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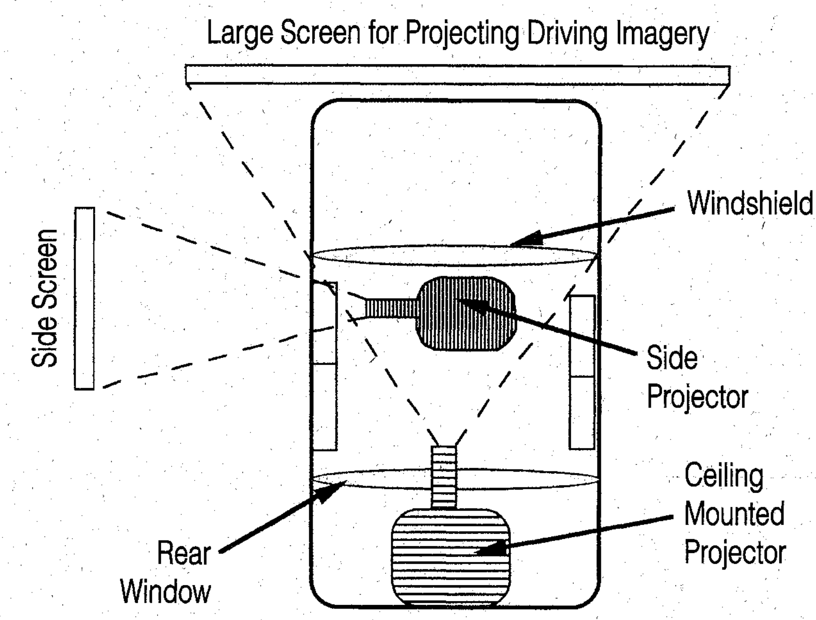

Simulation Layout

Report on Programmatic Evaluation at the Human Factors Research Laboratory

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Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
MN/RC - 95/13		

4. Title and Subtitle	5. Report Date
REPORT ON PROGRAMMATIC EVALUATION AT THE HUMAN FACTORS RESEARCH LABORATORY	March 1995
	6.
7. Author(s) P.A. Hancock, Ph.D., S. Shekhar, Ph.D., M.E. Burrus, R. Stephens	8. Performing Organization Report No.
9. Performing Organization Name and Address Human Factors Research Laboratory Room 141 Mariucci Arena 1901 4th Street S.E. University of Minnesota Minneapolis MN 55455	10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. (C) 69717 TOC #88
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard St.Paul Minnesota, 55155	13. Type of Report and Period Covered Final Report 1993-1994 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report summarizes human factors research for IVHS/ITS projects and focuses on the following five tasks:

- The comparative evaluation of ITS in-vehicle information prototypes. This experiment compares drivers' reaction to the use of three forms of in-vehicle information systems in driving simulation: the Delco prototype, the Volvo Dynaguide prototype, and a procedure that presented a voice generation information system. It includes recommendations for in-vehicle device designs.
- The evaluation of driver response to an in-vehicle ITS technology. This experiment evaluated drivers' responses to information presented on an in-vehicle ITS.
- Geographic databases for IVHS management. This work extends the concept of relational databases to model traffic information in an approach that uses abstract data types and triggers.
- The improvement of simulation facilities. This task describes the acquisition and installation of equipment and software to improve simulation capabilities at the Human Factors Research Laboratory and its impact on research efforts.
- In-vehicle collision avoidance warning systems for IVHS. This experiment examined the effects of presenting warnings of vehicle proximity on turn decisions.

17. Document Analysis/Descriptors		18. Availability Statement
Driver Response IVHS/ITS Technologies Driver Evaluation	Geographic Databases Simulation Facilities Collision Avoidance	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	101	

Report on Programmatic Evaluation at the Human Factors Research Laboratory

Final Report

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March 1995

Published by

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

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EXECUTIVE SUMMARY

Introduction

This report is part of the Minnesota Department of Transportation's (Mn/DOT) Programmatic project for enhancing and developing the Human Factors Research Laboratory's (HFRL) ability to evaluate and provide human factors research for IVHS /ITS projects. This report was divided into five tasks which focused upon areas of ITS research and on Mn/DOT's needs for future evaluation.

Tasks

Task One - The Comparative Evaluation of ITS In-Vehicle Information Prototypes. An experiment is reported which compared drivers reaction to the use of three forms of in-vehicle information systems in driving simulation. Specifically, the work compared the Delco prototype with the Volvo Dynaguide prototype and a procedure which presented a voice generation information system. This work was designed to link with systematic components of the GUIDESTAR program and extend such work to differing user populations and to different information prototypes. Tests were conducted upon Minnesota licensed drivers and driving was evaluated through root mean square error (RMSE) which is a direct measure of vehicle control as represented by lane drift. Results indicated a number of significant effects. With respect to individual driver capabilities, it was found that females had significantly lower RMSE than males, while older driver exhibited significantly larger RMSE than younger drivers. With respect to the in-vehicle information systems, there were significant effects depending upon device type. RMSE was largest with an alpha-numeric display, was intermediate with a graphics display and was lowest with an auditory display. Each device was significantly different in terms of RMSE response from the others. Also, with respect to device type, there were significant modifications in driving performance with respect to male versus female drivers and old versus younger drivers, indicating that different in-vehicle systems have different impacts on differing segments of the driving public. Overall results can be interpreted in terms of a multiple resource model of attention and recommendations for in-vehicle device designs are presented.

Task Two - Evaluation of Driver Response to an In-Vehicle ITS Technology

The present experiment evaluated driver's responses to information presented on an in-vehicle ITS. The system selected was the Indikta RBDS voice system. A simulation scenario was developed in which drivers could receive messages that confirmed or contradicted their own observations of traffic flow at a major intersection. The RBDS information could be correct (that is consistent with respect to conditions) or incorrect (that is inconsistent with respect to conditions). The behavior of concern was the drivers' turn decisions given these different sources of information. Both message and traffic condition were randomized across participating drivers. Thus, conditions which were presented were specific to individuals, although all messages were presented to all drivers. Analysis focused upon descriptive assessment of turn behavior since the randomization procedure did not present controlled replication of conditions, and the absence of feedback with respect to each turn meant that each trial presented a 'new' scenario. Results indicated that the turn decision for information presented on the RBDS system was contingent upon the delay time indicated. There was an inverse relation such that the shorter the communicated delay the lower the compliance rate to the RBDS message and consequently the more drivers relied on the evidence of their own eyes. There were clear individual differences in decision response where some drivers followed visual cues while others did not deviate from a straight route whatever information was presented. Among the latter, turn decisions were made which were contradicted by both visual and RBDS information. Consequently, driver compliance to broadcast messages is neither algorithmic nor necessarily logical. These idiographic behaviors are important to understand since they obviously impact the success of a wide-area RBDS system for traffic control.

Task Three - Geographic Databases for IVHS Management

An IVHS (Intelligent Vehicle Highway System) information management system obtains information from road sensors, city maps, event schedules, etc., and generates information for the use of drivers, traffic controllers, and researchers. We extended the concept of relational databases to model traffic information in an approach using abstract data types, and triggers.

Task Four - The Improvement of Simulation Facilities

The purpose of this task was the acquisition and installation of equipment and software to improve the simulation capabilities at the University of Minnesota, Human Factors Research Laboratory (HFRL). We describe the changes to the facility and the role that the present task component of the contract had in its improvement in order to conduct the research reported in the present work and other allied research efforts on additional Mn/DOT programs.

Task Five - In-Vehicle Collision Avoidance Warning Systems for IVHS

Improving transportation safety is a major rationale for the development of Intelligent Vehicle Highway Systems (IVHS). The heart of such safety efforts center around the development of collision avoidance and warning systems. Collision avoidance systems seek to inform the driver of imminent or impending collision and to present assistance in conflict resolution. Just how such conflict resolution can be enacted has yet to be determined. Various tactics have been suggested. They range from usurpation of control by some automatic system to messaging systems for preferred avoidance maneuvers. The present experiment examined the effects of presenting warnings of vehicle proximity on turn decisions. In addition to the manipulation of the distance threshold for warning, the warning modality was varied such that auditory or visual warnings of differing character were presented. This experiment was performed in simulation, since simulation is currently the most, if not the only, viable option by which such warnings can be safely evaluated. Turns were influenced by the presence of the warning and such behavior varied with the sequential intensity of the warning presented. There is interesting evidence that some warning are taken by individuals to represent a mandatory cue to turn rather than an advisory as to vehicle proximity. This display ambiguity must be resolved for such systems to achieve their stated aim. We conclude that situation specific approaches that appear to be favored in current engineering research are less viable than an envelope approach based on the ecological analysis first posited by Gibson. Resolving and integrating such technology-centered and driver-centered approaches is a critical step if the safety promise of IVHS is to reach fruition.

The Comparative Evaluation of GUIDESTAR In-Vehicle Information Prototypes

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Key Words: Driver Response, IVHS Technologies

Evaluation of GUIDESTAR In-Vehicle Information Prototypes

Introduction

Intelligent Vehicle-Highway Systems (IVHS) have been endorsed as the technological solution which will expand the capabilities of roadway systems. It is also aimed at reducing accidents and congestion and thereby to improve the productivity of travelers by ensuring their safe and timely arrival at their destinations. In one of its original conceptions, IVHS seeks to take advantage of technology transfer from military systems which have begun to scale down following change in the global political situation. One of these arenas in which technology transfer has a direct and immediate application is in-vehicle navigation systems (IVNS). In consequence, one of the most prominent in-vehicle technologies at present are heads-down map-navigation systems which, in their earliest prototypes, are direct copies of infantry navigation systems. The advantage of these systems is that they can be commercialized rapidly. Indeed, there are a number of different systems that have already begun to enter the market both in the United States and abroad. But, there are a number of problems with these systems which have been articulated by, among others, Hancock and Parasuraman (1992) (see also Andre, Hancock, & Smith, 1993). However, a principal problem is that electronic maps only provide static information about current location. Often these immediate environs are routes and neighborhoods that the driver is already familiar with. From the users perspective, a device costing some hundreds or thousands of dollars which is used about as frequently as a paper map, is of doubtful utility. However, if such devices were endowed with more than static capabilities their utility and value would increase significantly. What is required is more dynamic information pertaining to the momentary state of traffic or road repairs or daily closures of roadways. This information would be of daily use to each individual traveler and would promise to add considerable impact to the value of such IVHS technologies.

This approach has been adopted by the Minnesota Department of Transportation (Mn/DOT) in a number of IVHS-related programs including Guidestar and more recently Trilogy. These programs have sought to evaluate the impact of differing commercial systems to be linked with the Mn/DOT Traffic Management Center (TMC). The TMC acts as the unifying entity in these efforts and other related traffic broadcast projects such as the established 88.5 Traffic Radio KBEM station and the more recent GENESIS program. Each of these are part of the overall systems approach to Minnesota IVHS. In allied work, we have evaluated some aspects of in-vehicle technologies. The purpose of the present work was to expand the scope of that effort to include a new form of technology and evaluation of a wide-range of potential users under a number of differing driving conditions with the purpose of informing Mn/DOT of the value and efficacy of such systems from the drivers' viewpoint.

In-Vehicle Display Technologies

Traditional in-vehicle display technologies provide information concerning vehicle status but rely upon the driver and traditional signage to accomplish the basic task of getting from A to B. Indeed, because of the vast emphasis upon visuo-motor control, it is quite feasible to operate a vehicle with no in-car displays whatsoever. In reality, some form of gas gauge is necessary but only when gas is low. This observation indicates the importance of the out-of-the-window aspect of driver control. Over a period of time, some in-vehicle information concerning conditions beyond immediate sight became possible. Principal among these is the radio but more recent expansions into variable message signs also gives the alert driver the chance to find out what was going on 'around the next corner.' Today's information explosion promises much greater real-time access to all traffic conditions in an urban area. The problem being, the more attention is directed to distant concerns along the route, the greater the competition for attention in the immediate present. This problem is exacerbated by the fact that much of the new information is proposed to be delivered visually also, thus attracting visual attention inside the vehicle. The purpose of the present experiment was to perform pairwise comparisons of differing forms of display technology that permits the presentation of real-time traffic information to differing sensory modalities, e.g., vision and audition. This work was accomplished in simulation since on-road evaluation can be problematic if some form of simulation evaluation has not preceded it to indicate potential problems.

Purpose of the Present Experiment

Therefore, the specific purpose of the present experiment was a pairwise comparison of in-vehicle information systems under a variety of driving conditions with a broad spectrum of road users. The consequence of these combination of conditions is that conclusions drawn would apply to the driver population of Minnesota and other states. Recommendations are made in terms of traffic congestion, accident reduction, and user acceptance.

EXPERIMENTAL METHOD

Experimental Participants

The experimental participants were all licensed drivers in the State of Minnesota. They were chosen from a pool of eighty subjects that sampled, based upon their gender and age. Ten subjects from each group were randomly selected as well as a representative group of ten subjects from the entire pool to drive on the three driving segments and to test the three delivery systems. Their details are presented in Table 1.

