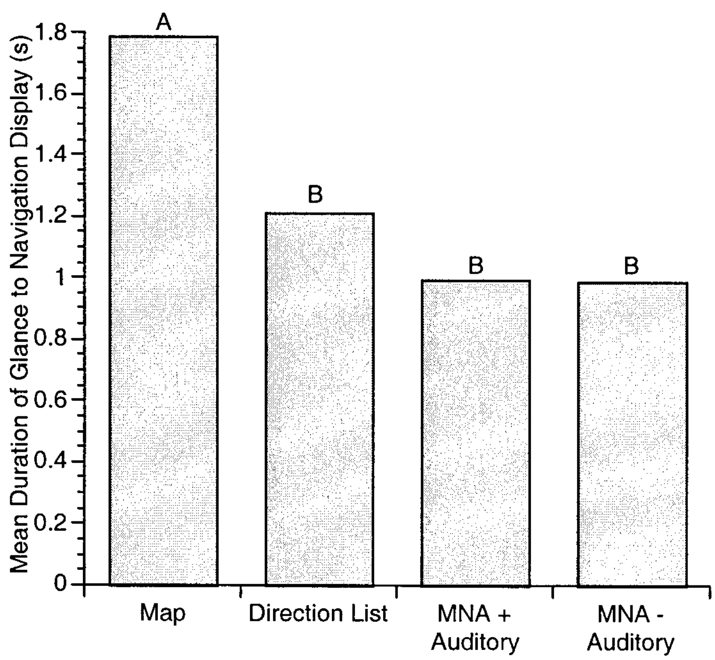

Figure 4. Mean Duration of Glances to Navigation Displays (means with different letters are significantly different from one another; means with the same letters are not significantly different)

To characterize glance activity, one might consider frequency along with duration.[1] Figure 5 shows a comparison of mean number of glances per minute for each navigation scenario, to provide further insight into the glance behavior of drivers. Use of the MNA scenarios increased mean glance frequency over the map and direction list. However, this increase for the MNA is offset by shorter glance durations. In general, average duration is considered a more significant indicator of glance impact on safety than frequency, as well as resulting net dwells. Dwells are further examined, normalized as a proportion of total glance time, in the next section.

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[1] Multiplying the glance frequency by mean glance duration for a driving time interval would yield a driver's total glance dwell time for that interval. Using the mean glance frequency, over the trip, provides an estimate of mean total dwell time for the trip

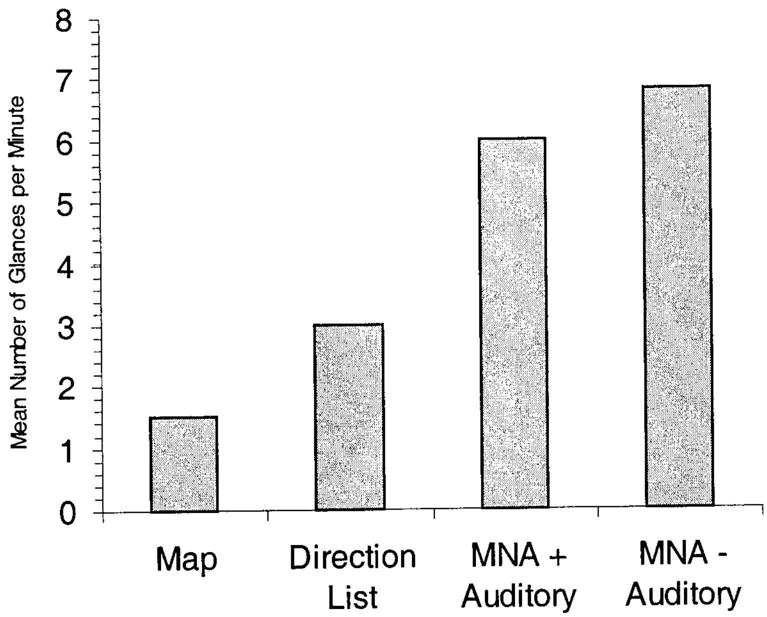


Figure 5. Mean Number of Glances per Minute to Navigation Displays

3.1.2 Proportion of Glance Time

Whereas brevity of single glances to the navigation displays favored the MNA and direction list, total dwell time remained greater for the MNA, when normalized as a proportion of glance time to all locations. Many short glances to the MNA resulted in more time away from the roadway than the fewer long glances to the paper map.

As shown in Figure 6, the MNA without voice scenario yielded the largest proportion of glance time to the display, followed by the MNA with voice, the direction list, and the paper map. The scenario effect was statistically reliable, $F\ (3,177) = 72.90$ ($p < 0.05$). The MNA with voice received less glance time than the MNA without voice, although this significant effect was small.

Experience. The experienced group spent less time looking at the MNA displays than did the inexperienced group, as shown in Figure 7. The effect of experience on the proportion of glance time to the displays was statistically reliable, $F\ (3,114) = 3.09$ ($p < 0.05$). There were no significant differences, as a function of experience, for the paper map and direction list conditions.

Age. Older drivers devoted a greater proportion of their glance time to the navigation displays, 0.093, than did the younger drivers, 0.075, and this difference was statistically reliable, $F\ (1,114) = 4.90$, $p < 0.05$. However, the age effect did not vary as a function of navigation scenario.

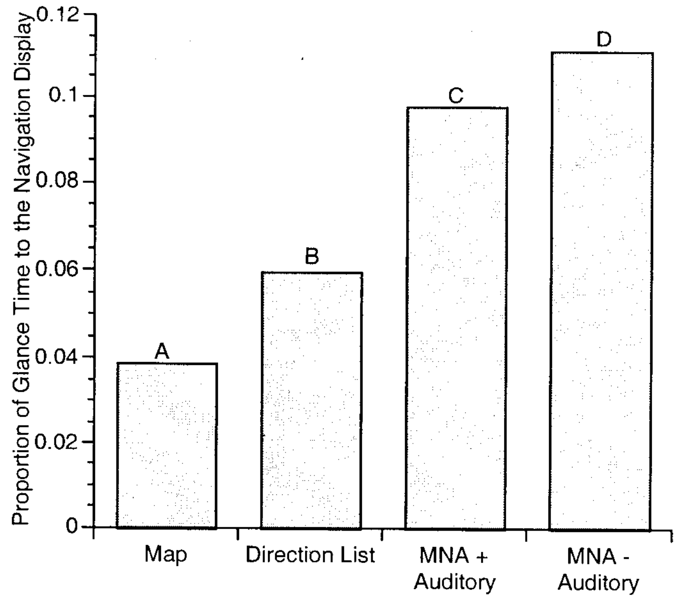


Figure 6. Proportion of Glance Time to the Navigation Display (means with different letters are significantly different from one another; means with the same letters are not significantly different)

3.1.3 Proportion of Glance Time to the Forward Roadway

It is assumed that of all the places drivers can look, the forward roadway is most critical to safety. Glances to navigation aids may detract from forward roadway monitoring, or may reduce glance time to locations other than the forward roadway. Whereas it is assumed that drivers have some spare visual capacity, such that a glance away from the forward roadway is not inherently unsafe, there is currently no accepted way of measuring this spare capacity. Therefore, we assume that the more time spent monitoring the forward roadway, the safer it is for the driver.

The proportion of glance time to the forward roadway, as shown in Figure 8, was greatest with the paper map, somewhat less with the direction list, and still less for the two MNA scenarios, which did not differ significantly from each other. The effect of scenario on proportion of glance time to the forward roadway was statistically reliable, $F\,(3,177) = 27.87, p < 0.05$. The apparent advantage of the paper map is, in part, explained by the anecdotal observation that most drivers were reluctant to look at the paper map while driving. Many drivers came to a stop at the side of the road before studying the paper map. Because this analysis includes only glances while the vehicle was traveling more than 8.05 km/h, the effort required to navigate with a paper map is not fully reflected in this analysis. While studying the map, drivers may have developed a mental model (Kosslyn, Ball, and Reiser, 1978) of the next several turns, and thus relieved themselves of the need to look at the map again for some time.

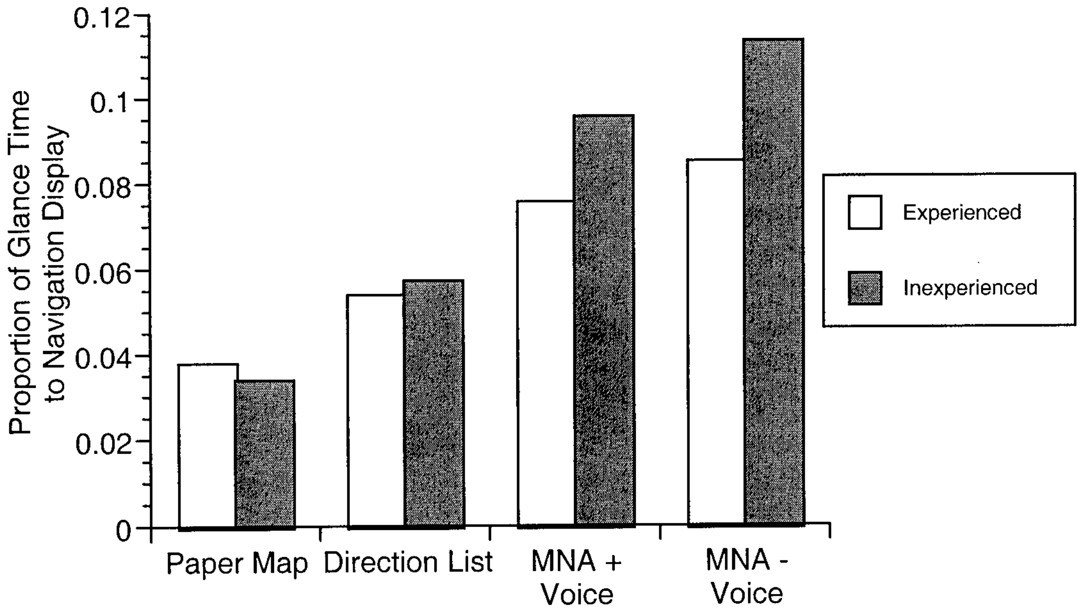


Figure 7. Young Drivers' Proportion of Glance Time by to Navigation Display as a Function of Navigation Scenario and Experience

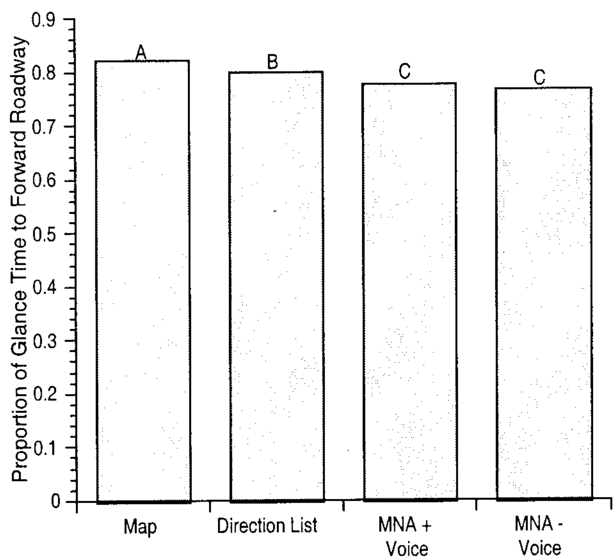


Figure 8. Proportion of Glance Time to the Forward Roadway (means with different letters are significantly different from one another; means with the same letters are not significantly different)

Experience and Age. Proportion of glance time to the forward roadway did not vary significantly as a function of MNA experience or age, despite the finding that the proportion of glance time to the navigation displays did vary as a function of these factors. Variability in allocation of glance time to other locations may have contributed to these non-complimentary findings.

3.1.4 Number of Glances to Navigation Displays Greater than 2.5 Seconds

The number of glances to the navigation display over 2.5 seconds was considered because some researchers (Bhise et al., 1986) have hypothesized that glances away from the roadway longer than 2.5 seconds are inherently dangerous. Because longer trips provide more opportunities for looking away from the roadway, the number of glances greater than 2.5 seconds was normalized by dividing the number of glances by the number of minutes per O-D. That is, glance frequency was transformed to the number of glances per minute.

As can be seen in Figure 9, there was a tendency for the experienced younger drivers to make long glances to the paper map more often, compared to young drivers who did not have previous MNA experience. These same young experienced drivers also showed a tendency to make fewer long glances to the MNA. The scenario by experience interaction was significant, $F(3, 113) = 2.88$, $p < 0.05$. However, it should be noted that the number of glances away from the forward roadway that exceeded 2.5 seconds was small, and thus may be overly sensitive to the idiosyncratic behavior of individual drivers.