Table 1.

Group	Number of Participants	Mean Age	Range of Age
Males	10	28.7	22 to 40
Females	10	25.2	21 to 31
Young* (<39 y/o)	10	23.9	21 to 25
Older* (>40 y/o)	10	56.6	41to 67
Segment Drivers#	10	33.2	21-55

* Evenly divided between males and females

\# Segment Drivers were evenly selected from the gender groups and of both age classes

All Participants were licensed unrestricted drivers in Minnesota

Experimental Procedure

The participant was welcomed into the Human Factors Research Laboratory (HFRL) and was informed of the general purpose of the experimental procedure. The participant then signed the subject consent form as an indication of their acceptance of participation. The participant was then given a fuller briefing on the specifics of the task as described below. The participant then completed a survey questionnaire which elicited details concerning their characteristics and their previous driving experience. The subject was then introduced to the simulation facility and given the opportunity to familiarize themselves with the controls and operation of the driving environment. They were then instructed on the use and functions of the various information delivery systems if they were to be tested on them. This required familiarizing the participants with the basic functions, and how to controls the information flow. Participants were given sufficient practice time to become familiar with each receiver and were statically tested as to their ability to operate, elicit information, and comprehend the messages.

At this juncture, the participant was asked if they were ready to commence the experiment which, on affirmation, was then begun. As illustrated in Figure 1, the participant was requested to driver the vehicle at a constant 55 mph. down a straight road against traffic toward the simulated down-town Minneapolis. Upon reaching an intersection with a stop sign, participants were requested to turn left across on-coming traffic. Having completed this maneuver, they continued down the straight road also with traffic to the next intersection which did not have a stop sign. At this intersection, they made another left-turn and again continued straight driving. While on this final component of the route, participants were asked to catch up to traffic in front of them and pass one of the cars ahead. On the first leg of the route, heading toward downtown, vehicles approached the driver in the other lane. This represented a typical two-way street configuration. When they turned onto the final element of the route, vehicles were traveling alongside and with them representing a freeway environment. Thus the three roadway traffic conditions covaried with the three roadway segments in an ecologically valid manner, i.e., the more extensive the roadway the greater the traffic. While driving this course, with these conditions, participants were asked to operate the traffic information devices, which are described in greater detail below. First, however, is a brief resume of the current simulation facility used in the Human Factors Research Laboratory (HFRL). As this facility has been used in numerous different experimental procedures, the following paragraph represents an overview that has been reproduced in a number of places.

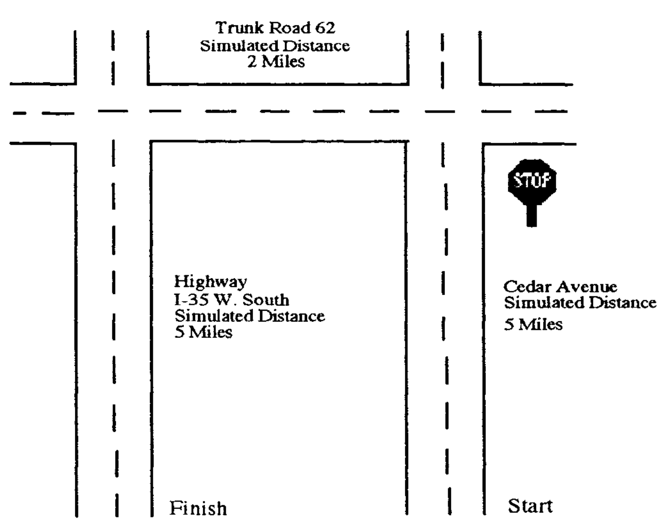

Figure 1. *Dynamic driving world indicating the start, route, and finish of the experimental environment. Note that the simulation s designed to accord with major roads and freeways of the Twin Cities Metro area to provide experimental participants with a frame of reference and to evaluate differing major driving conditions.*

Experimental Facility

i) The Simulation Facility

The Human Factors Research Laboratory's (HFRL) driving simulation facility is based upon a fixed-based Honda 1990 Accord model. Inputs from the driver, in terms of accelerator and brake activation and steering are converted from analog to digital inputs. These are used as information which is fed to a computer model which approximates the vehicle itself. Outputs from this model are then used to adjust the eye point of the driver in the environment in accord with the inputs given. These changes are then displayed in real-time. Calculations of such change proceed at least 15 times per second. In most simulation experimentation cycle times of 30Hz are exceeded. Above this value, the perception of the driver is one of actual driving. Scene fidelity is controlled by the number of objects to be displayed. The greater the number of objects, the greater the calculational load and the lower the possible updating rate for any one fixed computer system. A schematic side-projection of the actual facility is shown in Figure 2.

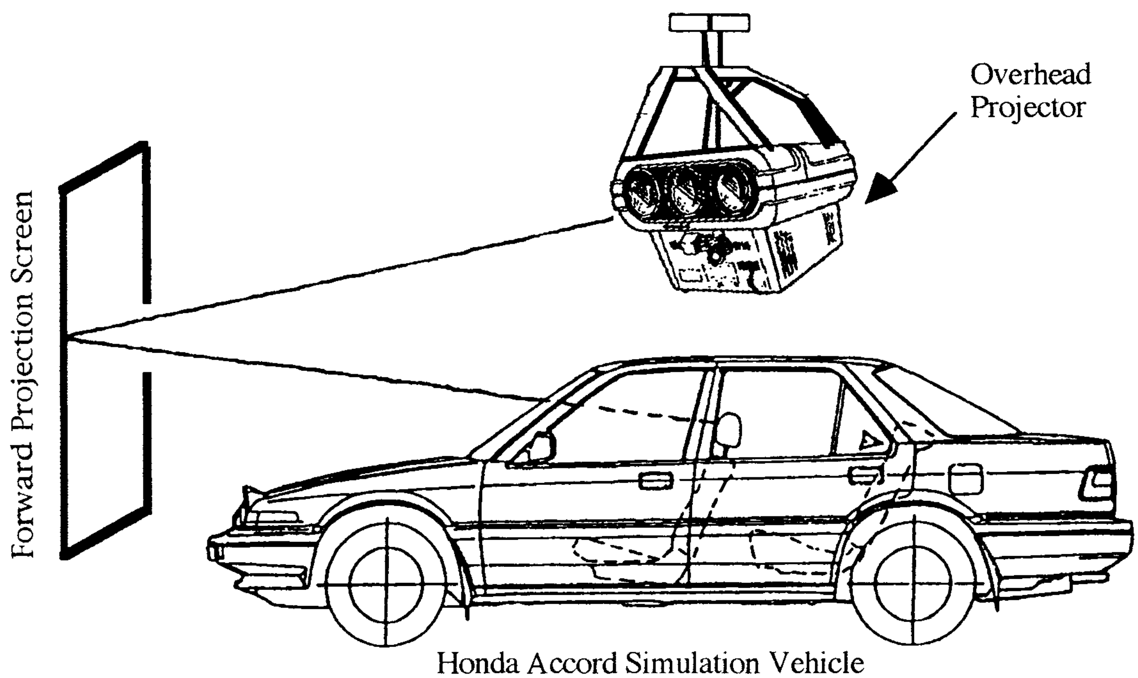

Figure 2. *Side projection view of the simulation facility illustrating the Honda 1990 fixed-position vehicle, the overhead projection system and the screen orientation and driver visual viewing angle.*

In-Vehicle Information Systems

ii) The Volvo Dynaguide System

The Volvo Dynaguide system is composed of a RBDS receiver and an attached screen, see Figure 3 The screen is capable of displaying a map of the Twin Cities Metro Area as well as symbols and text. Real time traffic information is sent to the receiver vie RBDS-TMC by the Mn/DOT Traffic Management Center. The screen displays a map and places icons representing accidents, constructions, delays, and other traffic information as well as arrows showing flow of traffic onto the effected highways. The driver can locate their planned route and note if any icons are displayed on the highways they plan to take. If so, the driver can highlight the icon and receive a text message describing the traffic event in full.

iii) The Delco System

The Delco system is a text screen system that is solely contained on the receiver, see Figure 4. RBDS messages are broadcast directly to the receiver which places lines of text upon the LCD screen attached to the front plate of the radio receiver. Eight lines of text can be scrolled through relaying traffic information to the driver. This unit features no route planning or filtering of the messages received.

iv) The Voice Presentation System

The simulated voice system consisted of a RBDS receiver that could alert the driver to traffic problems by having a digitized voice relay the first part of a message over the radio's speaker system, see Figure 5. If the short voice message was relevant to the driver they could read the message displayed on a text screen on the receiver (similar to Delco's text screen).

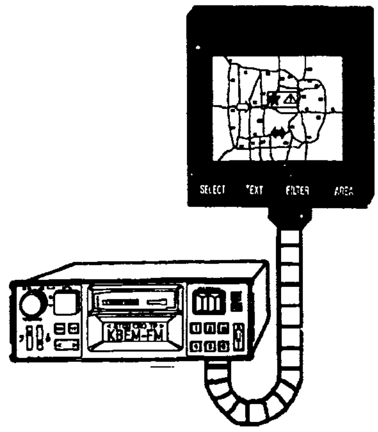

Figure 3. *The Volvo Dynaguide, receiver. Accepts input messages and displays them as a graphics representation imposed upon a Twin Cities Metro representation. As a graphics display, the messages are mainly iconic representations although text is also available for detailed message communications.*

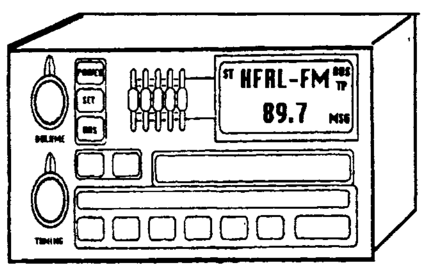

Figure 4. *The Delco RDS prototype system. Based upon a standard Delco radio system, this device also possesses the ability to present lines of alpha-numeric information. as illustrated.*

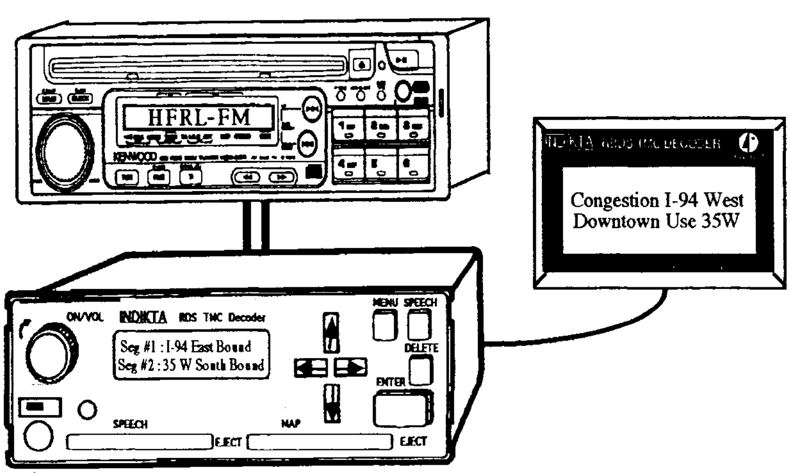

Figure 5. *The Indikta RBDS system generates an auditory display from the same basic information that is broadcast . The general conception of the system is similar to Radio Broadcast such as 88.5KBEM.*

Experimental Task and Design

In the present experiment, we measured the safety and driving performance of a sample of licensed drivers. We selected ten drivers for each of the following categories: Younger (<40 years of age), Older (>40 years of age), Male, and Female. We then tested them using one of three types of traffic information delivery systems and on three types of roadways. The traffic information systems included a text screen radio with eight characters of text on two lines with a maximum of four screens (the Delco receiver), a graphic map screen of the Twin Cities (the Volvo Dynaguide receiver), and a normal radio with a voice box relaying traffic announcements (KBEM taped traffic announcements). The participants were then tested with the dynamic driving simulator at the Human Factors Research Laboratory which employs simulated driving worlds. This simulated environment was representative of the Twin Cities Metropolitan roadways, included driving with and against traffic and maneuvers typical of driving including: merging into traffic, taking a left turn across traffic, and passing cars in front of the drivers. The simulation had three driving segments: (i) The first was a two lane rural street with traffic flowing in north and south directions. We have named this Cedar Avenue. (ii) The second segment consisted of urban traffic on a "Trunk" highway with traffic flowing freely with the driver. We have named this I-62 (Cross-town Highway). (iii) The final segment consisted of urban highway traffic with congestion and traffic flowing with the driver. Cars on this segment slowed to 40 M.P.H. and drivers were instructed to follow and then to pass the cars in front of them. We named this I-35W (southbound). The measure of performance was drift from the centerline of the participants car which was measured as RMS (Root Mean Square) error. This is measured in thirds of a meter as a function of the sampling rate and the frame rate of the simulation. It was measured by determining the area of participant's vehicles deviation from the center line of the simulated roadway and was collected every tenth of a second. Other variables collected included deceleration/acceleration changes, braking changes when stopping, and observable driver performance degradations. The simulation has a stop sign, and a left turn across traffic to provide complexity and other observable measures.

EXPERIMENTAL RESULTS

RMS error was measured as each driver proceeded on each segment using each device. We scaled data so that the X axis is the center of the lane driven as this gives us the best pictorial representation of actual deviation from the driver's perspective. Within some of the participant's data, we noticed that certain drivers are always to the positive side of this zero line. This is due to an individual driver's preferences to drive a few inches to a foot away from the center line. We all have our own margin of comfort where we like to drive near or farther from oncoming traffic. Often after participants begin to operate the information devices, they will wander over to the negative side of the center line. This represents abnormal driving behavior as normally drivers tend to stay away from the oncoming traffic lane. The more frequently the peaks and valleys appear in an RMSE graph the greater this translates to driving lane-drift.

The data was analyzed by using an Analysis of Variance Model (ANOVA) and yielded the following results. First, analysis was conducted on root mean square error by driving segment. That is, an evaluation was made to distinguish whether there were any intrinsic effects of the baseline driving segments themselves. Such analysis indicated no such differences, assuring that the segments were equivalent in terms of driver control response. We also examined the effects of driver characteristics upon vehicle control. For the effect of gender, there were significant effects such that males exhibited a significantly higher degree of lane drift than their female peers. Whether this is related to exploratory behavior, risk taking, or an intrinsic gender difference requires further evaluation. We also evaluated the effects of age and found that the older drivers, 40+ had a significantly higher RMSE than their younger peers. Again, whether this is a fundamental property of age or whether it is due to some additional factor such as skill with simulated driving deserves further evaluation.

Perhaps the prime concern of the present work is the pairwise comparison of the in-vehicle information systems as they influence driver control. Analysis did distinguish between the three devices investigated. Results showed that use of the Delco system generated the largest degree of RMSE, the Volvo system which presented a graphic map display generated the next lowest RMSE and the voice generation system produced the lowest RMS error. Each of the pairwise comparisons were significantly different. These findings are in direct agreement with the Wickens (1980, 1984) notion of distributed attentional resources. That is, since the three devices place differential demands upon visuo-spatial capabilities, which are the primary method used for vehicle control, the more they interfere with control. The basic lesson here is one that has been postulated upon theoretical grounds and is again confirmed by empirical evaluation, that is, distribute processing load across sensory and cognitive abilities as much as possible to reduce structural (that is physical) interference and functional (that is cognitive) interference.

Table 2. Results of the Vehicle Control Capability by Subject and Condition.

Seg 1	Seg 2	Seg 3	Female	Male	Delco	Volvo	Conv.	Young	Older
.562	2.65	.019	.562	2.605	1.117	.734	.569	-.181	1.547
.077	1.023	.665	.931	2.465	1.299	1.092	.092	.175	.649
.282	.618	.623	.077	1.372	1.314	.715	.16	.115	.852
1.6	.861	2.032	1.628	2.034	1.343	.777	.445	.252	.561
-.082	1.152	.702	.808	1.472	1.507	1.588	1.085	-.053	.478
.422	.077	1.112	.982	1.252	.727	.604	.201	.422	1.728
.265	.178	-.155	.282	1.002	1.116	.971	.762	.077	-1.493
2.455	1.843	2.619	.618	1.059	2.394	2.18	1.122	.951	1.231
1.547	.649	.852	.912	1.111	1.891	1.524	.874	.238	1.843
-.103	-.454	.111	1.12	.951	1.728	.856	.713	.403	2.533

We found significant interactions between two elements in the experimental design. Each of the interactions involved the type of in-vehicle device being used. The first interaction is illustrated in Figure 6.

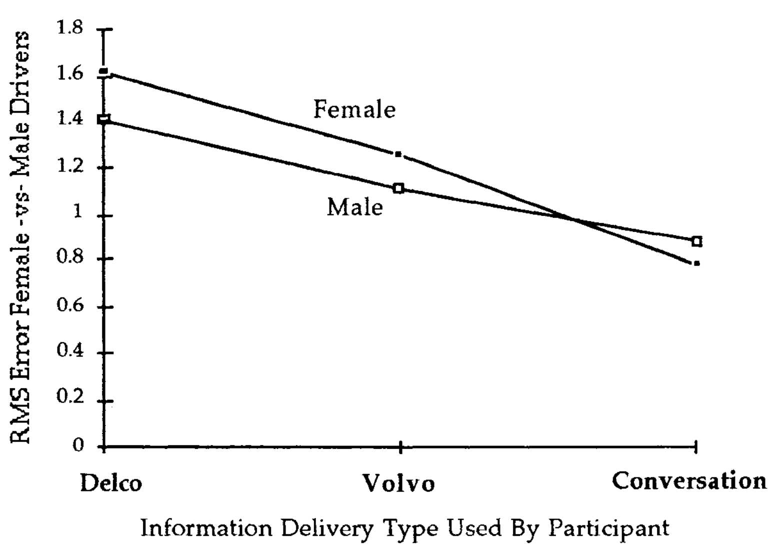

Figure 6. *Interaction between Device type and subject gender.*

This shows that the advantage that is demonstrated by male subjects when working with alpha-numeric and graphic systems is reversed when working with auditory systems. This finding is not unsurprising given the know differences between males and females in terms of spatial cognitive processing. We should also note that despite this interaction, the auditory system is still the best in terms of driving capability. The second interaction is between age and driving device. As can be seen from Figure 7, the older participants exhibited almost twice the RMSE using the alpha-numeric device compared with their younger peers. This difference disappears as the change is made to graphic representation and is reversed when a subsequent change is made to auditory display. Again, as with the main effect, auditory displays are the best for older individuals and second best for the younger drivers. We attribute this effect to experience. It might be expected that younger drivers have more experience interacting with complex technologies and representations that are similar to video-displays. However, when we get to auditory displays with which older drivers are familiar then this difference is negated.

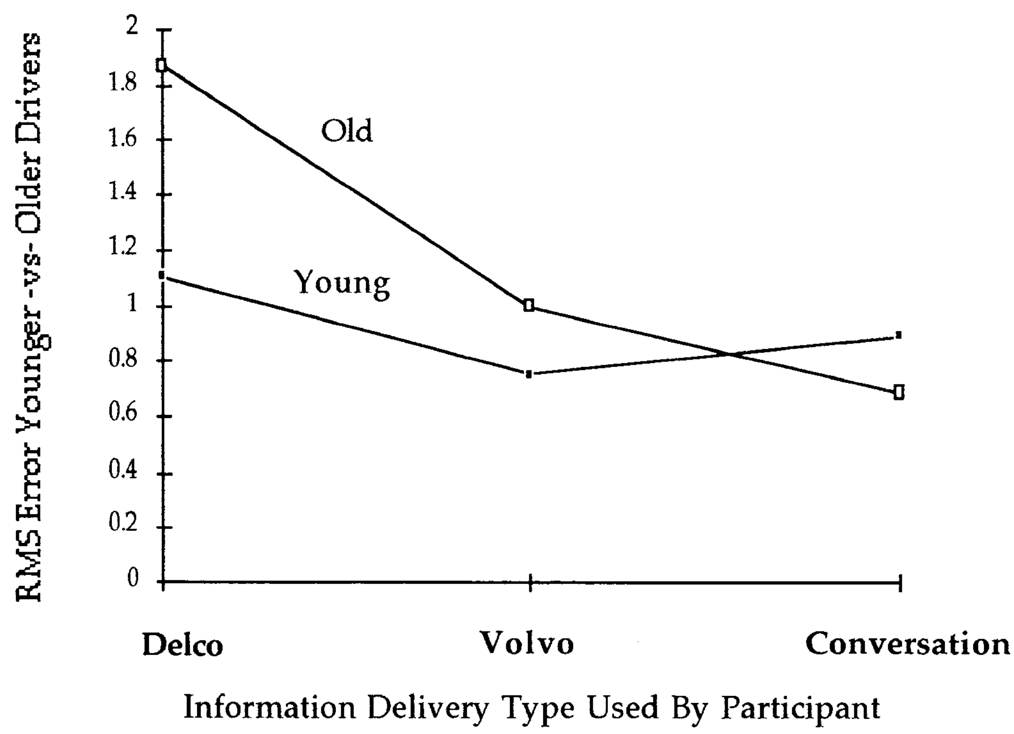

Figure 7. *Interaction between driver age and driving device.*

DISCUSSION

The present findings present a most interesting picture. First, they provide empirical confirmation that not all in-vehicle devices produce the same effects upon driver vehicle control. Second, they confirm that there are large individual differences in driver response and that any implementation procedure of IVHS technology must critically evaluate the whole spectrum of the user population. Third, they confirm that differences in design characteristics have a direct influence upon driver vehicle control. It is these central points that elaborated in discussion.

At present, there is a precipitous proliferation of IVHS technologies. While some of these affect the driver only indirectly, such as remote traffic observation techniques, the first real contact that most drivers will have with IVHS technologies will be those technologies that are located in private vehicles. For this, if no other reason, the impact of these ground-breaking technologies should be positive since many individual will not discriminate between different forms of IVHS and may reject the whole of the concept of IVHS based upon one single bad experience. However, there is a more fundamental reason than preference and acceptance and that is safety. IVHS has been touted as perhaps the major effort to reduce accidents and injury upon the roadways. If, however, in contrast, certain in-vehicle technologies compromise safety, we have clearly failed in one central mandate and have acted to endanger travelers. What the present findings confirm is that indeed, the addition of these technologies do affect driver behavior in he form of vehicle control. At some juncture, we must comment upon whether these effects are marginal or significant. In essence, we must distinguish whether the significant differences that are reported are substantive enough to cause concern. That is, 'a difference is only a difference if it makes a difference.' This concern is addressed below.

One of the main concerns for all of IVHS is the vast spectrum of individuals who will have to operate the highly advanced systems that are being proposed. In a society where setting the VCR has become a leitmotif for all that is unfriendly about technology, we cannot place similar levels of sophistication in the vehicle without expecting comparable problems. In essence, if individuals are unable to program systems at length in the comfort of their own homes, what makes us sanguine about their ability to perform the same function in dense traffic going 50 mph. The present results speak to this issue with a confirmation of wide individual differences embedded in some classic differentiates such as age and sex. If these represent veridical differences it argues strongly for some individualization or personalization of in-vehicle devices in the same way that the physical ergonomics of vehicles are now being conceived. To accomplish such an aim, there is a strong mandate to use adaptive interface technology which has begun to make an impact in other realms of advanced transportation such as aviation. Briefly, this position argues that the interface is the responsible entity that translates the needs and intentions of the driver into appropriate control actions. Similarly, the intelligent interface sits between the vehicle and the driver to present status information in an appropriate manner for driver assimilation. The concept of adaptive systems and intelligent interfaces has been discussed at length elsewhere and has been proposed as an answer to the problems of driver overload, as indicated in the control problems found with the present systems.

Finally, the present result support a theoretical position that is based in the literature on divided attention. After Kahneman (1973) had proposed to deal with attention as a resource, rather than a filter or limitation on an information-processing sequence, there arose a shift in the way that divided attention task were conceived. Rather than considering serial or multiplex types models, a parallel conception arose in which task 'competed' for a single, unitary attentional resource. This simple conception failed to capture situations in which two task were performed together with no appreciable degradation in either, that is 'difficulty insensitivity.' Wickens (1980, 1984) extended the model to incorporate stages of processing, modalities of processing and codes of processing. Stages such as encoding, decision-making and response execution were identified, while modalities such as vision and audition predominated. Codes of processing included graphics and alpha-numerics. This position predicts that as tasks compete for common resources, say the visuo-manual resource track, then two tasks requiring a common resource are performed worse together. In the present findings, the tasks competing for visual-manual resources were driving, a constant, an operating the devices. As is evident in the results, as a device used other modes, e.g., audition, there was less effect on driving. There are a number of theoretical problems with the multiple resource model which are not advanced here. However, suffice it to note that the physical interference of using the eyes to do two tasks is as much an 'explanation' as the limited central cognitive resource conception. This does not disguise the fact that sharing demand around between limbs, voice and sensory abilities is still a perfectly reasonable design criteria. On the 'physical interference' argument alone, the distribution of in-vehicle demand to audition and voice input is still a strong design imperative. This is especially the case in light of the findings of differences by user group in terms of age and gender.

APPLICATION TO THE MINNESOTA DEPARTMENT OF TRANSPORTATION

Congestion Reduction

The principal purpose of In-Vehicle Information Systems (IVNS), with respect to the Department of Transportation, is the reduction of congestion. The assumption is made that is timely and accurate information is provided to individuals drivers, they will use this information to avoid congested areas and thus re-route flow to provide a more even traffic distribution. This assumption has several parts. The first part is that timely and accurate traffic information is able to be communicated. At present this is somewhat problematic as some real-time broadcast information is intermixed with information of different time-scale such as that presented on electronic variable message signs. As we have pointed out, the accuracy of the information is vital to compliance. Already a number of user questions have been raised, especially with reference to out-of-date messages on variable message signs in the Twin City Metro area.