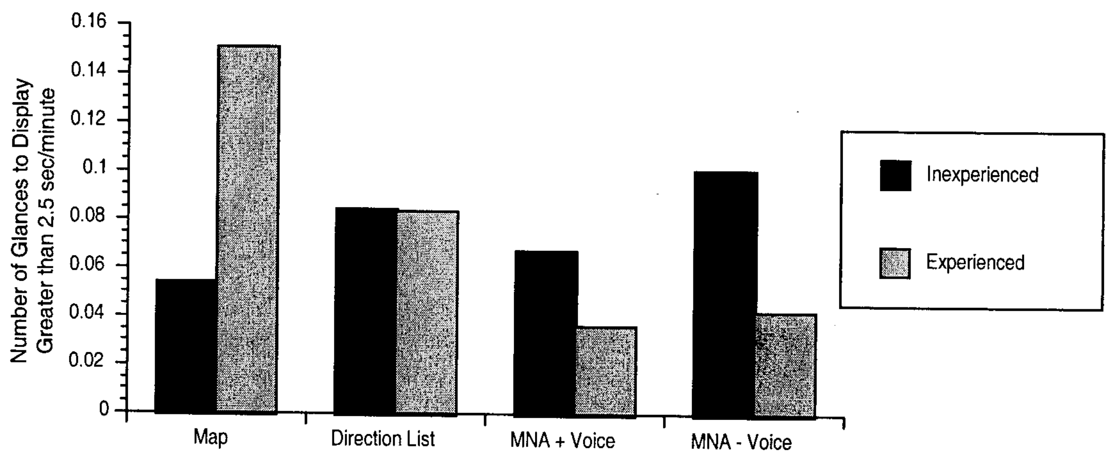


Figure 9. Number of Glances per Minute to the Navigation Displays that were Greater than 2.5 seconds, Shown as Function of Driver Experience

3.1.5 Eye Glance Summary

Table 3 summarizes the results of the eye glance data. The mean duration of glances to the direction list and MNA were of a shorter duration than those to the paper map — suggesting an MNA safety benefit relative to the paper map. However, the proportion of time looking at the direction list and MNA was greater than that to the paper map — suggesting an MNA safety disbenefit. The greater proportion of time spent looking at the navigation displays was complemented by a reduction in the proportion of time looking at the forward roadway. These results show that drivers looked to the MNA and direction list more frequently than to the paper map, thus making it appear that the MNA and direction list conditions are less safe, even though the glances, when they occurred, were of short duration. Examination of glances greater than 2.5 seconds suggested no difference in safety among the navigation scenarios. Whereas drivers in this sample tended to look at the paper map less, while moving, this does not necessarily imply that overall safety was greater with the paper map. In the hazard analysis section of this report it is shown that the paper map scenario saw approximately double the frequency of inappropriate (unsafe) stops relative to the other scenarios. The eye glance data are only reported for times when vehicle speed exceeded 8.05 km/h, and does not capture a substantial proportion of time spent studying the paper map while stopped.

There were few differences in eye glance measures between MNA with the voice supplement and without. Without voice, for all drivers there was greater total glance time to the display, and for drivers inexperienced with MNA, a greater number of long glances. Although the numbers are small, they indicate, in terms of eye glance measures, a slight advantage for the voice supplement, given a novice user base.

Table 3. Summary of Eye Glance Analyses

	Mean Duration to Navigation Displays	Proportion of Glance Time to Nav Display	Proportion of Glance Time to Fwd Roadway	Number of Glances > 2.5 Seconds
MNA with Voice	+	–	–	o
MNA without Voice	+	–	–	o
Direction List	+	–	–	o
Paper Map	CONTROL			

Notes:
+ indicates statistically reliable difference that favors the scenario as safer than the paper map
– indicates statistically reliable difference that suggests the scenario is less safe than the paper map
o indicates no reliable difference between scenario and the paper map relative to safety

3.2 Driving Performance

This section presents the findings derived from the non-video performance variables. Data recorded by the test vehicle instrumentation at a 10 Hz rate were reduced to means for each road type classification within each navigation scenario. The three classifications of road type were residential, two-lane, and multi-lane. The results presented are for the following variables:

- Mean time to complete scenario
- Mean time off route
- Mean number of times off route
- Number of steering reversals greater than 12 degrees
- Number of steering inputs greater than 125 degrees per second
- Standard deviation of accelerator pedal input

- Mean speed
- Standard deviation of speed
- Standard deviation of steering wheel input
- Number of longitudinal accelerations greater than 0.3 g's
- Number of lateral accelerations greater than 0.3 g's
- Number of brake activations.

3.2.1 Mean Time to Complete Scenario

Time to complete a scenario is indicative of more than just the speed the driver chooses to drive. It may be influenced by the number of wrong turns that the driver makes, and may also be influenced by the difficulty the driver has in locating turns. Regardless of the influences on travel time, and all other things being equal, the longer it takes to complete a trip, the greater the exposure duration to the possibility of a crash.

Navigation Scenario. No significant differences as a function of navigation scenario were identified, $p < 0.05$, in mean time to complete trips.

Experience. No significant differences as a function of MNA experience were identified, $p < 0.05$, in mean time to complete trips.

Age. There was a significant interaction between navigation scenario and age group, $F(3, 114) = 2.87$, $p < 0.05$. A simple effects analysis indicate that the older drivers took longer to complete trips when using the paper map, $F(1,38) = 4.72$, $p < 0.05$. Older drivers also took longer than younger drivers when using the MNA with voice, $F(1,38) = 4.82$, $p < 0.05$. The differences between age groups were not statistically reliable for the direction list or MNA without voice scenarios. Figure 10 shows time to complete scenarios as a function of age.

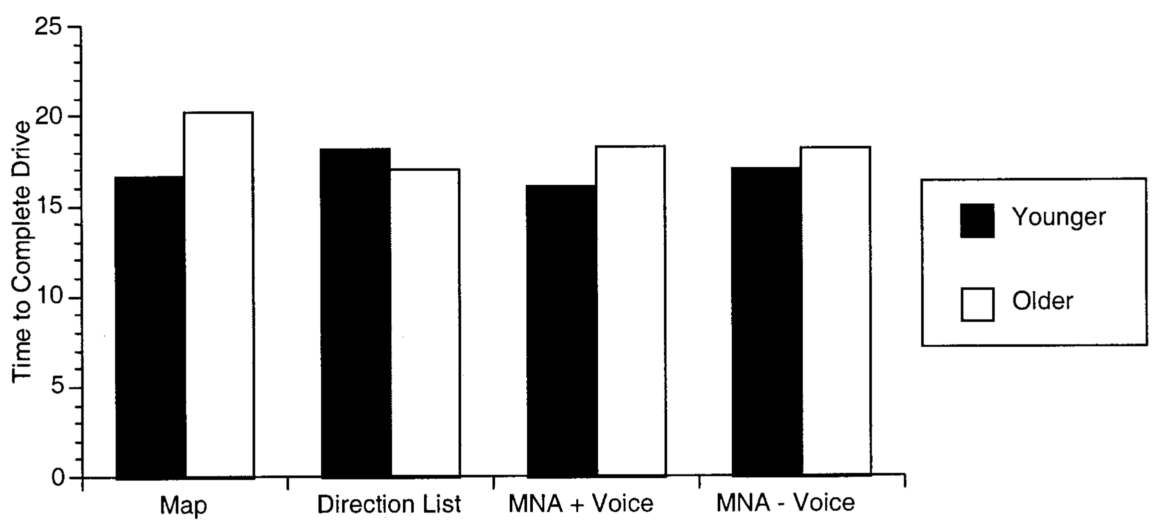


Figure 10. Time to Complete Scenarios by Age Group and Navigation Scenario

3.2.2 Mean Number of Turns to Complete Scenario

There were no statistically reliable relationships between the number of turns to complete the scenarios and navigation scenario, experience, age, or interactions of these variables.

3.2.3 Mean Time Off Route

There were no statistically reliable relationships between time off route and navigation scenario, experience, age, or the interaction of these variables.

3.2.4 Mean Number of Times Off Route

The mean number of times off route may indicate how efficient the navigation display is at providing useful navigation instructions. The greater number of times off route, the less efficient the system. More times off route may increase exposure time to crashes, and may also increase the number of maneuvers drivers must make. These extra maneuvers typically consist of a series of turns, e.g., a U-turn, or a turnaround in a parking lot. These types of maneuvers often occur in locations with greater crash risk, such as at intersections.

Navigation Scenario. There was a significant navigation scenario effect in mean number of times off route, $F\ (3,177) = 2.79, p < 0.05$. As shown in Figure 11, there was a significant difference between the paper map and direction list scenarios, with a greater number of times off route with the paper map.

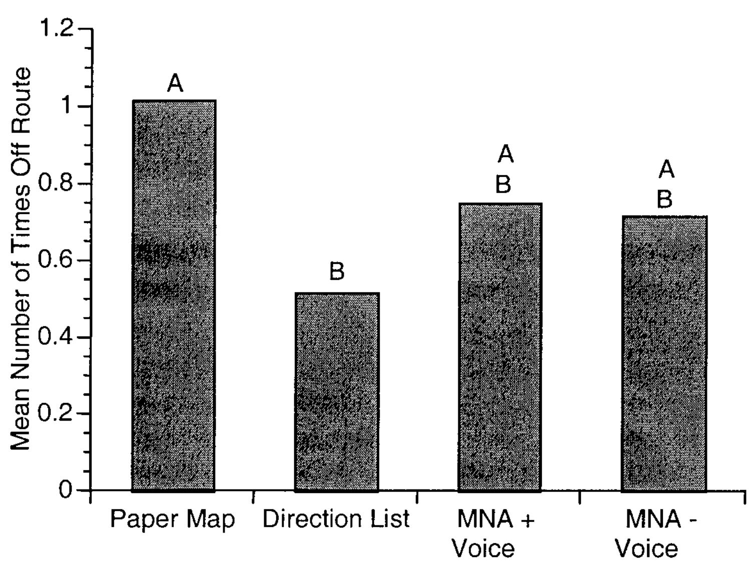


Figure 11. Mean Number of Times off Route (means with different letters are significantly different from one another; means with the same letters are not significantly different)

Experience and Age. There were no significant effects for age or experience in the number of times off route.

3.2.5 Number of Steering Reversals Greater than 12 Degrees

There were no significant differences in steering reversals as a function of navigation scenario, experience, age, or the interaction of these variables.

3.2.6 Number of Steering Inputs Greater than 125 Degrees Per Second

The number of steering inputs greater than 125 degrees per second was examined because steering wheel movements of this rate are thought to be indicative of steering corrections that follow lapses of attention. This measure was transformed by dividing the number of these steering wheel inputs greater than 125 degrees by the number of minutes in the trip. This transformation equated drivers by taking into account the amount of time available to make steering inputs.

Navigation Scenario. The transformed number of steering inputs measure varied as a function of navigation scenario, $F(3,177) = 3.28, p < 0.05$. As shown in Figure 12, the paper map and MNA without voice scenarios were significantly different from one another. The longer glance times in paper map scenario may have resulted in high steering wheel correction rates to compensate for the drift in vehicle lane position during those glances.

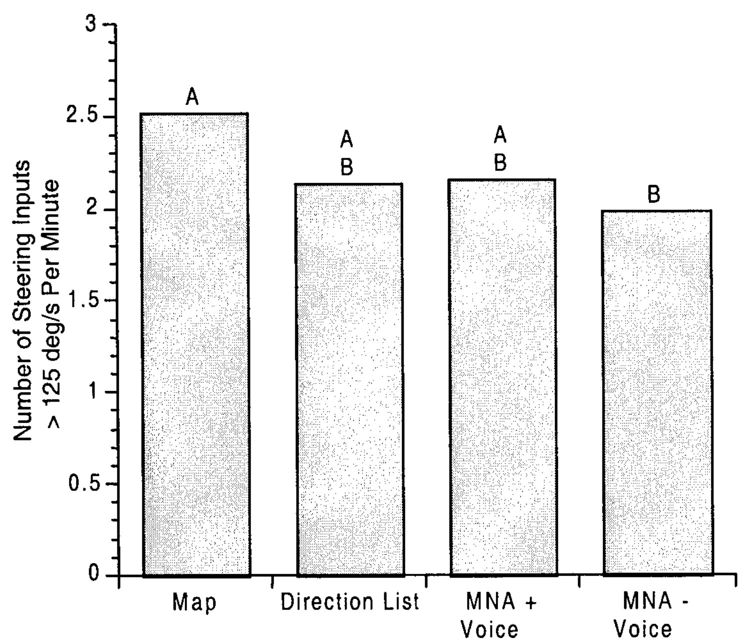


Figure 12. Number of Steering Inputs Greater than 125 Degrees per Second per Minute (means with different letters are significantly different from one another; means with the same letters are not significantly different)

Experience and Age. There were no significant differences due to age, experience, or the interactions of these with navigation scenario.