Assuming that timely information is provided, can drivers pick it up. The present results suggest that auditory information is much more easily assimilated and potentially, therefore, much more likely to be used than that from visual sources, especially when small, heads-down, alpha-numeric displays are involved. Our recent research on compliance further suggests that the transmission of quantitative information is beneficial. However, if presented upon alpha-numeric displays it would take considerable time and effort to assimilate and would interrupt driving during that time. In essence, the present results suggest that some 'low-tech' auditory displays might be the preferred way of communicating real-time traffic information to drivers. As such it argues for further support of services like KBEM and technologies that can select, store, and reproduce such auditory messages on demand. Solving the question of route-specific messaging, that is only presenting information relevant to a driver's current route is one that needs further research.

Accident Reduction

As well as the foregoing, some observations need to be made on safety. Driving safety, and the absence of that safety in accidents, is a complex issue. It is not the case that we can extrapolate accidents as an extension of poor driving control. For example, excessive lane-drift will be communicated to other drivers. Hence, adaptive adjustments are made on the roadway to driver who are performing poorly. As a result, there is no simple formula which extends RMS error, as measured here, into accident events. What we can note is that greater competition for visual attentional resources is liable to prove a distraction for the driver. Again, we cannot assert that increased distractions simply lead to accidents, they do not. However, it is suspected that attention is a vital factor in accidents and this is one element of the story that has to be given some prominence. As a recommendation, we have suggested the superiority of auditory displays. This does not mean some other configurations such as heads-up displays cannot be used also. However, with respect to accidents, it is vital that technologies introduced into the vehicle do not increase the likelihood of an accident. Again, this is a research area that needs more extensive work.

User Acceptance

What do drivers think of the systems that we have tested them on? With respect to performance, it is clear that the most broad spread acceptance in terms of driving with such devices favored the auditory display. However, individual comments on systems are also pertinent. A post simulation questionnaire was administered to assess the opinions on using the information delivery systems and the simulator.

The survey was divided into sections which aimed at trying to find specific areas of interest. The first area was Usage Patterns. We tried to assess how often participants used their normal radio, and if they listened for traffic announcements on a regular basis. The second section focused on Learning to Use the devices tested. We tried to assess if the participants truly understood how to operate the radio and drive the simulated car. This helps in developing better testing procedures and can be used to improve instruction and training. Next we assessed the Procedures and Functions of the simulation study. This was to determine how difficult or easy the devices are to operate from the participants standpoint. We also inquired how the participants felt as to their own attention to driving and to the traffic messages. The fourth section had questions on Clarity and Visibility. We questioned if participants can not read the messages due to lighting conditions or could not understand the messages due to abbreviations. The final questions were an overall evaluation. We ask participants to compare in-vehicle devices like the one they have just used to listening to radio traffic announcements. We also ask them which type of information they would trust, text messages or radio announcements.

The most interesting results from the survey concerned usage. The subjects were asked what percent of the time the radio was on when they drove their car every day. The average response was 91% of the time. However, only 38% of the subjects reported that they listened to the radio specifically for traffic announcements. The Delco , Volvo, and Indikta receivers were rated as being normal to operate on a scale where choices ranged from easy to difficult. This implies that the majority of subjects felt it was not much harder than operating a normal radio. We should note that participants were only taught one task, not all of the features available on each system. In contrast, only 23% of the participants felt that they were able to keep their eyes on the road the same amount of time that they do when they normally drive and operate a radio. This implies that they felt they were looking down at and concentrating on the radio to a much greater extent than normal. This is expected due to the time it takes to look down and read messages. On a similar question subjects felt that their attention was spread too thinly and felt that the radio distracted them from driving “occasionally to half the time“.

During the Clarity section several participants found it hard to understand some of the abbreviations that were used. Also, some said it was hard to distinguish between N and W on the Delco radio.

Overall assessment found that 85% of the participants said that they would not buy these systems if all they did was to provide additional traffic information on a screen. Interestingly, over half said that they would believe the radio screen for giving accurate traffic information over a radio announcement. This contradicted the finding that only one third said they would pay more attention to the radio screen over the radio station announcement. This means they are willing to believe what they read over what they hear on a radio, but are not convinced that they would use the screen as often as listening for occasional traffic messages.

Finally operator preferences were assessed and revealed a greater subjective satisfaction for the Dynaguide Iconic Map and Indikta Voice system. (Map > Voice > Text). This was primarily due to ease of use and decreased distractions from driving. Participants preferred the Voice synthesis for prompting, and Iconic Map system for interaction. Over-all, drivers preferred the expanded text screen on the Iconic Map over the limited truncated messages of the other two systems. Most participants expressed annoyance over the tremendous amount of irrelevant information received on the text and voice screens, preferring to be able to filter or select relevant messages on the Dynaguide Map.

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APPENDICES

One Factor ANOVA-Repeated Measures for X_1 ... X_3

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	9	13.547	1.505	4.031	.0045
Within subjects	20	7.467	.373		
treatments	2	.163	.081	.201	.8199
residual	18	7.304	.406		
Total	29	21.014			

Reliability Estimates for- All treatments: .752 Single Treatment: .503

One Factor ANOVA-Repeated Measures for X_1 ... X_3

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Seg. #1	10	.702	.864	.273
Seg. #2	10	.86	.894	.283
Seg. #3	10	.858	.879	.278

One Factor ANOVA-Repeated Measures for X_1 ... X_3

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Seg. #1 vs. Seg. #2	-.157	.599	.152	.552
Seg. #1 vs. Seg. #3	-.155	.599	.149	.546
Seg. #2 vs. Seg. #3	.002	.599	1.780E-5	.006

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_2$

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	9	3.04	.338	.699	.6991
Within subjects	10	4.832	.483		
treatments	1	2.74	2.74	11.791	.0075
residual	9	2.092	.232		
Total	19	7.872			

Reliability Estimates for- All treatments: -.43 Single Treatment: -.177

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_2$

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Female	10	.792	.439	.139
Male	10	1.532	.615	.194

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_2$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Female vs. Male	-.74	.488*	11.791*	3.434

* Significant at 95%

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	9	4.605	.512	2.278	.0601
Within subjects	20	4.492	.225		
treatments	2	3.583	1.791	35.454	.0001
residual	18	.91	.051		
Total	29	9.097			

Reliability Estimates for- All treatments: .561 Single Treatment: .299

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Delco	10	1.444	.467	.148
Graphic Map	10	1.104	.505	.16
Conversation	10	.602	.374	.118

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Delco vs. Graphic Map	.34	.211*	5.703*	3.377
Delco vs. Conversation	.841	.211*	35.019*	8.369
Graphic Map vs. Convers...	.502	.211*	12.459*	4.992

* Significant at 95%

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_2$

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	9	6.731	.748	.966	.5164
Within subjects	10	7.747	.775		
treatments	1	2.835	2.835	5.195	.0486
residual	9	4.912	.546		
Total	19	14.478			

Reliability Estimates for- All treatments: -.036 Single Treatment: -.018

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_2$

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Young (<40)	10	.24	.312	.099
Older (>40)	10	.993	1.094	.346

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_2$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Young (<40) vs. Older (>4...	-.753	.747*	5.195*	2.279

* Significant at 95%

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_{10}$

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	9	11.751	1.306	2.634	.0094
Within subjects	90	44.613	.496		
treatments	9	13.224	1.469	3.792	.0005
residual	81	31.389	.388		
Total	99	56.364			

Reliability Estimates for- All treatments: .62 Single Treatment: .14

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_{10}$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Delco vs. Graphic Map	.34	.554	.165	1.219
Delco vs. Conversation	.841	.554*	1.015	3.022
Delco vs. Seg. #1	.741	.554*	.787	2.662
Delco vs. Seg. #2	.584	.554*	.489	2.097
Delco vs. Seg. #3	.586	.554*	.492	2.103

* Significant at 95%

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_{10}$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Delco vs. Female	.652	.554*	.609	2.341
Delco vs. Male	-.089	.554	.011	.319
Delco vs. Young (<40)	1.204	.554*	2.077*	4.324
Delco vs. Older (>40)	.451	.554	.291	1.619
Graphic Map vs. Convers...	.502	.554	.361	1.802

* Significant at 95%

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_{10}$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Graphic Map vs. Seg. #1	.402	.554	.231	1.443
Graphic Map vs. Seg. #2	.244	.554	.086	.878
Graphic Map vs. Seg. #3	.246	.554	.087	.884
Graphic Map vs. Female	.312	.554	.14	1.121
Graphic Map vs. Male	-.428	.554	.263	1.538

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_{10}$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Graphic Map vs. Young (<...	.864	.554*	1.071	3.104
Graphic Map vs. Older (>...	.111	.554	.018	.399
Conversation vs. Seg. #1	-.1	.554	.014	.36
Conversation vs. Seg. #2	-.257	.554	.095	.925
Conversation vs. Seg. #3	-.256	.554	.094	.918

* Significant at 95%

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_{10}$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Conversation vs. Female	-.19	.554	.052	.681
Conversation vs. Male	-.93	.554*	1.24	3.341
Conversation vs. Young (...	.362	.554	.188	1.302
Conversation vs. Older (>...	-.391	.554	.219	1.403
Seg. #1 vs. Seg. #2	-.157	.554	.035	.565

* Significant at 95%

One Factor ANOVA-Repeated Measures for X_1 ... X_{10}

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Seg. #1 vs. Seg. #3	-.155	.554	.035	.559
Seg. #1 vs. Female	-.089	.554	.011	.321
Seg. #1 vs. Male	-.83	.554*	.987	2.981
Seg. #1 vs. Young (<40)	.463	.554	.307	1.662
Seg. #1 vs. Older (>40)	-.29	.554	.121	1.043

* Significant at 95%

One Factor ANOVA-Repeated Measures for X_1 ... X_{10}

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Seg. #2 vs. Seg. #3	.002	.554	4.143E-6	.006
Seg. #2 vs. Female	.068	.554	.007	.243
Seg. #2 vs. Male	-.673	.554*	.649	2.416
Seg. #2 vs. Young (<40)	.62	.554*	.551	2.226
Seg. #2 vs. Older (>40)	-.133	.554	.025	.478

* Significant at 95%

One Factor ANOVA-Repeated Measures for X_1 ... X_{10}

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Seg. #3 vs. Female	.066	.554	.006	.237
Seg. #3 vs. Male	-.674	.554*	.652	2.422
Seg. #3 vs. Young (<40)	.618	.554*	.548	2.22
Seg. #3 vs. Older (>40)	-.135	.554	.026	.485
Female vs. Male	-.74	.554*	.786	2.659

* Significant at 95%

Evaluation of Driver Response To An In-Vehicle ITS Technology

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Running Head: Driver Evaluation, ITS Technologies

INTRODUCTION

Intelligent Transportation Systems (ITS) technologies are entering the marketplace at an phenomenal rate. Already complex technical capabilities like heads-up displays (HUD's) are available on private automobiles in the United States (see Eliasson, 1994; Inuzuka, Osumi & Shinkai, 1991). One major manufacturer has sold over 30,000 units of a vehicle navigation system in Japan and is expecting similar market penetration in the United States upon release. The purpose of each of these technologies is a common one. They seek to promote safer and more efficient transport by aiding with the driving task (Hancock, Dewing & Parasuraman, 1993). In-car information systems present the driver with their present location, destination, and alternate route options to that destination (Konig, Saffran, & Langbein, 1994). These forms of in-vehicle technologies are emerging rapidly since they represent a direct transfer of technology from military capabilities, especially those related to infantry operations. However, they provide only a static perspective on the roadway conditions. They are helpful in unknown regions or if the driver has to make many trips to different locations. Thus, the penetration of these technologies is expected in commercial businesses such as taxis and delivery companies, and in the private sector in specialized pursuits such as recreational vehicle (RV) usage.

However, there are several reasons to expect that map navigation systems alone will not be particularly attractive to buyers, especially private vehicle owners. First and foremost, drivers simply don't drive in unknown areas very often. That is, the vast majority of use of any vehicle is in areas that the driver knows. Second, these systems are costly and have to be maintained, they can rarely keep up with changes in roadways in terms of database change and even if they do, they have to be updated by downloading new material. However, most importantly, they give no information as to current travel conditions. Therefore, to obtain the full benefit from in-vehicle information systems, some form of real-time information about traffic conditions needs to be presented. The present work focuses upon these dynamic facets of in-vehicle information presentation through the evaluation of a contemporary Radio Broadcast Data System (RBDS). (see also Vaughan, May, Ross, & Fenton, 1994)

There are several ways to present real-time traffic information. These alternatives include different technologies to collect, format, and broadcast such information. Each of these stages, data collection, integration, and broadcast, are critical to the success of a real-time traffic control system. They are, in large part, functions of advanced traffic management systems (ATMS) (see also Folds, Kelly, & Mitta, 1994; Kelly & Folds, 1994). Consequently, the collection, integration, and broadcast are not addressed in the present work but are taken as already operational. The focus here is on the in-vehicle presentation of information and the drivers' response to such information. But, since the collective systems nature of ITS is critical and the architecture which supports this function is also a key issue, some characteristics of collection, integration, and broadcast are referred to as they affect the individual driver in the assimilation and use of such broadcast messages.

With respect to in-vehicle displays themselves, information can be given to the driver in a number of ways. These depend directly upon sensory modalities. The primary sensory modality is vision. In driving, it is clear that vision is critical. Indeed, the only current sensory assessment for driver licensure is static visual acuity. There is the propensity to overload vision in driving since most traditional displays are visual and the critical task of the driver is the use of visual attention with respect to the driving environment itself (Hancock & Parasuraman, 1992; Owens, Helmers, & Sivak, 1993). Cognizant of this propensity to visual overload, the present experiment examined the Indikta Radio Broadcast Data System (RBDS) which provides voice synthesis of messages over the car's radio speakers. This system also provide a redundant visual representations of traffic information on a display pod but the use of this component was not emphasized here. Therefore, the primary message delivery system was in the auditory mode. Although audition does not demand visual attention, it does have some of its own intrinsic drawbacks. Audition is serial in the sense that information is presented as a stream and missing one component of the stream can be highly disruptive. Hence, in the present experiment drivers were able to examine the visual display if they missed part of the voice synthesized message.

In light of these general observations, the purpose of the present study was to examine drivers response to RBDS information when such information either confirmed or disconfirmed the evidence before the drivers' eyes. This was accomplished by assembling messages with the Crusader software package to send to the Indikta RBDS device while participants were driving in the HFRL dynamic driving simulator. The specific evaluation thus assessed trust in the information as a function of driving condition and message content. If a driver saw congestion on the road ahead, and was told "no traffic problems exist", which source of information (their own observations or the RBDS data provided information) do they follow? This is one facet in the general question of 'trust' in automated systems which has been the subject of recent extensive study (see for example Lee & Moray, 1992; Riley, 1994)

EXPERIMENTAL METHOD

The Simulation Facility

Simulation allows the measurement of driver reaction and response to information received from an ITS device in a safe and efficient manner. The Human Factors Research Laboratory (HFRL) driving simulator allows the experimenter to observe the simulation vehicle and also view the driving world and record the driver's reactions, see Figure 1. Thus, it is possible to evaluate how a participant reacts to, for example, a message concerning congestion or an accident ahead. Drivers can brake, they can turn to an alternate route, or they can choose to ignore the message based on what they saw in the road conditions ahead. The dynamic driving simulator at the HFRL is illustrated in detail in Figure 1. The driving world can be programmed to include driving segments ranging from single lane roadway to two lane roadway with bi-directional traffic flow to a three lane single traffic flow highway. This allows the experimenter to use a variety of driving scenarios to assess the participant's driving behavior and decision making process.

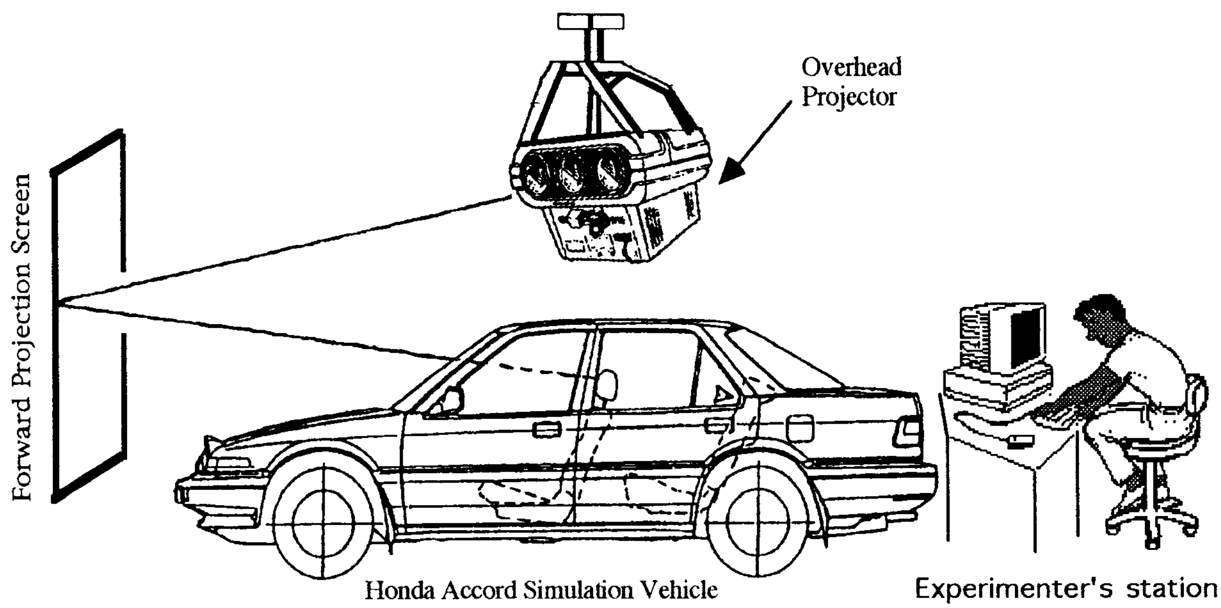

Figure 1. *Side projection view of the simulation facility illustrating the 1990 Honda fixed-position vehicle, the overhead projection system, the screen orientation and driver visual viewing angle.*

Specifically, the HFRL driving simulation facility is founded upon a fixed-based Honda 1990 Accord. Inputs from the driver, in terms of accelerator, brake activation, and steering are converted from analog to digital inputs. These are used as inputs to a computer model which represents the equations of motion of the actual vehicle. Outputs from this model are then used to adjust the eye point of the driver in the environment in accord with the inputs given. The simulation changes to fit the orientation of the driver based on their driving actions. These changes are then displayed in real-time, constituting the dynamic driving world observed by the driver. The simulated driving world was programmed to be representative of the Twin Cities Metropolitan roadways, including driving with and against traffic and maneuvers typical of driving: merging into traffic, making a left turn across traffic, and passing cars on a multi-lane highway. To facilitate the driver's recognition of the routes they were driving, we programmed the driving worlds to represent roadways traveling from the south side of Minneapolis into the downtown area. The first segment represented "Cedar Avenue" (State Highway 77) and was programmed as a two lane bi-directional highway. The second segment represented the "Crosstown" (State Highway 62) as a two lane roadway with single direction traffic flow.

The use of local roadways allowed the generation of scenarios based on the messages that can and will be sent eventually with the Crusader software from the Mn/DOT TMC. For example, it was possible to send any messages that had a location on Cedar Avenue, the Crosstown, or on the Crosstown's most used freeway connector I-35W. This gave drivers a frame of reference for where they were driving and what types of conditions they were likely to encounter. These configurations are illustrated in Figure 2. To send messages, the simulation vehicle was hardwired to the Indikta receiver installed in the dashboard. The antenna was wired directly to the signal generator and RE531 encoder. Finally, a terminal connection was made between a 486 PC computer which ran the Crusader message assembly software and the RE531 encoder. This meant that messages could be relayed directly to the car by the experimenter without being broadcast. This system proved effective in allowing the experimenter to manipulate the variables of interest.

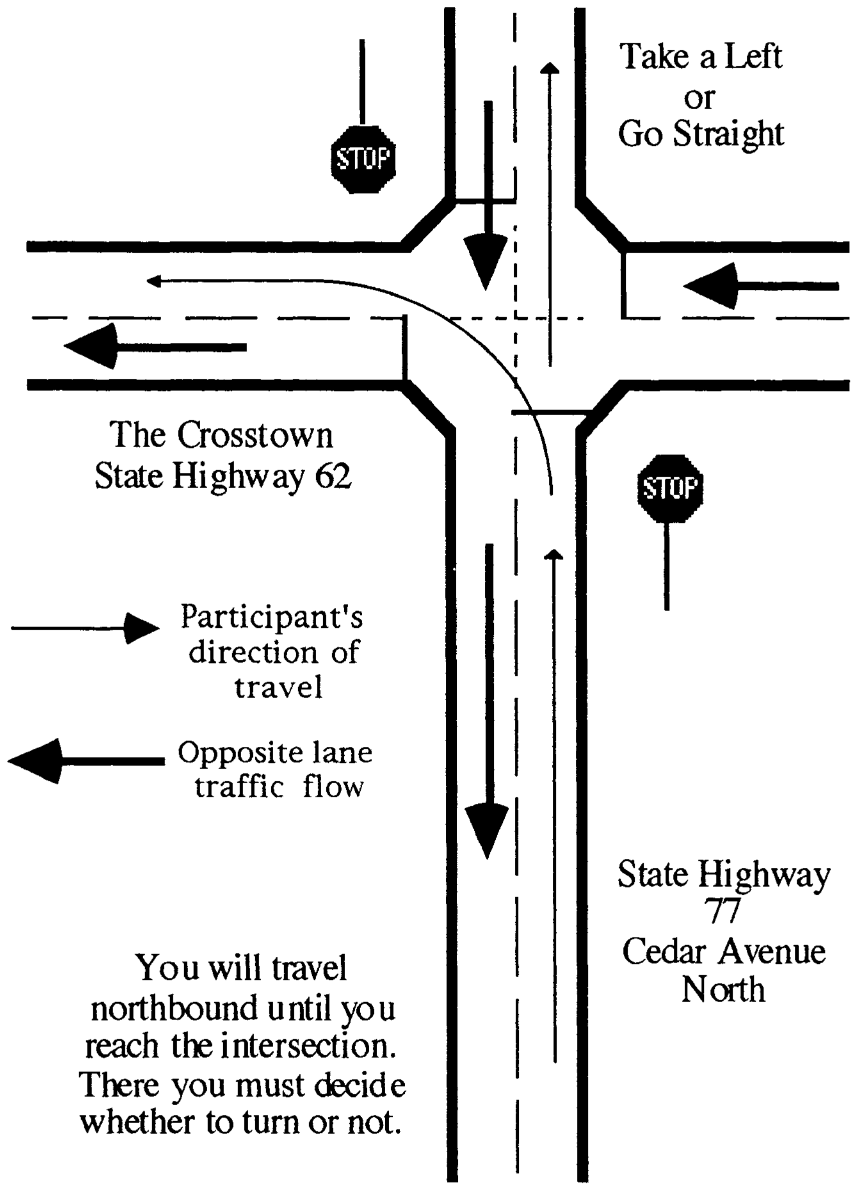

Figure 2. *Simulated driving world containing three segments of differing driving conditions. Note that drivers cross traffic at he end of segment one and flow into traffic on segment two.*

The receiver in the simulator was tuned to 89.7 MHz which was the HFRL "broadcast" frequency. Specific messages of various states of traffic conditions and delays of different duration's were selected. These messages were entered into Crusader depending upon the differing scenarios. Thus exactly which messages were sent and when they were sent were under experimental control as shown in Table 1.

Table 1. *Messages sent to Drivers.*

Incident	Location	Cross Street	Duration
1) Serious Accident	At S. H. 77	and I-94	Next Hour
2) Stop & Go Traffic	At S. H. 62	and Penn Avenue	Next 15 Minutes
3) Traffic Flowing Freely	At I-35W N	and 60th. Street	No Delays
4) Delays	At I-35W N	and Lake Street	Next Half Hour
5) Expect Delays	At S. H. 77	and I-494	Next Ten Minutes
6) Expect Heavy Traffic	At S. H. 77	and Shakopee Rd	Next Three Hours

Experimental Participants

The experimental participants were volunteers from the University of Minnesota. Each was a licensed Minnesota driver. None of the participants had direct experience with the Indikta in-vehicle device, although some of the drivers had participated in earlier HFRL research projects. They were informed of the general purpose of the experiment for consent purposes. All drivers were in professed good health at the time of testing. There were five female and seven male subjects. The mean age for the males was 38.6 years old, while the mean age for the females was 39.8 years old.

Experimental Task and Procedure

The task in the present study was designed to assess how the Indikta device was used during driving on a simulated roadway. The experiment assessed; i) drivers' ability to receive complex information from the systems (user interaction) and; ii) drivers' decision-making based upon the information given (user reaction). The overall objective was to establish how drivers would use and trust this system and the information that it communicated in light of what traffic was presented in front of them. All drivers completed six, five-minute trials in the simulator. These trials consisted of driving the car at 55 mph northbound on State Highway 77 (Cedar Avenue North) toward the Twin Cities. Traffic approached them in the other lane of this two way street. They approached an intersection with a stop sign[1]. This intersection was State Highway 62 (The

[1] *Although this intersection is actually a cloverleaf, it was presented as a stop sign for convenience in the present evaluation. There is no direct reason to believe that decisions are critically dependent upon the form of intersection as of the present date.*

Crosstown Highway) which heads east/west. Drivers were told they were to try to reach downtown as quickly as possible. If they remained on Cedar Avenue North it would take them 35 minutes. If they took the Crosstown and then went north on I-35W it would take them 16 minutes. They were instructed that congestion or accidents could slow them down on I-35W and it may take up to 180 minutes with bad traffic congestion, see Table 1. Drivers were to decide whether to make a left turn onto the Crosstown towards I-35W or remain on Cedar Avenue North based on their perceived transit time.