3.2.7 Standard Deviation of Accelerator Pedal Input

The standard deviation of accelerator pedal position reflects the amount of variability in driver application of the throttle. This measure is correlated with speed variability, which has been shown to be a sensitive measure of changes in the attention demands of secondary tasks (Monty, 1984). Accelerator pedal input variability may be more sensitive than speed variability because it is measured as an operator input rather than a change in speed, which is a derivative of control input.

Navigation Scenario. The paper map scenario yielded significantly greater variability in accelerator input than the MNA did without voice, as shown in Figure 13. The navigation scenario effect was reliable, $F\ (3,177) = 2.80, p < 0.05$. This finding is consistent with greater driver distraction in the paper map scenario.

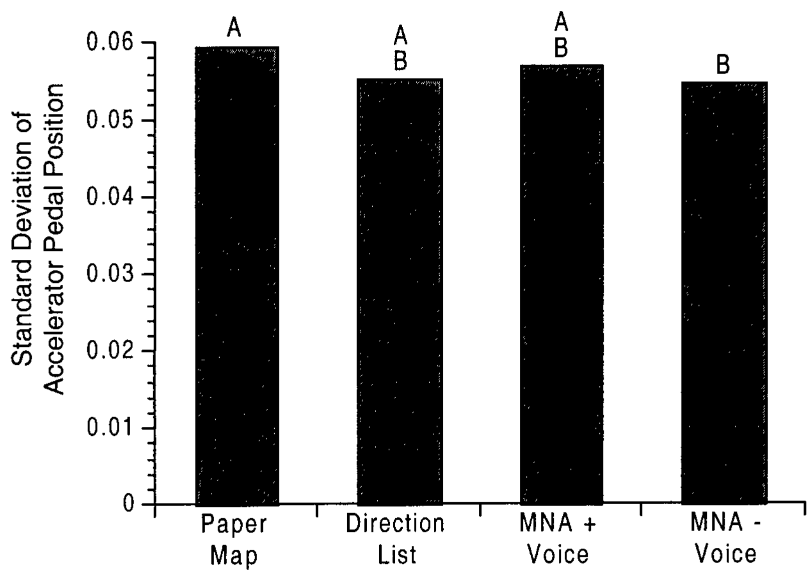


Figure 13. Standard Deviation of Accelerator Pedal Position (means with different letters are significantly different from one another; means with the same letters are not significantly different)

Experience. There were no significant differences in accelerator pedal input variability as a function of experience.

Age. Older drivers exhibited less variability in accelerator pedal input than the younger drivers, $F\ (1, 38) = 13.23, p < 0.05$.

3.2.8 Mean Speed

Mean speed did not vary as a function of navigation scenario or MNA experience. There was an age effect, $F\ (1,38) = 5.39$, $p < 0.05$. Younger drivers drove, on average, approximately 3.2 km/h faster than the older drivers.

3.2.9 Standard Deviation of Speed

The standard deviation of speed did not vary as a function of navigation scenario or MNA experience. There was an age effect, $F(1,38) = 11.42$, $p < 0.05$, with younger drivers exhibiting greater speed variability than the older drivers. Note that with speed limited at the low end at zero km/h and unlimited at the high end, any group that drives faster would be expected to show greater speed variability.

3.2.10 Standard Deviation of Steering Wheel Input

Steering wheel motion did not vary as a function of navigation scenario or age. However, inexperienced MNA users exhibited greater wheel movement than the experienced users did, $F(1,38) = 5.16$, $p < 0.05$. As this effect was across all navigation scenarios, no explanations are apparent.

3.2.11 Number of Longitudinal Accelerations Greater than 0.3 g's

There were no significant differences in longitudinal acceleration as a function of navigation scenario, experience, age, or the interaction of these variables.

3.2.12 Number of Lateral Accelerations Greater than 0.3 g's

There were no significant differences in lateral accelerations as a function of navigation scenario, experience, age, or the interaction of these variables. (Note, whereas 0.4 g's was used as the criterion for performing a hazard analysis, 0.3 g's, a more frequent occurrence, was used to assess overall driving performance.)

3.2.13 Number of Brake Activations

There were no significant differences in brake use as a function of navigation scenario, experience, age, or the interaction of these variables.

3.2.14 Summary of Driver Performance Findings

Table 4 summarizes the driver performance measures. The performance measures provide no indications that MNA use is less safe than paper map use. Furthermore, there is some indication that the MNA without voice may contribute to an overall reduction in driver workload; e.g., frequency of sharp steering movements and deviation of accelerator input, relative to using a paper map. These indications were neither strong, nor consistent across all performance measures.

There was no significant reduction, compared to the paper map, in any of the driver workload measures, neither in aggregate nor by age nor MNA experience, using the MNA with voice supplement. One might have expected at least a comparable reduction in one of the measures noted for MNA without voice, since verbal instructions would appear less burdensome and distracting to the driver task. This is one indication that the voice supplement, as implemented, might have detracted from, rather than enhanced, the overall effectiveness of the MNA. This is a theme that will be revisited in other findings.

Table 4. Summary of Driver Performance Measures

	Mean time to complete drive	Mean number of turns to complete drive	Mean number of times off route	Mean time off route	Number of steering reversals > 12 degrees	Number of steering imputs > 125 degrees/sec.	SD of accelerator pedal input	Mean speed	SD of speed	SD of steering input	Number of longitudinal accelerations > 0.3 g's	Number of lateral accelerations > 0.3 g's
MNA with Voice	o	o	o	o	o	o	o	o	o	o	o	o
MNA without Voice	o	o	o	o	o	+	+	o	o	o	o	o
Direction List	o	o	+	o	o	o	o	o	o	o	o	o
Paper Map	CONTROL											

Notes:

+ indicates statistically reliable difference that favors the scenario as safer than the paper map

o indicates no reliable difference between scenario and the paper map relative to safety

3.3 Hazard Analysis

As the number of commercial ATIS products moving towards deployment increases, the need for timely and efficient methods for proactive safety evaluation also increases. Whereas the most accurate measure of safety impact would come from an analysis of changes in the number and severity of crashes after deployment of ATIS products, it would be more desirable to identify dangerous products before they result in crashes and injuries.

Previous attempts to assess the impact of ATIS technologies on drivers have followed the model of the preceding sections and assessed driving performance rather than driving safety. Whereas driving performance and driving safety are probably correlated, the degree to which performance changes are related to safety is largely unknown. For instance, an analysis of driving performance may indicate that, due to interactions with an ATIS system, drivers deviate from their lane more often when using the system. In the absence of any obstacle or vehicle to collide with during the lane deviations, there is no measurable safety impact. Furthermore, drivers have been found to do a relatively good job of deferring interactions with in-vehicle devices until a time when it is safe to do so.

Because the direct relationship between component driving performance measures and driving safety has yet to be empirically identified, conclusions about safety are based on researchers' interpretation of performance measures and their relevance to the safety construct. Although evaluation of performance measures is appropriate, it is not sufficient for assessing the impact of ATIS use on safety.

The hazard analysis was designed as the next step in the development of the safety evaluation process. Adapted for use with instrumented test vehicles, the hazard analysis provides a method of systematically classifying driver errors and near misses. The hazard analysis technique is based on the traffic conflict technique (TCT), which has been used previously to examine intersection geometry safety.

The TCT is used to quantify near-crash or potential crash situations. The technique utilizes observation of crash avoidance situations, or near-crashes, to extrapolate recommendations about hazardous designs and recommend appropriate corrective action. Traffic conflicts have conventionally been defined as a potential crash situation involving one or more vehicles. In unexpected or unusual situations, drivers in these conflicts take evasive actions such as braking or weaving to avoid a collision (Perkins and Harris, 1967a, 1967b).

TCT data acquisition usually takes place over a short period of time. Trained observers and/or cameras provide a continuous record of events. The observers quantify factors such as time to avoid a collision, severity of evasive action, type of evasive action, and proximity of vehicles involved. The data collection is typically labor intensive, and intense data collection requirement is probably the reason that this methodology has not gained wider acceptance. However, results utilizing the traffic conflict technique consistently show that high crash frequencies are associated with high conflict frequencies. Study results concentrating on specific intersection types yield correlations approximating 0.80 between serious conflicts and high crash rates. According to Older and Spicer (1976), the ratio of crashes to serious conflicts is highly dependent upon intersection demographics, the technique used by the conflict rater, and the type of vehicles involved in the conflicts. Urban area intersections have shown a serious conflict-to-injury crash ratio for four or more wheeled vehicles to be approximately 2000:1. Situations involving motorcycles, bicycles, and pedestrians show a much lower conflict-to-injury ratio, between 500:1 and 300:1.

The TCT was modified for use in the TravTek Camera Car Study (Dingus et al., 1995). That study used a vehicle on the road, as opposed to analyzing conflicts from a stationary point. That methodology was extended to the present study. The classification of error type, potential severity, and the proximity of hazards, provides a context for how close errors came to becoming crashes. This technique relies on the underlying principle that, at some level, driver errors and near misses are predictors of crashes. This concept is related to the Heinrich's Triangle (Heinrich, Petersen, and Roos, 1980) and is visually represented in Figure 14. The numbers in the figure represent hypothetical relative frequencies of driver errors, near misses, and increasing severity of crashes. Driver errors and near misses occur with much greater frequency than crashes. Thus, relatively small studies like this one, analysis of errors and near misses offers greater potential for collecting enough observations to support statistically reliable safety inferences.

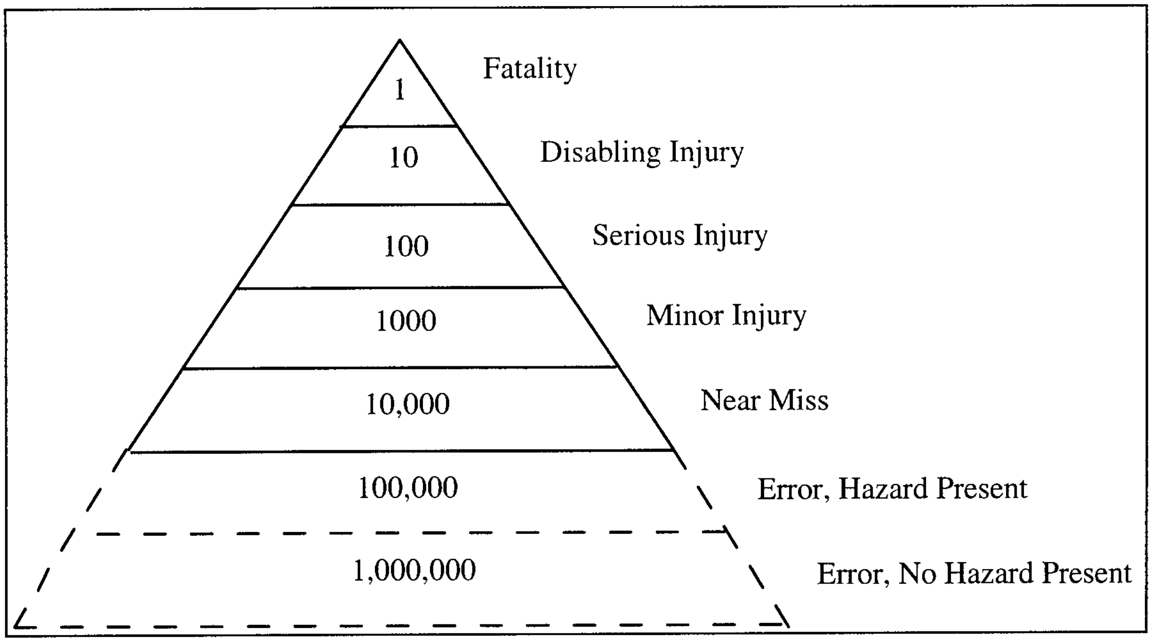


Figure 14. Heinrich's Triangle

In the first phase of the hazard analysis, driver errors and near misses were identified by reviewing the in-vehicle experimenter logs, triggers from the electronic data stream, and experimenter flags. Events judged to represent driver errors were classified under the criteria provided on error classification flow charts (Dingus et al., 1995). These flow charts provided a systematic method of classifying and recording pertinent data for each type of error. Factors included the type of error, vehicle speed, type of roadway where error was committed, presence or absence of potential hazards (environmental proximity), and corroborating information from the electronic data stream. Nine hundred thirty-four errors were classified. Careful examination of the driver's actions was made to determine whether the error was committed because the driver was directing attention towards a navigation display.