The sources of information which allowed them to determine the best route was by using their observation of the traffic flow on the Crosstown and the information given to them by messages communicated on the Indikta device. The messages indicated whether traffic was backed up on I-35W, that the Crosstown was congested, or if traffic was flowing freely or if these were problems on State Highway 77. If the Crosstown was congested drivers were advised to consider driving straight through the intersection and continuing on Cedar Avenue North. Alternatively, the message could indicate that traffic was flowing freely or that there were no reports of incidents on the Crosstown or I-35W. In that case they were instructed to make a left turn onto the Crosstown. Their main task was to drive the car, listen or look for traffic messages and then decide whether to turn onto the Crosstown Highway or to continue on Cedar Avenue. To evaluate user reaction to messages and the 'trust' they placed in the information from the device, conflicting traffic scenarios were devised in the following manner. When the drivers arrived at the Crosstown Highway they could observe one of two driving scenarios.

Thus, to asses trust in the device, messages received were either consistent or inconsistent with the appearance of traffic on the Crosstown, as illustrated in Figure 3. The Indikta system might say, for example, traffic was flowing freely on the Crosstown, however, as the participant approached the intersection they would see stop and go traffic. Alternatively, the device might indicate congestion on I-35W lasting for the next hour but as they approached the Crosstown, traffic would be moving freely.

RBDS	VISUAL CONDITION: CONGESTED	VISUAL CONDITION: FREE FLOWING
CONGESTED	**Confirmation**	**Contradiction**
FREE FLOWING	**Contradiction**	**Confirmation**

Figure 3. *The four possible combinations of conditions that drivers encountered. When both sources presented the same information it implied confirmation. When sources differed there was contradiction. While emphasis is given to examining contradictory cases, there* were *turn decisions taken even when both sources indicated congestion.*

The participants were informed that cars might be traveling freely on the Crosstown where they were, but might be backed up some miles ahead or on I-35W (as is frequently the case in crowded ramp meter conditions). Drivers were instructed to make a turn decision based on optimization of transit time. This allowed the comparison of 'trust' in the different respective sources of information.

In this experiment, for the purpose of simplicity, we have asserted that the visual conditions are 'correct' and that the information which contradicts those visual cues is 'incorrect.' This is, of course, an arbitrary selection since we could have affirmed the 'correctness' of the RBDS messages instead. As no feedback was presented, and as drivers did not subsequently drive the selected route with its associated delays, we are examining independent cases. Therefore, in this work we are not examining the history of drivers' interaction with the device, although we recognize this as a critical element of a more extensive investigation. Rather, we are examining the relative confidence of choice upon immediate exposure to an ITS device.

After the driver had decided on their course of action (either to turn or go straight), the trial was terminated and the experimenter began the next trial. Thus each scenario was independent. After the participants had completed all trials, they were debriefed with respect to the Indikta system itself. Each subject received a random order of presentations for each message and state of roadway congestion. Trials were thus uniquely ordered for each individual driver. Table 2 presents an example of one participant's experience. Due to the idiographic nature of this design, responses of all drivers are presented in the appendix.

For each of the six trials, a random order of messages was selected, with the limitation that once a message had been picked it was removed from the pool of messages. Next the two traffic conditions, congested and not congested were randomly assigned to each of the six trials. This was a computer generated random function allowing for each case to have equal probability of being chosen for each trial. The message could therefore relay 'correct' or 'incorrect' information. These responses are examined in the following results.

Table 2. *Example of one driver 's data.*

SUBJECT NUMBER	TRIAL #	CONGESTED NOT CONGESTED	CRUSADER MESSAGES	TRUE / FALSE	DECISION Left or Straight
1	2	Not Congested	Serious Accident State Hwy. 77	FALSE	Straight
	4	Not Congested	Stop & Go Traffic S. Hwy. 62	FALSE	Straight
	3	Congested	Traffic Free Flowing : I-35W	FALSE	Turn Left
	5	Congested	Delays I-35W	TRUE	Straight
	6	Congested	Expect Delays : State Hwy. 77	FALSE	Straight
	1	Not Congested	Expect Heavy Traffic S.H. 77	TRUE	Straight

EXPERIMENTAL RESULTS

Driver Compliance With Information

The descriptive data are most interesting. All four drivers who received the confirmatory information of free-flowing traffic combined with an RBDS message indicating the same condition, turned left onto the Crosstown, which we scored as correct response. In the other confirmatory condition shown in Figure 3, where both sources indicated congestion, there was only an 80% correct decision rate to continue on Cedar Avenue. That is, despite both sources of evidence confirming congestion, one in five drivers turned into the stream of traffic. In the contradictory cases, there is a larger degree of divergence. When the evidence of their own eyes indicated congestion but the RBDS system indicated the traffic was free-flowing only one driver of eight turned on to the congested Crosstown. In the final case, the visual information indicated no congestion, however, less than half the subjects turned on to the Crosstown indicating a high degree of compliance with the RBDS information.

Table 3. *Matrix data of the visual versus RBDS information.*

		VISUAL CONDITION	
		CONGESTED	NOT CONGESTED
RBDS	CONGESTED	**24/30 = 80%**	**14/30 = 46.7%**
	NOT CONGESTED	**7/8 = 87.5%**	**4/4 = 100%**

There is a further decomposition of this data that can be achieved. This is the case since RBDS messages could refer to traffic conditions on either the 62/I-35W route or on the 77 (Cedar Avenue) route. This breakdown of the data revealed further interesting trends. As all messages were sent to all drivers, we described response in terms of message content. One message indicated free-flowing traffic on I-35 and the compliance to that message has already been shown to be high, bottom right corner of Table 3. However, the congestion messages had two of the remaining five concerning delays on the 62/I-35 route and three of the remaining five concerning delays on Cedar Avenue. Therefore, we can plot turn decisions in light of this information. When the visual information shows congestion and the RBDS confirms this with specific messages about delays on the 62/I-35 route, 11 of 13 (84.6%) drivers go straight and avoid the congestion although two drivers still turned left when both sources of evidence indicated problems, Table 4. Note that in this condition there is no additional information as to the state of traffic on Cedar Avenue. When the Crosstown was visually congested and the driver received a delay message for Cedar Avenue, they were in the difficult position of choosing between two forms of delay. In our analysis, we scored a turn into congestion on the Crosstown as incorrect. However, given the information available neither choice is entirely inappropriate. Actually, three quarters of the drivers (76.4%) did proceed on Cedar Avenue, even though delay messages were sent. This emphasizes the priority of immediate visual information over the distal RBDS communication.

Table 4. *Congested conditions separated by highway vs. free flowing traffic.*

RBDS	VISUAL CONDITION: CONGESTED	VISUAL CONDITION: FREE FLOWING
CONGESTED 35W / S.H.62	**11/13 = 84.6%**	**7/11 = 63.6%**
CONGESTED S.H. 77	**13/17 = 76.4%**	**6/19 = 31.6%**
FREE FLOWING	**7/8 = 87.5%**	**4/4 = 100%**

When the Crosstown was free-flowing, drivers could also receive delay messages concerning either the route they were going on Cedar or about the Crosstown. 63.6% of drivers followed their own visual information and turned left on to the Crosstown, even though they had received RBDS information that there were delays on that route. However, the most interesting finding comes in the final possible combination. These drivers saw a free-flowing Crosstown and were given RBDS information as to delays on the Cedar route. Despite these dual and confirming stimuli to turn, only 31.6% of drivers did turn on to the Crosstown. That is, the majority of drivers here ignored the RBDS message and the visual evidence and did not change route. This might be some indication that drivers have a tendency to choose a route and stick to it despite information on adverse conditions on their present route and evidence of open conditions on an alternate route.

There is a further nuance to this finding which is of critical importance. It will be noted by those familiar with the Twin Cities area, and is explicit here, that two of the messages, shown as message five and six in Table 1, refer to traffic conditions on Cedar Avenue (SH 77) which are behind the driver and do not affect their travel route from their current position into downtown. While it might be assumed that this radically affected the turn decision, it did not. For those messages concerning SH 77 when the Crosstown was free by visual inspection, only 2 of 7 drivers turned left when the incident was in front on their planned route. This compares with 4 of 12 turning left when the incident was reported behind them. This brings up a most interesting question which is how drivers integrate information broadcast with their mental 'map' of the roadways which affect their route. This evidence certainly suggests that there is an incomplete integration of such information in that the location of the incident apparently did not affect decisions. However, one piece of information that apparently did affect decisions was the time of delay that was communicated.

Decisions As A Function of Delay Duration

There is a relationship between the duration of the incident communicated on the RBDS and the number of incorrect decisions made. According to our criteria if a participant makes an incorrect decision it means that they either turned left into congested traffic on the Crosstown or went straight ahead on Cedar Avenue North when the Crosstown was flowing freely. This data shows that drivers were more likely to make an incorrect decision based on the information given as the communicated duration of delay increased. This would imply that when an incident was projected as lasting greater than a half hour, drivers would avoid turns even if the visual information that they perceived was that the Crosstown was flowing freely. Participant's used the information given and despite what they saw on the road, if they were told that an incident had delays of significant length, they would ignore the visual information and choose to follow the advice from the in-vehicle device. However, this conclusion must be tempered by the few but recorded cases of individuals ignoring information when delay is on the straight route up Cedar on which they are traveling. Therefore, with a small sample it is not possible to establish one critical duration delay for this decision except to note that the inversion occurs here between thirty minutes and one hour, see Figure 4. The participants were instructed to get downtown as fast as possible and if they added over thirty minutes to their trip by taking the Crosstown, it would increase their total travel time past the thirty-five minutes needed if they went straight on Cedar Avenue. However, the critical difference between the 16 minutes on I-35 and the 35 minutes on Cedar is 19 minutes. But, the change does not occur between fifteen and thirty minutes of delay, suggesting that pure, numeric decision making is not operating here. Obviously this is a fruitful area for further investigation.

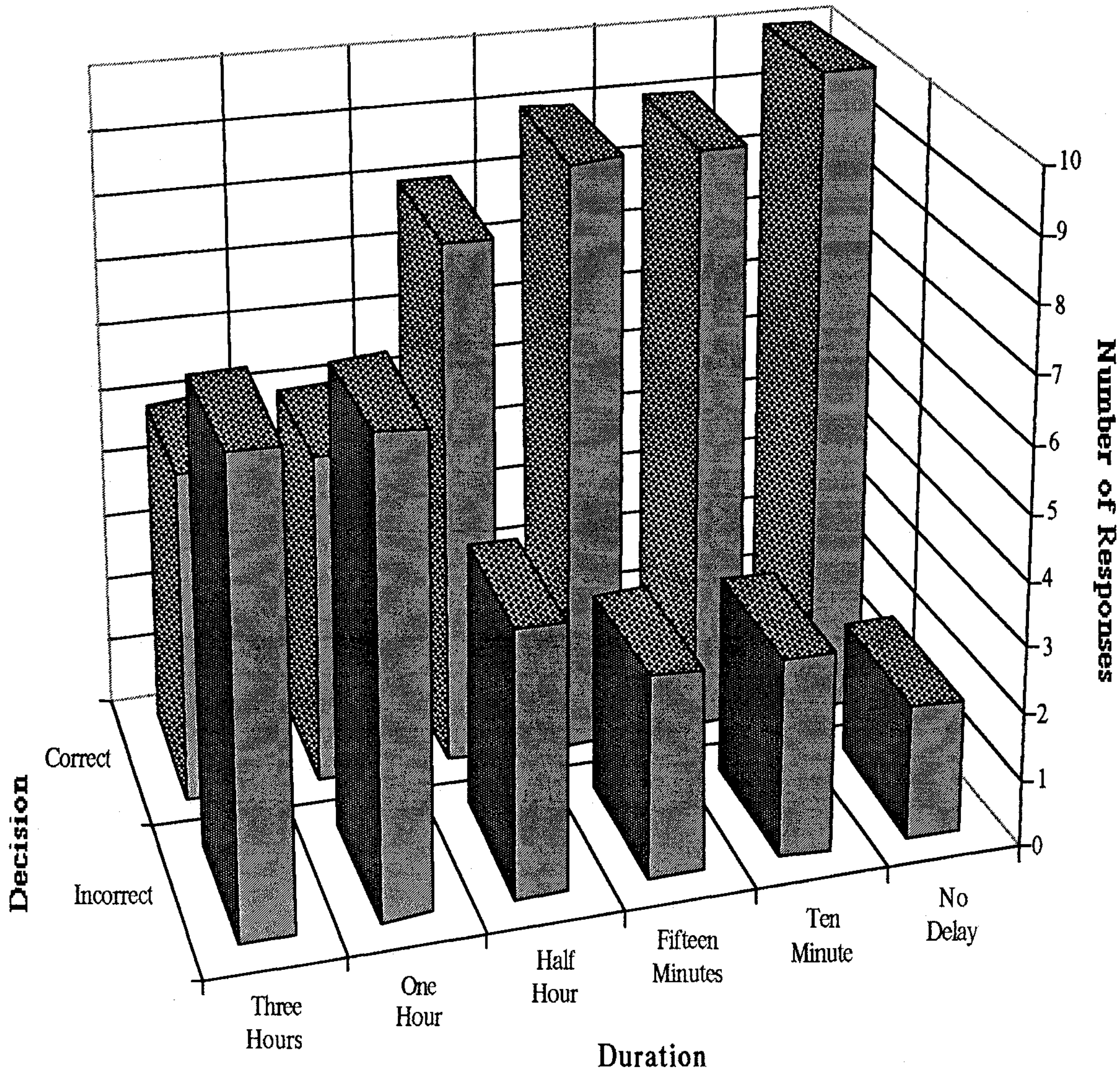

Figure 4. *Number of decisions made by choice and duration times.*

Decisions As A Function of Delay and Traffic State

The data also revealed that when individual traffic states were compared with delay duration of messages, there was an interesting pattern of response. As duration time increased there is an increase in incorrect decisions but this increase is directly related to the visual information seen by the driver. As they approach the intersection they see congestion, if the message says an incident for the next three hours, they believed that this implied a confirmation of the information they perceived visually. If the Crosstown was in the non-congested state with cars flowing freely, the messages were used as a warning. As duration of the incident increased, the participants made fewer and fewer decisions to turn into congested traffic implying that as delay levels increased they believed their own observations and the devices were used to confirm this. This is evident when comparing each traffic state by duration in the incorrect column. (See Figure 6). As the delays begin with brief periods, the driver is more likely to choose an incorrect decision when the traffic state is congested. Either they believe the device when it says the duration will be short, or they trust in their ability to get downtown quicker by way of the Crosstown.

Table 4. *Participant decisions compared to traffic conditions and durations.*

Duration by Traffic State as a Function of Decision Made

	Correct	Incorrect
No Delay Congested	6	2
No Delay Not Congested	4	0
Ten Minute Congested	6	2
Ten Minute Not Congested	3	1
Fifteen Minute Congested	5	2
Fifteen Minute Not Congested	4	1
Half Hour Congest	5	1
Half Hour Not Congested	3	3
One Hour Congested	3	2
One Hour Not Congested	2	5
Three Hours Congested	4	0
Three Hours Not Congested	1	7

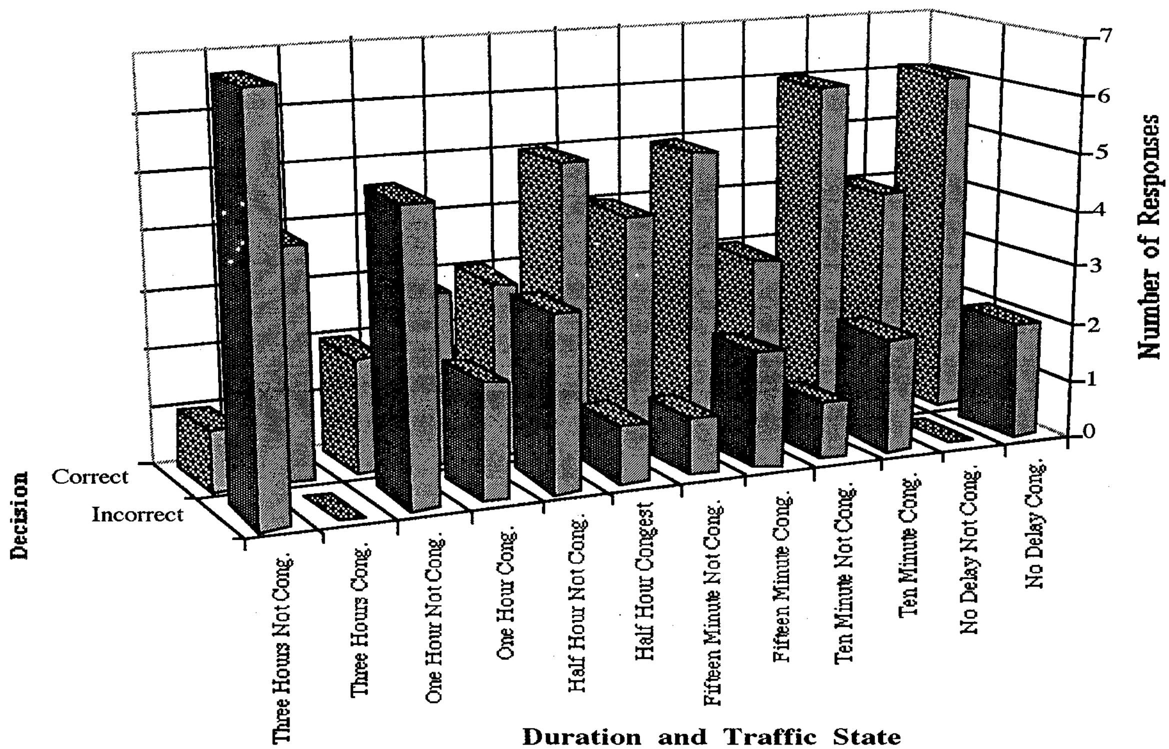

Figure 5. *Number of decisions made by choice compared to duration times during the two types of traffic conditions.*

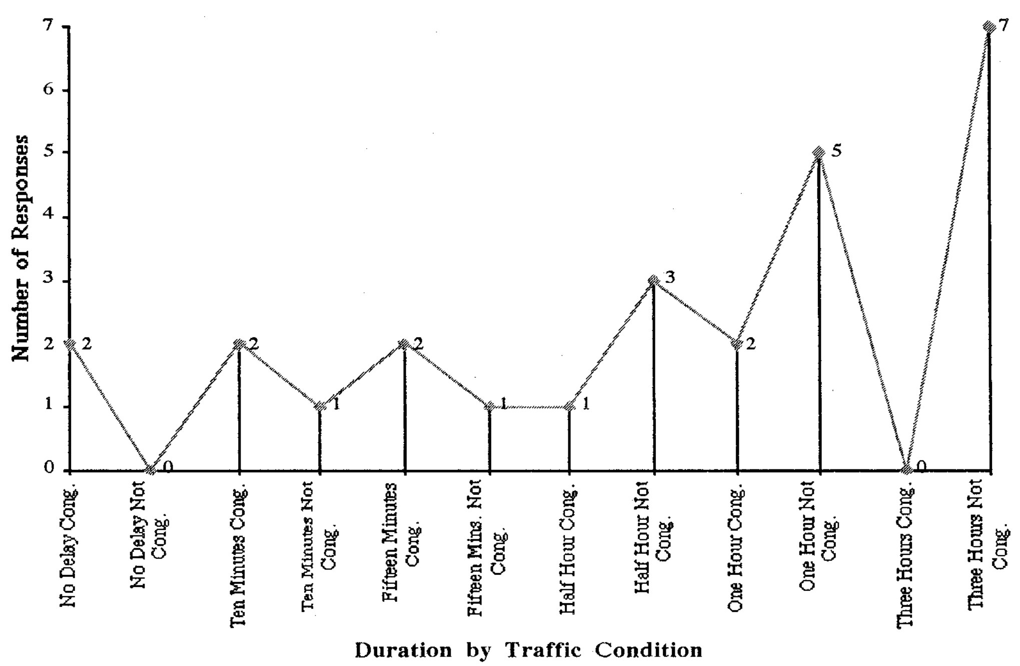

Figure 6. *Incorrect decision made as a function of the duration of the incidents compared to the traffic conditions on the Crosstown.*

As the duration increase drivers are less likely to turn into heavy congestion because they were told by the Indikta that the incidents had extremely long delays or to expect heavy traffic for long duration's. This is especially evident as no drivers turned onto the Crosstown when delays exceeded one hour. Note that this implies a high priority for quantitative temporal information since this pattern occurred almost independently of the spatial location of the incident. This implies that both temporal and quantitative information exert dominant effects on driver behavior, a clearly important observation fro RBDS communication.

DISCUSSION

The present experiment clearly illustrates that driver's use of in-vehicle information is done in a selective manner. That is, conformance to the information presented depends not only on the traffic context but on the message content. The main finding from this preliminary investigation is that there is a trend toward greater conformance as the perceived penalty for ignoring the information increases. As has been illustrated, drivers follow in-vehicle information over their own direct perception when the communicated delay exceeds the expected differential time between routes. At present, we cannot be sure whether this is a direct matter of trust of in-vehicle information, or a simple computational approach on behalf of drivers. The latter is somewhat contradicted by the actual time differences involved. That is 35 minutes for the unchanged route, versus 45 minutes for the communicated delay, with the recognition that some degree of spatial independence is thus implied. This is certainly a facet of response that requires further evaluation since the differences are not clear here and an unequivocal interpretation cannot be drawn.

However, this conclusion must be viewed in light of a recognition that there are a number of drivers who appear to ignore all information presented. That is, shown a free-flowing alternate and given RBDS information of congestion on their present route some drivers still do not turn. In a like manner, given visual evidence of congestion and confirmation by RBDS information some drivers still turn into congested traffic. In our limited sample, decision patterns did not appear to be related to either age or gender. However, this is certainly a facet of investigation that should be expanded in future evaluations. Identification of those characteristics which influence a driver's routing and re-routing decisions is an important objective since it will not only improve the probability of compliance but may also help distinguish who follows RBDS information and what their demographic characteristics and capabilities might be. In sum, the present investigation indicates a most useful line of practical research to follow.

APPLICATION FOR THE MINNESOTA DEPARTMENT OF TRANSPORTATION

- There is evidence in the present work that compliance to in-vehicle information is dependent upon the quantitative nature of that information.

- Where time is considered an important travel criteria, the evidence suggests drivers believe their direct observations when communicated delay periods are short.

- Further research is important on the history of how trust is established and maintained with RBDS systems.

- Evidence suggests that some drivers ignore all sources of information and continue on their preset route whatever is presented. Identification of such individuals may help Mn/DOT establish practical compliance ceilings for RBDS effects.

- There is partial support for the assertion that temporal information is prioritized over spatial information, since drivers appeared to key in on length of time delay but failed to locate where the delay was in respect of their present route options.

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Appendix:

Subject Data

SUBJECT NUMBER	TRIAL #	CONGESTED NOT CONGESTED	CRUSADER MESSAGES	TRUE / FALSE	DECISION Left or Straight	CORRECT?
1	2	Not Congested	Serious Accident S. H. 77	FALSE	Straight	NOT C
	4	Not Congested	Stop & Go Traffic S. H. 62	FALSE	Straight	NOT C
	3	Congested	Traffic Free Flowing : I-35W	FALSE	Turn Left	NOT C
	5	Congested	Delays I-35W	TRUE	Straight	C
	6	Congested	Expect Delays : S. H. 77	FALSE	Straight	C
	1	Not Congested	Expect Heavy Traffic S. H. 77	TRUE	Straight	NOT C
2	5	Not Congested	Serious Accident S. H. 77	FALSE	Turn Left	C
	2	Congested	Stop & Go Traffic S. H. 62	TRUE	Turn Left	NOT C
	4	Congested	Traffic Free Flowing : I-35W	FALSE	Turn Left	NOT C
	3	Congested	Delays I-35W	TRUE	Straight	C
	1	Not Congested	Expect Delays : S. H. 77	TRUE	Turn Left	C
	6	Not Congested	Expect Heavy Traffic S. H. 77	TRUE	Straight	NOT C
3	3	Not Congested	Serious Accident S. H. 77	FALSE	Straight	NOT C
	4	Congested	Stop & Go Traffic S. H. 62	TRUE	Straight	C
	6	Not Congested	Traffic Free Flowing : I-35W	TRUE	Turn Left	C
	2	Congested	Delays I-35W	TRUE	Straight	C
	1	Not Congested	Expect Delays : S. H. 77	TRUE	Turn Left	C
	5	Not Congested	Expect Heavy Traffic S. H. 77	TRUE	Turn Left	C
4	6	Not Congested	Serious Accident S. H. 77	FALSE	Straight	NOT C
	2	Congested	Stop & Go Traffic S. H. 62	TRUE	Straight	C
	5	Congested	Traffic Free Flowing : I-35W	FALSE	Straight	C
	1	Not Congested	Delays I-35W	FALSE	Straight	NOT C
	4	Not Congested	Expect Delays : S. H. 77	TRUE	Straight	NOT C
	3	Congested	Expect Heavy Traffic S. H. 77	FALSE	Straight	C
5	1	Congested	Serious Accident S. H. 77	TRUE	Straight	C
	6	Not Congested	Stop & Go Traffic S. H. 62	FALSE	Turn Left	C
	4	Congested	Traffic Free Flowing : I-35W	TRUE	Straight	C
	3	Not Congested	Delays I-35W	FALSE	Turn Left	C
	2	Congested	Expect Delays : S. H. 77	FALSE	Turn Left	NOT C
	5	Congested	Expect Heavy Traffic S. H. 77	FALSE	Straight	C
6	2	Not Congested	Serious Accident S. H. 77	TRUE	Straight	NOT C
	1	Congested	Stop & Go Traffic S. H. 62	TRUE	Straight	C
	3	Not Congested	Traffic Free Flowing : I-35W	TRUE	Turn Left	C
	5	Not Congested	Delays I-35W	FALSE	Turn Left	C
	6	Not Congested	Expect Delays : S. H. 77	TRUE	Turn Left	C
	4	Not Congested	Expect Heavy Traffic S. H. 77	TRUE	Straight	NOT C