During the second phase of the hazard analysis, another rater examined the electronic data, experimenter logs, and 934 previously categorized errors. The second rater completed the same process as the first rater. The two raters' classification were then compared and differences reconciled. The reconciliation yielded 920 errors. The majority of disagreements between raters occurred for errors in the vicinity of intersections: either (a) distinguishing between lane deviations and wide turns, or (b) distinguishing between turn indecision and late braking to prepare for a turn. The severity and proximity ratings were unaffected by these classification differences.

The third phase of the hazard analysis was to assign a potential severity to each event. The tool developed for the TravTek Camera Car Study (Dingus et al., 1995) was used to rate potential severity. This tool ascribes potential severity based on historical data from similar types of incidents in the National Highway Traffic Safety Administration's General Estimates System (NHTSA, 1991). The potential severity ascribed was that for the worst-case crash that could have occurred.

The fourth step of the hazard analysis was a general risk assessment. The output of this step is a classification of overall risk of each error including acceptable risk, undesirable risk, and unacceptable risk.

3.3.1 Driver Errors

The number of errors by each driver is shown in Figure 15. The fewest errors by any driver was five. The highest number of errors by any driver was thirty-nine. The younger experienced group averaged 11.8 errors with a standard deviation of 5.9. The younger inexperienced group averaged 13.4 errors with a standard deviation of 7.3 errors. The older group averaged 20.8 errors with a standard deviation of 8.2 errors.

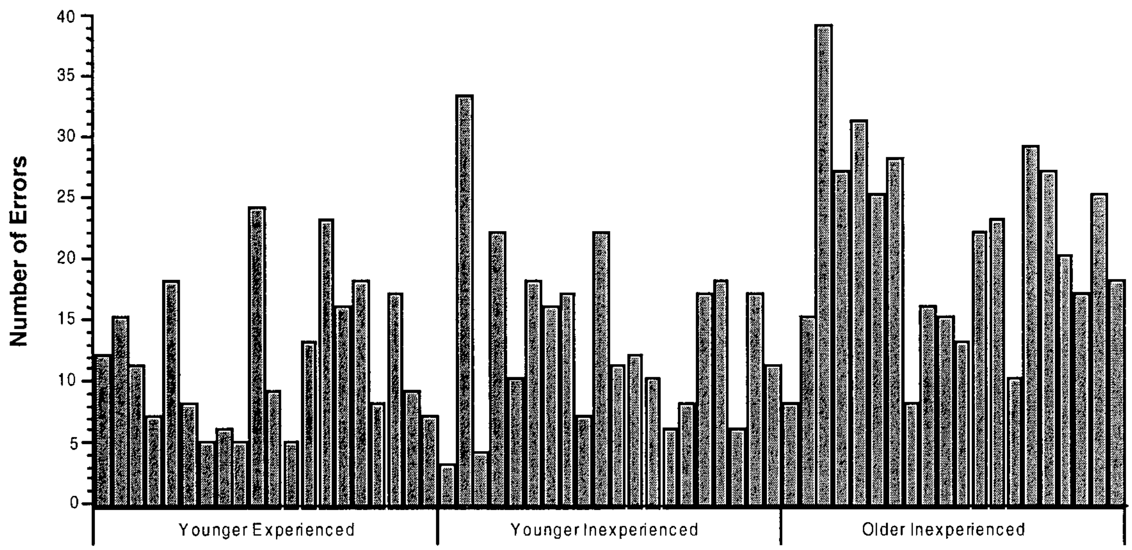


Figure 15. Number of Errors made by Drivers from each Group

Navigation Scenario. Navigation scenario had a significant effect on the number of errors, $F\,(3,177) = 2.68, p < 0.05$. As shown in Figure 16, the number of errors made during the paper map scenario was reliably greater than the number of errors made in the MNA without voice scenario.

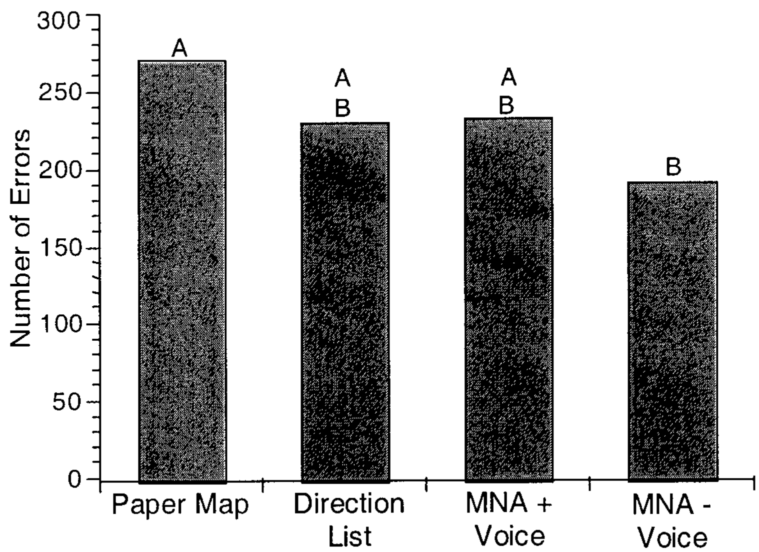


Figure 16. All Errors Combined, by Navigation Scenario (means with different letters are significantly different from one another; means with the same letters are not significantly different)

Experience. There were no statistically reliable differences in the number of errors as a function of drivers previous MNA experience.

Age. Older subjects made more errors then the younger subjects $F\ (1{,}38) = 9.53, p < 0.05$. When only navigation-related errors were considered, older drivers also made more errors than younger drivers, $F\ (1{,}38) = 16.47, p < 0.05$.

3.3.2 Environmental Proximity

Each error was rated for environmental proximity. This rating indicates how close the test vehicle came to a crash. The operational definitions for the three levels of environmental proximity are:

- **Near Miss**. The driver was startled and took immediate evasive action to prevent a crash. Near misses included situations where the experimenter gave an imperative verbal warning to drivers to bring their attention to unsafe situations.
- **Hazard Present**. The driver committed a safety-related error when an object (e.g., another vehicle, a pedestrian, or a guardrail) was present. This rating required that the object be close enough to represent a hazard to the test vehicle, but not close enough that an immediate evasive action was necessary to avoid it.
- **No Hazard Present**. The driver committed a safety-related error, but no close-proximity obstacle was present. An example of this would be a lane deviation where no objects that constituted a hazard were near the test vehicle.

The distribution of proximity ratings is shown in Figure 17.

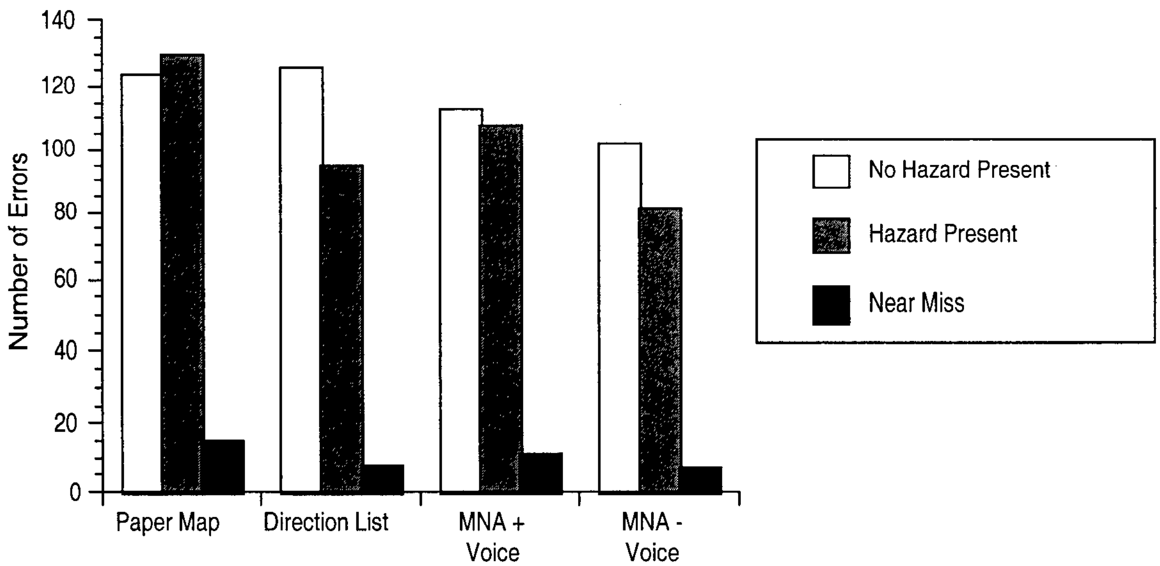


Figure 17. Distribution of Proximity Ratings as a Function of Navigation Scenario

Navigation Scenario. Proximity did not interact with navigation scenario either when only navigation-related errors were considered, or when all errors were considered.

Experience. There was no effect of experience on the proximity of errors.

Age. Figure 18 shows the number of errors as a function of age group and proximity. Older drivers made significantly more errors with no hazard present than did younger drivers: the interaction of age with proximity was F (2, 50) = 3.70, $p < 0.05$. The results were similar when only navigation-related errors were considered.

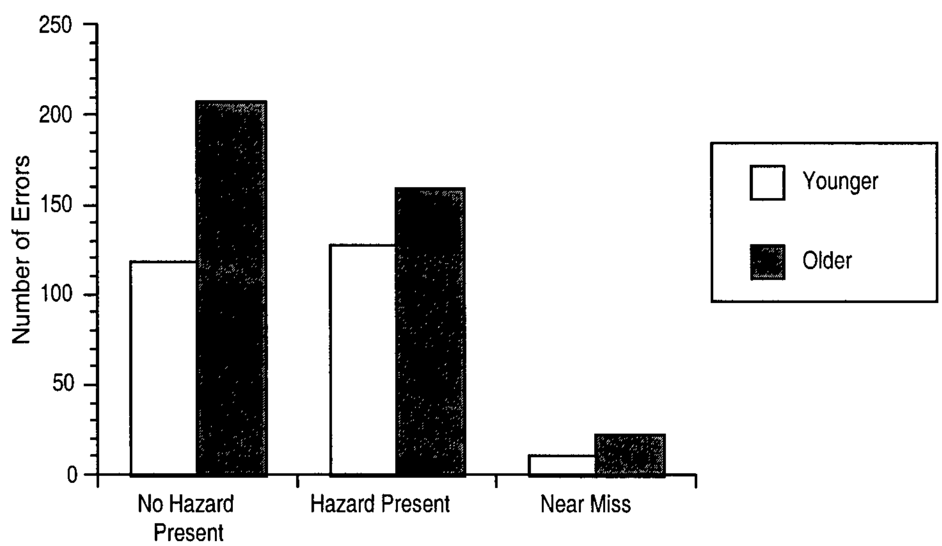


Figure 18. Number of Errors as Function of Age Group and Proximity

3.3.3 Potential Severity

Navigation Scenario. There were no differences in severity ratings as a function of navigation scenario.

Experience. Experience with the MNA had no effect on severity ratings.

Age. There was no severity age effect.

3.3.4 Types of Errors

Figure 19 shows the types of errors that drivers made in situations that were classified as navigation related. On an average, braking errors occurred more in the MNA scenarios than in the two control scenarios. It can also be seen that the paper map scenario resulted in roughly twice as many unsafe stops on average as the other scenarios did. However, a primary analysis of interaction between error category and navigation scenario indicates significant differences only for lane deviations, $F(3, 177) = 3.35$, $p < 0.05$.

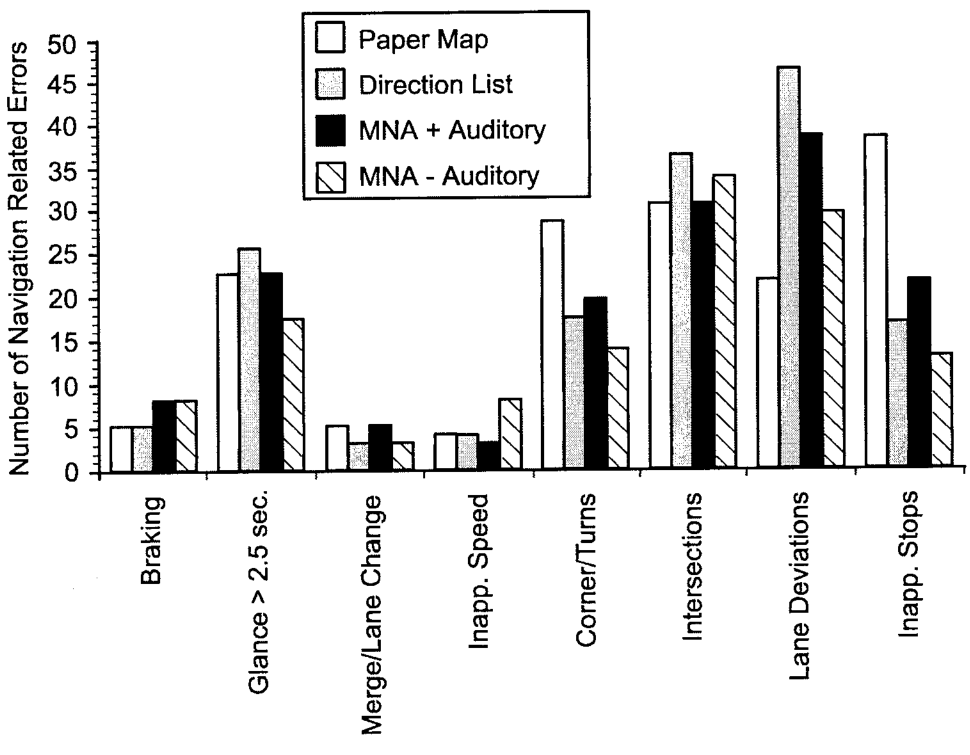


Figure 19. The Number of Navigation-Related Driving Errors as a Function of Type of Error

Figure 20 shows the types of errors as a function of age group. Older drivers were more likely than younger drivers to make lane deviations, $F(1, 38) = 9.50$, $p < 0.05$, have glances longer than 2.5 s, $F(1, 38) = 10.65$, $p < 0.05$, drive at an inappropriate speed, $F(1, 38) = 21.06$, $p < 0.05$, and make inappropriate stops, $F(1, 38) = 13.44$, $p < 0.05$. Experience with the MNA appeared to have no influence on the types of errors drivers made.

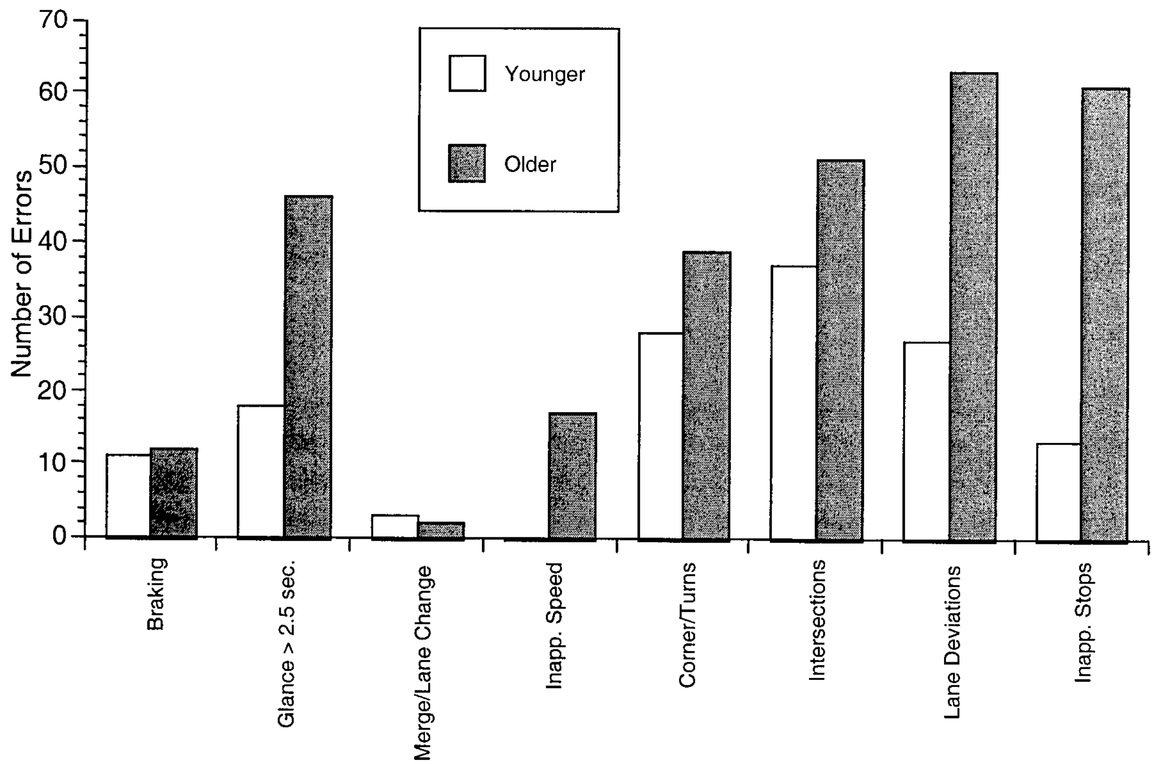


Figure 20. Types of Navigation-Related Errors as a Function of Age Group

3.3.5 General Risk Assessment

The Failure Modes Effects and Criticality Analysis (FMECA), which is typically used in industrial safety applications, was used to combine the potential severity and environmental proximity into a single measure designed to assess overall risk. Table 5 shows how general risk, as a function of environmental proximity and potential severity, for a given error, was calculated.

Table 5. Risk Assessment Matrix

Risk Assessment Assignment		Environmental Proximity			
		Crash	Near Miss	Driver Error Hazard Present	Driver Error No Hazard Present
Potential Severity	Catastrophic	Unacceptable	Unacceptable	Unacceptable	Undesirable
	Critical	Unacceptable	Unacceptable	Undesirable	Acceptable
	Marginal	Unacceptable	Undesirable	Acceptable	Acceptable
	Minor	Undesirable	Acceptable	Acceptable	Acceptable
Unacceptable Risk=	(dotted shading)	Undesirable Risk=	(hatched shading)	Acceptable Risk=	(solid black)

Navigation scenario had no significant effect on the frequency of errors in each risk category. Figure 21 shows the mean frequency of errors in each risk category as a function of age and navigation scenario. In aggregate, there were no significant differences in any risk category, all ages and experiences combined, by navigation scenario. Older drivers made significantly more acceptable and undesirable errors than did younger drivers, and the magnitude of the difference varied by error type and navigation scenario, which resulted in a significant three-way interaction, $F(6, 228) = 2.15, p < 0.05$. Older drivers tended to make proportionally more (relative to the overall age trend) undesirable errors in the MNA scenarios. These are indications that older drivers could face greater risk exposure than younger drivers with MNA, although this differential is not statistically significant from this field test. On balance, however, error rates for each risk category for age group were low and not significantly different between tested scenarios.

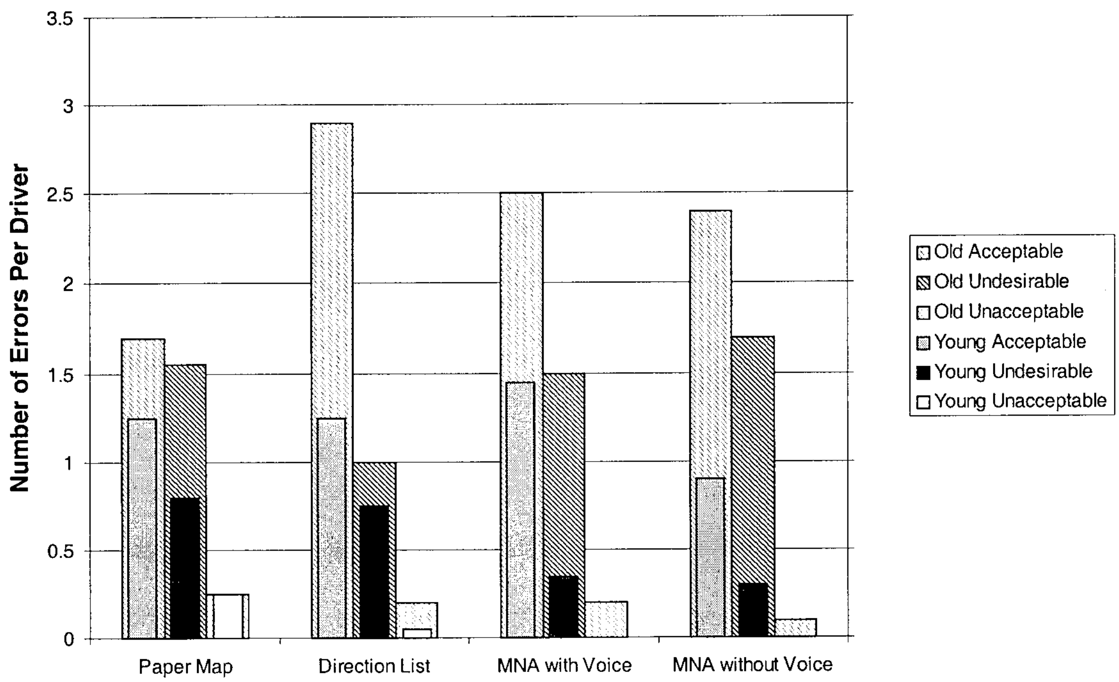


Figure 21. Mean Frequency of the Navigation-Related Errors as a Function of General Risk Categorization and Age Group

3.3.6 Hazard Analysis Summary

Table 6 summarizes the hazard analysis findings. The MNA without voice yielded fewer driver errors (all errors combined) than the paper map, which suggests a safety benefit for MNA without voice over the paper map. (MNA with the voice supplement did not yield significantly fewer total driver errors.) The direction list yielded fewer navigation-related lane deviations than the paper map, which suggests a safety benefit for the direction list over the paper map.

Older drivers made more undesirable navigation errors using the MNA, with and without voice, than younger drivers. These errors are primarily in the categories of long glances, lane deviations, and inappropriate stops. Total estimated risk for undesirable errors of younger drivers using either MNA scenario is significantly less than with the other scenarios. The comparable risk for older drivers using MNA is not significantly different. These differences indicate relatively greater risk improvements to younger drivers from MNA, with or without voice.

Older drivers showed fewer undesirable errors using the MNA with voice supplement than without. Beyond that, there were few indications from the hazard analysis that MNA with voice is safer than without the voice supplement. Combined with evidence that driving performance is impacted by the digitized voice supplement, the error findings suggest that on balance the voice enhancement may have actually detracted from MNA, as compared with the paper map scenario. While it is not considered a hazard, per se, and post hoc tests show no significant performance differences from the MNA without voice, the investigators have compared the results with similar tests in the TravTek Car Camera Study. TravTek showed improved eye glance, workload, and error performance using the synthesized voice supplement, which allowed for complete street names in the directional instructions, and, perhaps, more consistent message timing. Computer capacity limited the clarity of verbal instructions at the time the ADVANCE digitized voice supplement was designed, but will not be such a limiting factor in the future.

Table 6. Summary of Hazard Analysis Results

		Potential Severity				Proximity			Navigation Related Errors								Risk Assessment		
	Error Frequency	Catastrophic	Critical	Marginal	Minor	Near Miss	Error, Hazard Present	Error, No Hazard Present	Braking	Glance > 2.5 Seconds	Merge/Lane Change	Inappropriate Speed	Corner/Turns	Intersections	Lane Deviations	Inappropriate Stops	Unacceptable Risk	Undesirable Risk	Acceptable Risk
MNA with Voice	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
MNA without Voice	+	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Direction List	o	o	o	o	o	o	o	o	o	o	o	o	o	o	+	o	o	o	o
Paper Map	Control																		

Notes:
+ indicates statistically reliable difference that favors the scenario as safer than the paper map
o indicates no reliable difference between scenario and the paper map relative to safety

3.4 Driver Perceptions

Driver perceptions were assessed with two instruments: a questionnaire and subjective workload ratings.

3.4.1 Questionnaire

The questionnaire was administered after the driving portion of the test. Three areas were explored in the questionnaire: (1) perceptions of the effect of the navigation scenarios on safety and driving performance, (2) perceptions of the usability of the MNA, and (3) the comparability of the test drives to the participant's normal driving experience.

Perceptions of safety and driving performance. The following questions related to drivers' perceptions of the effects of the navigation scenarios on safety and driving performance:

- I [Always Sometimes Never ● ● ● ● ●] found myself **distracted** from driving when using the [***navigation scenario***].

- I [Always ● Sometimes ● ● ● Never ●] felt **unsafe** while using the [***navigation scenario***].

- I was [Less ● Same ● ● ● More ●] **aware** of my surroundings when driving with the [***navigation* scenario**] as compared with my normal driving.
- I experienced [Many ● Some ● ● ● None ●] **close calls** when driving with the [***navigation scenario***].
- I kept my **eyes on the road** [Less ● Same ● ● ● More ●] when using the [***navigation scenario***] as compared to my normal driving.
- In general, I drove [Better ● Same ● ● ● Worse ●] when using the **ADVANCE MNA** as compared to how I normally drive while navigating.

In addition, participants were asked to rank order the navigation scenarios from most safe to least safe.

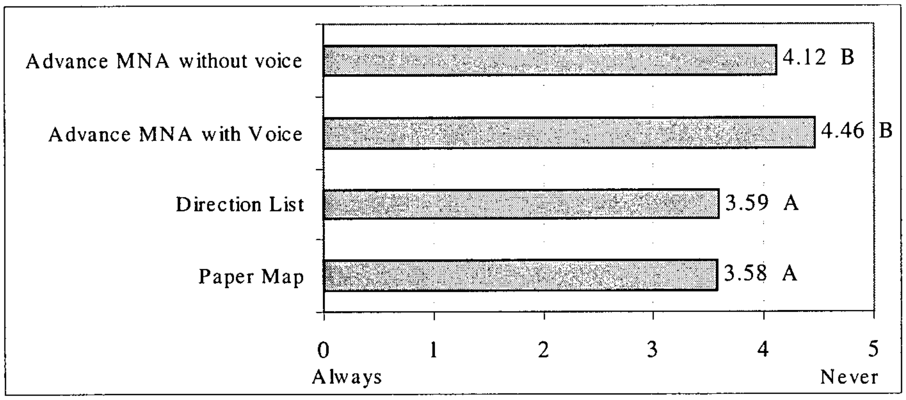
As shown in Table 7, drivers ranked the MNA with voice as the safest of the navigation scenarios. The MNA without voice was ranked second safest. The direction list and paper map were ranked least safe, with the rankings for these two scenarios not significantly different from each other.

Table 7. Mean Driver Rankings of the Navigation Scenarios with Respect to Safety

Scenario	Mean Rank (1 = Safest, 4 = least safe)
MNA without voice	2.14^{B}
MNA with voice	1.22^{C}
Direction List	3.00^{A}
Paper Map	3.22^{A}

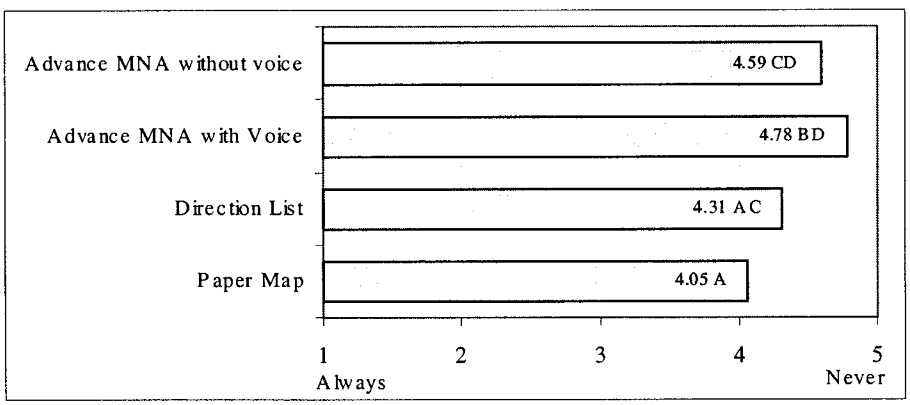
Notes:
1. Means with different letters are significantly different from one another. Means with the same letters are not significantly different.
2. Ranking totals add up to less than 10, because ties were permitted.

The ratings for the other safety and driving performance questions were consistent with the overall safety rankings for the navigation scenarios. As shown in Figure 22, drivers reported less distraction with the MNA than with the paper map or direction list. Drivers tended to say they never felt unsafe during the test, and this tendency was strongest with the MNA with voice, as shown in Figure 23. For the paper map and direction list scenarios, ratings of awareness of surroundings, shown in Figure 24, were close to neutral (about the same as for normal driving). For the MNA with voice, drivers stated that they were more aware of their surroundings compared to normal driving. It can be seen in Figure 25 that participants said they experienced fewer close calls in the MNA with voice scenario, than they did in the other scenarios. Drivers perceived that they kept their eyes on the road more with the MNA with voice, as shown in Figure 26.



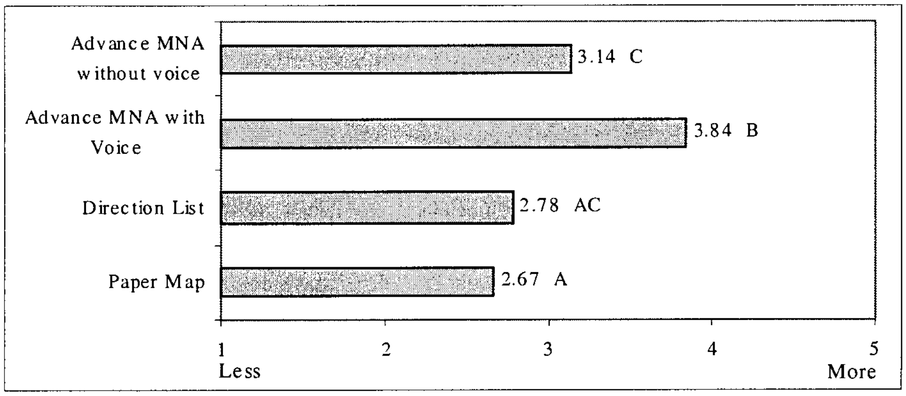
Means with different letters are significantly different from one another.

Figure 22. Mean Responses, as Function of Scenario, to "I found myself distracted from driving using the [navigation scenario]"



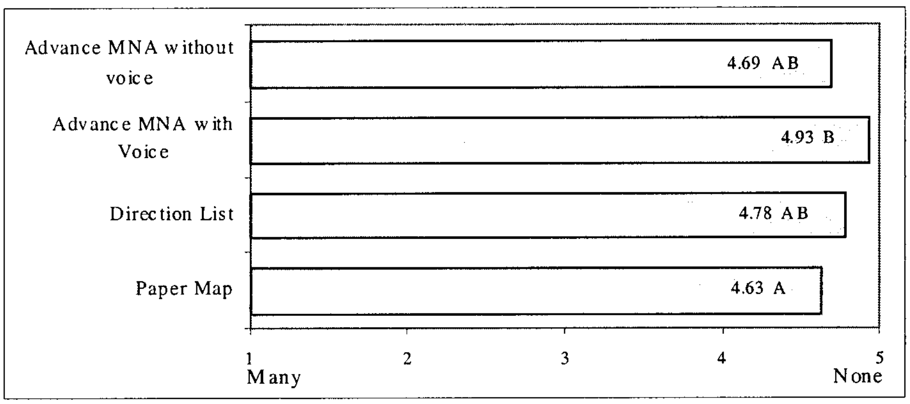
Means with different letters are significantly different from one another.

Figure 23. Mean Responses, as Function of Scenario, to "I felt unsafe using the [navigation scenario]"



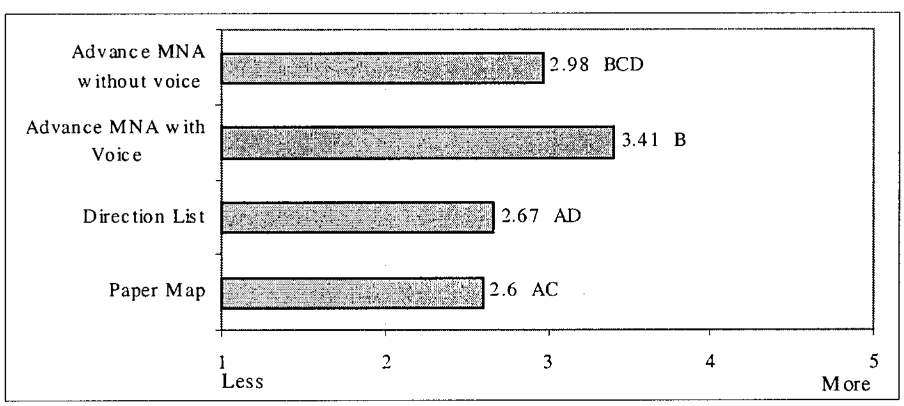
Means with different letters are significantly different from one another.

Figure 24. Mean Responses, as Function of Scenario, to "I was aware of my surroundings using the [navigation scenario]"



Means with different letters are significantly different from one another.

Figure 25. Mean Responses, as Function of Scenario, to "I experienced close calls using the [navigation scenario]"



Means with different letters are significantly different from one another.

Figure 26. Mean Responses, as Function of Scenario, to "I kept my eyes on the road using the [navigation scenario]"

Although all participants indicated that they were more aware of their surroundings when using the MNA, participants with previous MNA experience were stronger in making this assertion: the interaction of navigation scenario with experience was statistically reliable, $F(3, 113) = 3.34, p < 0.05$. This interaction can be seen in Figure 27.

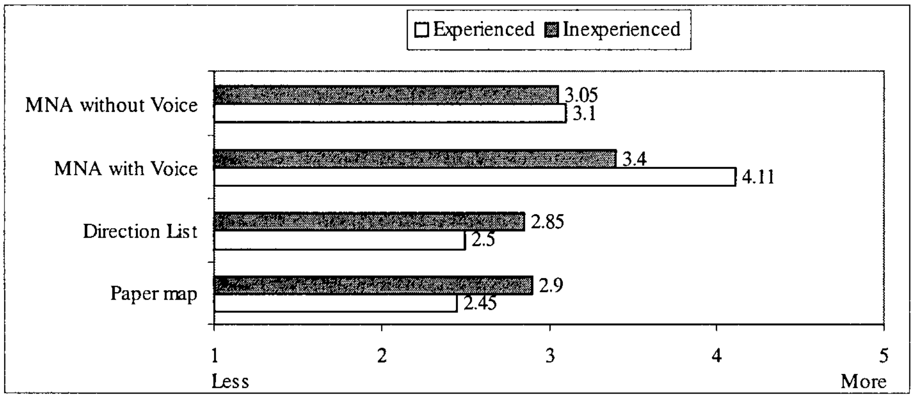


Figure 27. Mean Rating of Awareness of Surroundings as a Function of MNA Experience

Participants tended to say that their driving was about the same with the MNA as it is in their normal driving. However, drivers with previous experience with the MNA tended to rate their driving performance with the MNA slightly better than their normal driving performance. These results are summarized in Table 8.

Table 8. Assessment of Driving Performance

	Experienced	Inexperienced
In general, I drove | better - same - worse | when using the ADVANCE MNA as compared to how I normally drive while navigating. 1. Better 5. Worse	2.10^{A}	2.60^{B}

Means with different letters are significantly different from one another.

Perceptions of MNA Usability. Three questions addressed the usability of the MNA:

- I found it [Very Difficult ● ● ● ● ● Very Easy] to **understand** the **visual** information the **ADVANCE MNA** was presenting to me.
- I found it [Very Difficult ● ● ● ● ● Very Easy] to **understand** the **auditory** information **(sounds)** the **ADVANCE MNA** was presenting to me.
- I had [Very Much ● ● ● ● ● Very Little] **confidence** in the information the **ADVANCE MNA** was presenting to me.

Participants reported that the voice and visual information presented by the MNA was easy to understand. They also reported that they had confidence in the information that they were presented. As can be seen in Table 9, experience with the MNA tended to yield slightly better usability ratings.

Table 9. Mean Ratings for Usability Questions Shown as a Function of Driver Experience

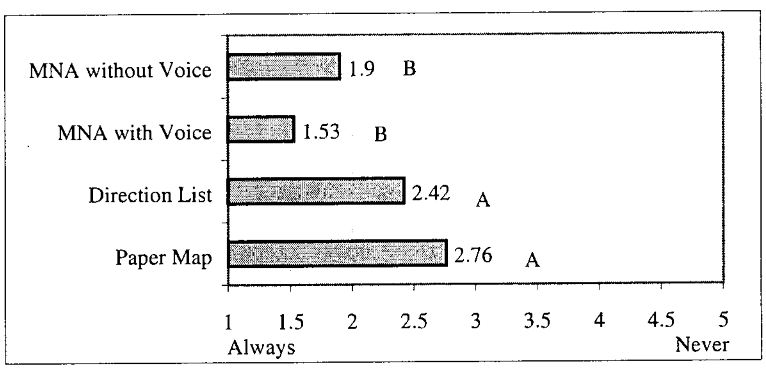
Question	Experienced	Inexperienced
I found it | very difficult - - - very easy | to understand the visual information the ADVANCE MNA was presenting to me. 1. Very difficult 5. Very easy	4.70^{A}	4.15^{B}
I found it | very difficult - - - very easy | to understand the auditory information (sounds) the ADVANCE MNA was presenting to me. 1. Very difficult 5. Very easy	4.90^{A}	4.45^{B}
I had | very much - - - very little | confidence in the information the ADVANCE MNA was presenting to me. 1. Very much 5. Very little	1.56^{A}	2.06^{A}

Means in the same row that have different letters are significantly different from one another.

A fourth question, somewhat related to usability was:

- I [Always ● ● Sometimes ● ● Never ●] felt **comfortable** when driving with the [***navigation scenario***].

Mean responses to this question are presented in Figure 28. Participants gave significantly higher comfort ratings to the two MNA scenarios, with no significant difference between these two scenarios.



Means with different letters are significantly different from one another. Means with the same letters are not significantly different.

Figure 28. Mean Response to "I felt comfortable using the [navigation scenario]"

Comparability of the Test Drives to Normal Driving Experience. Two questionnaire items were intended as a check on how representative the selected O-D pairs were to the traffic situations the drivers normally experience. These questions were:

- The **traffic congestion** was [Less ● ● Same ● ● ● More] during my drive with the [*navigation scenario*] as compared to when I normally drive.
- I was [Familiar ● ● ● ● ● Not familiar] with the roadways I drove on while using the [*navigation scenario*] today.

Drivers perceived congestion to be slightly higher than what they normally experience, but perceived no differences among the O-D pairs. Ratings of familiarity with the roadways were on the "not familiar" side of neutral.

Subjective Workload Ratings. Ratings of "time stress," "visual effort," and "psychological stress" were captured at five different times during each test drive, and an average for each driver was computed to minimize the standard error of measurement. These ratings were uniformly low across all navigation scenarios. Altogether there were no significant differences in workload ratings between navigation scenarios, age groups, or as a function of MNA experience.

3.4.2 Summary of Driver Perceptions

Table 10 summarizes the results of the driver perception data, factored by scenario. On the questionnaire, the drivers rated the MNA with voice safer than the paper map in all categories, and in direct comparison, ranked MNA with voice as safer than without. The MNA with voice was rated safer than the paper map in all but two categories. The finding that subjective workload ratings were uniformly low across scenarios was consistent with these preferences.

Other questions captured driver perceptions of overall usability of the MNA and base conditions that may have biased the test. It can be concluded that experience with the MNA enhances its subjective usability and driving performance, and that test conditions were perceived as slightly more difficult than with normal driving.

Whereas the objective measures of performance suggest little safety-related benefit derived from MNA use, with or without the voice supplement, the subjective measures suggest a benefit. Overall, drivers indicated that they felt the MNA was safer than the paper map, and that MNA with voice was safer than without.

Table 10. Summary of Driver Perceptions

	Questionnaire							Subjective workload			
	Unsafe Assess.	Eyes on Road	Awareness of Surroundings	Distraction	Frequency of Close Calls	Comfort of Navigation Condition	Safety Preference	Time Stress	Visual Effort	Psychological Stress	All Combined
MNA with Voice	+	+	+	+	+	+	+	o	o	o	o
MNA without Voice	+	o	+	+	o	+	+	o	o	o	o
Direction List	o	o	o	o	o	o	+	o	o	o	o
Paper Map											

Notes:

+ indicates statistically reliable difference that favors the scenario as safer than the paper map

o indicates no reliable difference between scenario and the paper map relative to safety

Drivers also made distinctions between the MNA with voice supplement and without, as compared with the other scenarios. Only with the voice supplement were they both more aware of their surroundings compared to normal driving and felt more safe than using the direction list. Only with the voice, did drivers feel they kept their eyes on the road more, and had fewer close calls that with the paper map.

Consistent with the overall rankings of the scenarios, drivers of all ages and experience levels clearly preferred the voice supplement; there were no questionnaire responses significantly favoring the MNA without voice.

4. Discussion

This section summarizes the findings with respect to each of the objectives of the safety evaluation. Specifically, the following objectives, outlined in the Introduction, are discussed:

1. Determine whether drivers drive more or less safely with the ADVANCE system than without it, in ways related to the system.
2. Extend the ITS knowledge base with respect to vehicle navigation and in-vehicle navigation aids.
3. Support refinement of Advanced Traveler Information Systems (ATIS) design.

4.1 Drivers Drive about as Safely with the ADVANCE System as Without It, In Ways Related to the System

Four indicators of safety were assessed:

1. Eye glance behavior
2. Driving performance
3. Hazard indicators
4. Driver perceptions.

The paper map scenario served as the primary "control" condition against which the MNA scenarios were compared. The direction list scenario served as a second "control" condition to provide a more direct point of comparison between electronic navigation assistance and an analogous written list.

4.1.1 Eye Glance Behavior

Counting all glances to the display when the vehicle was in motion, use of the MNA resulted in the shortest average durations for all navigation scenarios, suggesting a safety benefit. Each glance to the MNA was brief, about 1.0 second on average. These glances were significantly shorter than glances to the paper map, for which the average glance time was 1.8 seconds. Furthermore, although not all drivers stopped the vehicle to look at the paper map, stopping in unsafe locations was more than twice as likely in the paper map scenario than in the other scenarios.

As opposed to duration, use of the MNA resulted in more frequent glances to the display, for greater total duration (dwell) over the trip. The fact that drivers looked at the MNA for a greater proportion of the time than they did to either the paper map or the direction list, suggests an MNA safety disbenefit. The MNA without voice was the focus of gaze about 11 percent of the time, followed by the MNA with voice at 10 percent, the direction list at 6 percent, and the paper map at 4 percent. Experience with the MNA reduced the glance time to the displays by about 20 percent, to 8.2 and 7.8 percent respectively, to the MNA with voice and the MNA without voice.

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Relative glance times to the visual display corresponds with relative distraction from the forward roadway. Drivers using the MNA spent about 78 percent of the time monitoring the forward roadway; for the paper map scenario, drivers spent approximately 82 percent. The time spent looking at the MNA was, at least partially, at the expense of monitoring the forward roadway. The other part was at the expense of other glance locations. MNA users glanced at locations other than the MNA display less frequently and for a lesser percent of glance time.

Despite the apparent contradiction between relative mean duration and frequency or dwell resulting from each scenario, the evaluators felt that duration may be the more meaningful indicator of the total glance impact on safety performance. Intuitively, the safety impact of x (short) glances of y duration is considerably less than a single (long) glance of xy duration. Moreover glances of duration greater than 2.5 seconds have been proposed as a threshold for inherently hazardous glances. Without knowing the precise safety degradation from glances of varying durations, the evaluators examined how frequencies would change if only long, safety critical, glances were counted. Glances to the navigation displays greater than 2.5 seconds did not vary as a function of scenario.

On balance, the glance data indicates that the MNA does not negatively impact driver safety over the paper map or direction list. Glance durations are shorter, but frequency and dwells are greater. However, frequency and dwells are considered less important than duration. Like the increased dwells to the display, increased glance time away from the forward roadway were the result of more frequent but short, benign glances under the critical 2.5 second safety threshold.

4.1.2 Driving Performance

Use of the MNA, with or without voice, did not degrade driving performance, as indicated by the measures discussed below. In fact, performance with MNA without voice showed improvements in some navigation and workload measures over the paper map.

Navigation-related measures. The first three measures of performance — travel time, frequency of wrong turns, and time off-route — suggested that all four navigation scenarios are equally effective in getting drivers to their destination. There were no scenario-related differences in these measures, other than a tendency for the paper map scenario to result in more wrong turns. Drivers tended to take longer to reach their destination, and this effect, though small, was most pronounced with the paper map.

Workload-related measures. The remaining measures of performance, aside from mean speed, are hypothetically related to driver workload, with higher means suggesting drivers may have devoted less attention to driving. Two measures suggested that workload was higher in the paper map scenario than in the other scenarios: the rapid number of steering wheel inputs (greater than 125 degrees per second), and variability (standard deviation) in accelerator input. None of the other measures suggested that workload varied with scenario.

Overall, the performance measures suggest that the MNA does not adversely affect driving performance and yields slightly superior performance relative to navigation with a paper map.

Older drivers drove somewhat slower than young drivers did. Driving performance with the MNA benefited from previous experience with respect to only one performance measure: steering wheel input variability.

Only using MNA without voice were there improvements in workload measures — rapid steering wheels inputs, and variability in accelerator input — from the paper map. There was no significant reduction in any of the driver workload measures, neither in aggregate nor by age nor MNA experience, using the MNA with voice supplement. One might have expected at least a comparable reduction in one of the measures realized for MNA without voice, since aural instructions would appear less burdensome and distracting to the driver task.

Along with similar findings from the Hazard Analysis, lack of workload benefits realized from the MNA with voice supplement (that have been achieved without voice) are counterintuitive. In previous ATIS operational tests like TravTek, incremental driver performance benefits of voice supplements are predominant, and point to the advantages of aural turn-by-turn instructions, principally in the area of driver workload enhancement. With ADVANCE, one is forced to conclude that the voice supplement, as implemented, might have detracted from, rather than enhanced, the workload effectiveness of the MNA.

Pilot drivers reported problems with the timing of aural instructions; they were calibrated for suburban grid densities, the instruction sometimes preceded the intended street by more than a block. In lieu of complete street names, such as those synthesized by the TravTek supplement, such mistiming would sometimes result in hesitation by the driver, who might revert to the information on the visual display. Such incidents were disconcerting, often overriding the apparent benefit of a voice instruction in not interrupting a forward view. Whether variations from the tested voice supplement may have yielded different results are addressed in Section 4.3, Route Guidance Interface Design Recommendations.

4.1.3 Hazard Analysis

Drivers made more safety-related errors in the paper map scenario than in the other scenarios. However, only for the MNA without voice scenario were any categories of error totals significantly less than the paper map. Notwithstanding this difference, there was no resulting variation of risk between scenarios. Neither the severity of the accidents that could have resulted from the errors, nor the proximity of the errors to crashes varied as a function of scenario.

MNA experience had no observable effect on driving errors. Older drivers tended to make more errors than younger drivers. Older drivers exceeded younger drivers in the frequency of lane deviations, frequency of driving too slow or too fast, and the frequency of stopping in inappropriate locations.

Overall, the hazard analysis suggests that MNA use was as safe as paper map and direction list use - but not safer. This begs the question: with improvements to the voice supplement, could MNA become safer than the control scenarios? The sensitivity of computed risk with respect to scenario enhancements and test conditions is open to question. For example, improving the timing and content of the voice supplement, as discussed in Section 4.3. could reduce error rates to the point where total risk over the control scenarios is reduced.

4.1.4 Driver Perceptions

Drivers said that the MNA provided greater feelings of safety than the paper map. When asked to rank order the four navigation scenarios with respect to safety, MNA with voice was ranked safest, followed by the MNA without voice. Thus, whereas eye glance, performance, and hazard analysis suggest few safety-related benefits derived from MNA use, drivers perceived a distinct safety benefit. They reported less distraction, and greater comfort and feelings of safety, with either MNA scenario. Also there are indications that experience with MNA make it seem easier, and perhaps safer, to use.

MNA did not, however, alter perceived workload demands. In terms of time stress, visual effort, and psychological stress, the subjective workload across all scenarios was uniformly low.

Without exception, the responses to the questionnaire favor the MNA with voice supplement over MNA without the voice supplement. Drivers stated that they were more aware of their surroundings compared to normal driving with either MNA scenario than they were with the paper map or direction list; but more so with voice than without. Also, only with the voice supplement did drivers feel they kept their eyes on the road more, and had fewer close calls, than with the paper map. After providing this specific feedback, drivers indicated they felt somewhat safer, relative to the other scenarios, with the voice supplement than without.

4.2 Extension of the ITS Knowledge Base

The primary contribution to the ITS knowledge base is the information gathered on how drivers interact comparatively with both turn-by-turn graphical guidance displays and conventional navigation methods. Combined with similar information from prior ATIS studies, the information can be useful in assessing the capabilities of vehicular navigation systems to achieve their primary goals without sacrificing safety. Source (video and digital records) and processed data files of system performance, as well as questionnaire data, are components for an ATIS safety research database.

In particular, the data not only compares performance with varied display devices per se, but also offers insight into how the age of the driver and their experience with the technology affects their performance. The evaluation collected and organized a considerable storehouse of data that can be combined and analyzed with data from similar studies. The study provides data to answer the research questions not only addressed by the ADVANCE operational test but also by a continuing series of in-vehicle navigational device tests.

Aside from addressing the first of the evaluation objectives, a significant by-product of the evaluation was the development of a new and faster method for reduction of eye glance data. Custom software was developed for this project that enabled analysts to input glance locations at near real-time speed. In addition, glance time and other descriptive measures were extracted automatically with the input of glance location. This development significantly reduced the amount of time and labor required, when compared to earlier efforts in the same laboratory.

The tools developed for this study were intended to be utilized in future driver-vehicle interface studies. For the safety evaluation of the Intelligent Cruise Control (ICC) system, the ADVANCE eye glance classification software was used to develop an enhanced Video/Digital Data Integration tool. This program allowed efficient file classification of a number of visually recorded and interpretive phenomena, into the digital time stream and relational research data base, for the greater ease and convenience of ICC safety evaluation.

4.3 Route Guidance Interface Design Recommendations

The study has provided data on contrasting approaches to the integration of voice supplements to ATIS in-vehicle systems. The ADVANCE MNA, as with the TravTek navigation guidance system before it, incorporated a voice supplement to the visual display. However, the two navigation guidance systems incorporated very different design compromises in integrating the voice supplements: the ADVANCE system used *digitized* voice, whereas the TravTek system used *synthesized* voice.

MNA developers selected digitized voice because it provides higher quality sound than machine-like synthesized voice. Digitized voice technology uses recordings of human speakers. With available technology, it was impractical to digitize the names of all the roads in the ADVANCE coverage area. Therefore, the MNA did not provide street names when it suggested turns.

The TravTek developers wanted to provide drivers with street names. They therefore chose to use synthesized voice. Synthesized voice generates speech from text. This enabled the developers to generate speech from text messages that were displayed on the visual displays. Synthesized speech tends to sound non-human or foreign. Indeed, drivers who participated in the TravTek field operational test often complained about the sound of the voice messages. However, an interesting irony was that TravTek participants (often the same participants) identified the voice as both their least favorite and their most favorite TravTek feature (Inman and Peters, 1996). That is, they praised the usefulness of the voice information, but criticized the tone and clarity of the sound of the voice.

Whereas ADVANCE users indicated that the voice was easily understood, their eye glance, workload and error performance suggested that the voice did not appreciably change the visual demands of navigation. In contrast, the voice supplement in the TravTek system did result in less glance time away from the roadway when compared to the TravTek system without voice supplement, and reduced hazard and workload measures. Thus, from a safety perspective, the TravTek compromise of providing street names, at the sacrifice of tonal quality, may be preferable to provision of high quality sound with less information content.

In contrast to TravTek, MNA aural messages sometimes were heard sooner, or later that usual relative to the target street. Without street names, this was disconcerting to the driver and impeded the driver's performance. Timing in the TravTek study was not as critical as ADVANCE, mainly because navigational decisions were oriented to major highways and arterials, not for navigating an urban/suburban grid.

Perhaps compensating for the brevity of the aural message, MNA designers felt the need to include more information in the display message. Lengthy text and a directional prefix sometimes interfered with basic instruction of the directional label of the street name (e.g., turn East on North Elm).

Despite their clear, subjective preference for the voice supplement, ADVANCE participants performed more safely, as indicated by some of the workload and hazard measures, without the voice. Since none of these objective measures favored the voice supplement, in contrast to TravTek, the actual quality of that feature becomes suspect. To remedy these difficulties, there is sufficient anecdotal evidence to warrant making recommendations for enhancing the MNA driver interface, in the following areas:

Text message length. When MNA users made wrong turns, the system displayed a text message with instructions on how to get back on route. These messages could fill up to five lines on the display. Some drivers pulled off the road to read these messages. Others were unable to completely read messages before the message information was obsolete: they had driven far beyond the point where the instructions were appropriate. In the latter case, the driver could get back on route by selecting the replan route option. Long text messages are probably inappropriate when the vehicle is in motion, and were not helpful to drivers in this test. Shorter messages, such as turn-by-turn instructions given one maneuver at a time, would be more appropriate. Voice guidance would also be appropriate for off-route guidance.

Directional labels. Drivers had difficulty with the North, South, East, or West as a prefix in the name of the street for the next turn. These prefixes were part of the street name, and were based on the relationship of the roadway from the center of the township. However drivers often interpreted the prefix as a turn instruction. Both new and experienced MNA users made this error. The error persisted despite special instructions given before and during the practice drives. The compass direction prefix was compelling enough that some drivers turned to it even though the MNA turn arrow was pointing in the opposite direction. Although North, South, East, and West may be parts of proper street names, in most cases drivers will still recognize the street name without them. Our experience suggests that North, South, East, and West prefixes should be omitted when providing visual and verbal en route navigation instructions.

Enhance consistency and precision in the timing of directional instructions. The timing of voice messages that instructed them to turn occasionally confused drivers. Ambiguity in the content and timing of aural navigation instruction should be minimized. Sometimes voice messages came late, relative to the usual timing, and drivers who relied on the voice made last second maneuvers to avoid getting off route. There were also occasions when the messages came early, which resulted in drivers preparing to turn at an intersection prior to the one indicated by the system. More consistent and precise timing of messages could alleviate the erratic driving sometimes observed when messages were ill timed. Although achieving such timing is an extremely difficult objective for ATIS, TravTek did not reveal a similar problem, apparently because its announcement of street names over a courser navigational grid may have overridden most ambiguities. With the expanding capacity of small computers available for future systems, inclusion of street names in digitized messages might also reduce directional ambiguity, and obviate the need for resolving the voice timing problem directly.[2]

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[2] This problem, however, has yet to be resolved, at the time of this writing. It was recently noted that a popular in-vehicle route guidance system offered by a major rental car fleet did not provide street names as part of turn-instruction voice messages.

The problems that lead to these three design recommendations were not pervasive enough to be reflected in the quantitative results in this report. However, all three did lead to wrong turns (which can increase travel distance), and erratic driving that, over millions of trips, might be expected to increase accident risk exposure. This increase in exposure would be a baseline for evaluating benefits of recommended MNA design enhancements. Because the MNA as tested yielded performance on par with the paper map and direction lists, any improvement to the MNA design would be to make the MNA safer, as it is already safe, relative to the paper map and direction lists.

5. Conclusions

The ADVANCE Safety Evaluation study has addressed three main objectives:

1) *Determine whether drivers drive equally as safe with the MNA as without it, when the MNA is used to navigate to unfamiliar destinations.*

To test the main safety hypothesis, four MOEs of the impact of the MNA on safety were examined: (1) eye glance behavior, (2) driving performance indicators, (3) hazard indicators, and (4) driver perceptions. Extensive analysis of the MOEs suggest that drivers drive equally as safely with the MNA system than without it. Furthermore, no collisions occurred in over 2,000 miles driven while navigating with the MNA. Specific findings for each MOE are summarized below:

Eye Glance Behavior: The durations of individual glances to the MNA were short compared to driving with a paper map, suggesting an MNA safety benefit. On the other hand, the glance data suggest that the MNA increases total glance time away from the forward roadway – a safety disbenefit. These effects were more pronounced for MNA without voice than with. The MNA without voice yielded the largest proportion of glance time to the display, followed by the MNA with voice, the direction list, and the paper map.

Because average duration of glances is considered a better safety indicator than dwell, the initial results suggested examining the frequency of long glances. In fact, the frequency of glances to the navigation displays longer than 2.5 seconds did not vary with navigation scenario.

The total proportion of time looking at the MNA displays was reduced by having MNA experience. However, this did not alter the relative results between scenarios by experience level.

Older drivers devoted about 2 percent more of their glance time to the navigation aids than did the younger drivers, this age difference was roughly uniform across scenarios.

Driving Performance: Overall, the driving performance measures suggest that drivers drive at least as safely with the MNA as with other navigation scenarios.

There were some indications that navigating with the MNA without voice may have reduced driver workload (e.g., frequency of sharp steering movements and deviation of accelerator input) relative to the paper map, thereby rendering it potentially safer. However, these indications were neither strong, nor consistent across all performance measures. There was no significant reduction in driver workload with the MNA voice supplement. This counterintuitive finding may be explained by design deficiencies in the voice supplement.

Hazard Analysis: The hazard analysis also showed few differences in the effects of navigation scenarios. The MNA without voice yielded fewer aggregate driver errors than the paper map. The MNA with voice supplement yielded no comparable differences for any error category, and did not improve on the MNA without voice. This reversal from expectation is similar to the findings on driver workload, and may also be explained by design deficiencies in the voice supplement.

For the entire test sample, incidence of near misses and driver errors in the vicinity of a hazard did not increase with either MNA scenario. Observations of the limited distribution of errors in certain risk categories, however, suggest that the MNA might help younger drivers who made fewer undesirable errors using the MNA, than with the paper map or direction list. Older drivers, already at higher risk, did not realize this benefit. To close this gap, further improvements in the navigational interface or its user training should be investigated.

Driver Perceptions: Whereas the objective measures of performance suggest little safety-related benefit derived from MNA use, the subjective measures suggest a benefit.

When asked to rank order the four navigation scenarios with respect to safety, drivers ranked either MNA scenario as significantly safer than paper map or direction list. Drivers also reported less distraction, and greater comfort and feelings of safety, with either MNA scenario. Drivers clearly rated MNA with voice as safer than without in a direct preference polling, and ranked both MNA scenarios safer than the paper-based scenarios.

While the differences in assessments between MNA and the control scenarios were predominant, there were also differences between the two MNA scenarios. Drivers stated that they were more aware of their surroundings compared to normal driving with either MNA scenario than they were with the paper map or direction list; but more so with voice than without. Also, only with the voice supplement did drivers feel they kept their eyes on the road more, and had fewer close calls, than with the paper map. After providing this specific feedback, drivers indicated they felt somewhat safer, relative to the other scenarios, with the voice supplement than without.

Drivers were also asked periodically to rate their workload, in terms of time stress, visual effort, and psychological stress. Subjective workload was rated uniformly low, and, unlike objective driver performance measures, did not vary with navigation scenario.

Objective (1) Summary: For the four measures of effectiveness, there is no clear, unifying evidence that drivers drive less safely using ADVANCE MNA than with the paper map. Findings on glance measures are mixed with respect to MNA safety impact. Mean durations are less, whereas the proportion of total glance time is greater, although the frequency of long glances greater than 2.5 seconds are no different between the scenarios. In fact, the workload and hazard analyses indicate that MNA without voice enhances some safety surrogates, particularly for younger drivers. There are indications that the MNA voice supplement has safety advantages for drivers with prior MNA experience, but these benefits are not realized for all users. Also, MNA while providing benefits over the paper map, did not significantly outperform the direction list scenario. Drivers as a whole perceive safety advantages with the MNA and, in particular, the voice supplement.

On the basis of these findings, the evaluators concluded that drivers drive equally as safe with the MNA system, particularly without using the MNA voice supplement, as with the paper map.

2) *Extend the knowledge base of ATIS use for navigation*

The primary contribution to the ITS knowledge base is the information gathered on how drivers interact comparatively with both turn-by-turn graphical guidance displays and conventional navigation methods. Combined with similar information from prior ATIS studies, the information is useful in evaluating the potential of vehicular navigation system in achieving their primary goals without sacrificing safety. Source (video and digital records) and processed data files of safety performance, as well as questionnaire data, are components for an ATIS safety research database. In particular, the data not only compares performance with varied display devices per se, but also offers insight into how the age of the driver and their experience with the technology affects their performance.

A significant by-product of the evaluation was the development of a new and faster method for reduction of eye glance data. Custom software was developed for this project that enabled analysts to input glance locations at near real-time speed. In addition, glance time and other descriptive measures were extracted automatically with the input of glance location. This development significantly reduced the amount of time and labor required, when compared to earlier efforts in the same laboratory. The tools developed for this study have been utilized in further driver-vehicle interface studies.

3) *Gain insight into ATIS design improvements*

The study has provided data on contrasting approaches to the integration of voice supplements to ATIS in-vehicle systems. Unlike prior ATIS prototypes, MNA developers selected digitized voice because it provides higher quality sound than machine-like synthesized voice. Digitized voice technology uses recordings of human speakers. With the technology available at the time of the test, it was impractical to digitize the names of all the roads in the ADVANCE coverage area. Therefore, the MNA did not provide street names when it suggested turns.

ADVANCE users indicated that the voice was easily understood, provided relief from distractions, and enhanced feeling of safety over the direction list or paper map. On the other hand, their eye glance and safety performance suggested that the voice did not appreciably change the visual demands or error rate of navigation. Considering the contrasting results of TravTek, there was some indication that with design improvements discussed below, the MNA voice supplement has the potential to further reduce driver workload, yield fewer driver errors, and enhance the safety preference of the participants.

Using ADVANCE MNA voice supplement, drivers reported isolated instances where the timing of the instruction was premature or late. In such cases the driver was forced to hesitate and/or respond irregularly to make the turn, if not actually commit a navigational error. Lengthy text messages, intended to clarify brief aural instructions, were judged disconcerting. Added directional labels, sometimes redundant or conflicting with the prefix of a street name, were similarly confusing.

Timing and directional labels with the TravTek voice supplement were not such an issue. It is reasonable to conclude that replicating the quality of TravTek — in terms of message timing and completeness — would further enhance the performance of the voice supplement relative to the MNA without voice, as well as the other scenarios. The above findings lead to the following recommendations for the design of the ATIS driver interface:

- Include street name information in the voice supplement's directional instructions
- Enhance the consistency and precision in the timing of voice directional instructions
- Limit the length of text messages the driver must process while driving
- Avoid use of directional labels in street names (e.g., North Second Street).

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