SUBJECT NUMBER	TRIAL #	CONGESTED NOT CONGESTED	CRUSADER MESSAGES	TRUE / FALSE	DECISION Left or Straight	CORRECT?
7	4	Congested	Serious Accident S. H. 77	TRUE	Turn Left	NOT C
	6	Not Congested	Stop & Go Traffic S. H. 62	FALSE	Turn Left	C
	1	Congested	Traffic Free Flowing : I-35W	FALSE	Straight	C
	3	Not Congested	Delays I-35W	FALSE	Turn Left	C
	2	Congested	Expect Delays : S. H. 77	FALSE	Straight	C
	5	Congested	Expect Heavy Traffic S. H. 77	FALSE	Straight	C
8	4	Congested	Serious Accident S. H. 77	TRUE	Straight	C
	1	Congested	Stop & Go Traffic S. H. 62	TRUE	Turn Left	NOT C
	6	Not Congested	Traffic Free Flowing : I-35W	TRUE	Turn Left	C
	5	Congested	Delays I-35W	TRUE	Straight	C
	2	Congested	Expect Delays : S. H. 77	FALSE	Straight	C
	3	Not Congested	Expect Heavy Traffic S. H. 77	TRUE	Straight	NOT C
9	3	Not Congested	Serious Accident S. H. 77	FALSE	Turn Left	C
	4	Congested	Stop & Go Traffic S. H. 62	TRUE	Straight	C
	5	Congested	Traffic Free Flowing : I-35W	FALSE	Straight	C
	2	Congested	Delays I-35W	TRUE	Straight	C
	1	Congested	Expect Delays : S. H. 77	FALSE	Straight	C
	6	Not Congested	Expect Heavy Traffic S. H. 77	TRUE	Straight	NOT C
10	1	Congested	Serious Accident S. H. 77	TRUE	Straight	C
	4	Not Congested	Stop & Go Traffic S. H. 62	FALSE	Turn Left	NOT C
	5	Congested	Traffic Free Flowing : I-35W	FALSE	Straight	C
	6	Congested	Delays I-35W	TRUE	Turn Left	NOT C
	2	Congested	Expect Delays : S. H. 77	TRUE	Straight	C
	3	Not Congested	Expect Heavy Traffic S. H. 77	TRUE	Straight	NOT C
11	2	Not Congested	Serious Accident S. H. 77	FALSE	Straight	NOT C
	3	Congested	Stop & Go Traffic S. H. 62	TRUE	Straight	C
	6	Congested	Traffic Free Flowing : I-35W	FALSE	Straight	C
	1	Not Congested	Delays I-35W	FALSE	Straight	NOT C
	5	Congested	Expect Delays : S. H. 77	FALSE	Straight	C
	4	Congested	Expect Heavy Traffic S. H. 77	FALSE	Straight	C
12	6	Congested	Serious Accident S. H. 77	TRUE	Turn Left	NOT C
	2	Not Congested	Stop & Go Traffic S. H. 62	FALSE	Turn Left	C
	4	Not Congested	Traffic Free Flowing : I-35W	TRUE	Turn Left	C
	5	Not Congested	Delays I-35W	FALSE	Straight	NOT C
	1	Congested	Expect Delays : S. H. 77	FALSE	Turn Left	NOT C
	3	Not Congested	Expect Heavy Traffic S. H. 77	TRUE	Straight	NOT C

GEOGRAPHIC DATABASES FOR IVHS MANAGEMENT

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GEOGRAPHIC DATABASES FOR IVHS MANAGEMENT

INTRODUCTION

We are designing a traffic information database for Intelligent Vehicle Highway System (IVHS). The central goals of this work is to create a shared resource, efficient disk based computation, and integrity of data for multiple usage. The information stored in the IVHS database will be used by transportation system designers for traffic modeling and control. The same information will be used by human factors researchers to simulate driving conditions in intelligent cars with heads-up displays and on-board computer. Computer scientists involved in the generation of this facility are concerned with efficient disk based computation to detect collisions and traffic incidents when needed. Spatial access methods, rules and triggers, provided by the database system will be used for efficient disk computation for incident-detection. One of the important benefits a database may offer is the integrity of stored data. Changes (deletions or additions) of maintenance work on highways, for example, should not leave any management holes under the database's integrity constraints. Database technology has evolved over last two decades in response to the needs of commercial data processing. However, these databases are not able to provide reasonable performance in today's newer applications.

Consider the example where a spatial object (e.g., road intersection) is stored in a traditional database by using the boundary representation approach. In this approach, a two dimensional region is represented as a collection of edges, and edges are represented by their endpoints. Three relations (regions, edges, and points) may be used to model the data. The representation decomposes as simple an object as a square into parts spread over different relations and therefore across the storage medium. The question whether a region intersects a given line (L) is answered by joining two tables. This takes considerable amounts of computation. Efficiency requires, at least, retrieving as a unit all the data that defines a basic region such as square given in the present example.

Two semantic domains that are essential to dealing with IVHS concepts. Space and time, are provided by the formalism. Without excluding alternate views of space and time, we provide a kernel set of spatial and temporal concepts and operators. Based on spatial and temporal logic, they allow one to state that a fact is true at some point in time and in a particular place. Our formalization views the world as a collection of entity instances. Information about individual objects are captured via the set of attributes defining its properties. For example, the University of Minnesota, EE/CSci building is characterized by its location, office hour, capacity, parking availability and other traffic relevant attributes. Related individuals are grouped into entities represented as a table with one column for each attribute and one row for each individual. All buildings are grouped in one table. All roads may be grouped in another table.

Spatial and temporal aspects of data are modeled via a set of abstract data types specifying the spatial and temporal attributes and operations. The space is modeled via a rectangular coordinate system. Objects are modeled approximately by a collection of primitive objects. Primitive objects include rectangles and rectangular solids. The embedding of objects to space is modeled by the coordinates of the center of object. Translation, and rotation operations are supported and modeled by altering the values of relevant attributes of the objects representing the new embedding. Proximity relationship is preserved via the **MoBiLe** mapping function, which determines the disk address of an object from its space coordinates. The mapping function is monotonic and continuous to preserve the proximity relationships. The boundary traversal and other algorithms are supported efficiently by the mapping.

An important constraint in defining the formalism has been the desire to implement it in an extensible database such as Postgres. Postgres provides a template database which can accept user defined data types and operators to model IVHS applications. We are implementing the formalism on Postgres version 2.0 in Unix environment on Sun Sparc machines using C and Lisp. Graphic interface for the map data is provided from the Xfig and Pic tools. The purpose of the experiment is to identify ways to overcome the limitations of traditional database systems in areas of efficiency, modeling, and user interface configuration.

DATABASE SCHEMA: REPRESENTING THE ENTITIES IN THE TRAFFIC WORLD

A database schema models application domain as a collection of entities with attributes and the relationships among the entities. To represent a domain efficiently, several data models have been proposed. Among them are the network model, the hierarchical model, the relational model, the entity-relationship model, the functional model, the semantic model and the object-oriented model. In addition, variants and extensions of the above models also exist. The extensible relational model, for example, has been a main research area since the emergence of the relational model.

The first step of creating an extensible database application is to model the entities in the application domain as abstract data types (ADTs). An ADT contains attributes and operators specific for the type. A circle, for example, contains a center and a radius. A circle can be modeled as an ADT containing two attributes: a center coordinate (centerX, centerY) and a radius. In addition, operations such as `get_circle_center (circle)', `get_circle_radius (circle)', `circle_equal (circle1, circle2)' may be defined for efficient manipulation of circles. An operation is usually defined as a function taking one or more parameters. The `circle_equal' operation, for example, is a function taking two circles and returning a boolean value (equal/unequal or True/False).

We model the example IVHS data with the following entities: vehicle, building, traffic_sign, traffic_area, traffic_location, sensor, road, bridge, congestion, collision, and event. Each entity is represented as a relation table. Each table contains several columns representing attributes of the entity. Each column has a type, which is offered when building an entity into the database. A type specifies the domain of a column. The building entity, for example, includes the following attributes:

name, box, business, use-hrs.

The semantic domain of a traffic information system can be classified into two classes: the spatial (geographical) domain and the temporal domain. The spatial objects are modeled with entities such as points, line segments, paths, boxes. The space is modeled by a coordinate system to embed objects in space. The temporal domain is modeled by time point (absolute time), time interval, periodic time (e.g., every Wednesday, every day at 9 a.m., etc.), and schedule. The spatial and temporal classes are modeled as types and used together with the primitive types to specify the type domain of columns in a relation.

Each data type has a set of operations defined for easy and efficient use of the data type. The box data type, for example, has the following operations: box_overlap(), inside(), box_center(), passesVia(), near(), enclosure(), and adjacent(). The same operation may take different parameters. The operation near() , for example, has four different parameter pairs: point/box, box/box, lseg/box, and path/box. Although with the same name, each individual operation is actually defined differently, but the user does not need to worry about the details. This is one of the strong features of abstract data types.

QUERY LANGUAGE OF THE IVHS DATABASE

Once the application database is created, users can use the types and functions together with the data access commands to retrieve information from or change information inside the database. The query language includes commands defining new types and functions not available in traditional database language like SQL or QUEL. These commands include define type, define function, define rule, define index, and define operator. Once a function is defined, it can be used in the queries. The database run time system will automatically load the corresponding function code when it processes the queries. A function can also be bound to an operator for improving the syntax of a query. The inside(box,box) function, for example, can be bound to the operator `<=' using the define operator command. The user of the database can then issue a more natural expression such as `box1 <= box2' rather than `inside (box1, box2)'.

Queries may be classified as relevant to drivers, experimenters, or traffic-controllers. The following are two example queries and their corresponding Postquel commands.

Query: ``Find adjacent camera pair on common lane with high difference (50% = 0.5) in average lane occupancy for last 5 minutes. "

retrieve (c1.id, c2.id) from c1, c2 in sensor
where c1.class = "camera" and c2.class = "camera" and c1 != c2
and
floatmi(average_overt(c1.occupancy, [timenow(), timemi(timenow(), @5 minute)]),

average_overt(c2.occupancy, [timenow(), timemi(timenow(), @5 minute)])) >= 0.5.

Query: ``Find all the objects existing within the safety envelope of the self vehicle."

define POSTQUEL function safety_check (vehicle) returns string is
retrieve (building.name)

where box_overlap(self.safety_envelope, building.box)
retrieve (vehicle.name)

where box_overlap(self.safety_envelope, vehicle.box)
retrieve (traffic_sign.name)

where inside(traffic_sign.point, self.safety_envelope)
retrieve (cd_list = safety_check(self))

Queries can also be classified using a different criteria based on the data types involved. A query may be an instance of point queries, range queries, aggregate queries, join queries, transitive closure or boundary queries. Most of the above queries can be implemented efficiently.

Point and range queries are implemented with the help of spatial and temporal access methods. Aggregate, join, and transitive closure queries, however, are expensive in terms of implementation cost and space and time cost. Transitive closure query, in particular, is very expensive. We are investigating the method of formulating path planning as a function. **MoBiLe** Files may be used in a rule-based route computation method to reduce the search space of transitive closure queries.

EVENT DETECTION AND DATABASE TRIGGERS

Once built into the database, rules function like a demon and constantly monitors the database state for matching the condition part of the rule. If the state satisfies the condition, the action part is fired to conduct predefined actions (e.g., report collision). It is apparent that triggers are useful in a IVHS database application, where incidence detection and warning system for drivers are important features. To integrate knowledge into a database system, two approaches have been proposed: the loose-coupling approach and the tight-coupling approach The tight coupling approach integrates rules into the database management system. The integration of rules into a DBMS has the capability of dealing with dynamic environment, where data are updated frequently. Another advantage of tight coupling is that it can be used with a database application which is not partitionable. One of the limitations of the loose coupling approach is that it needs a partionable database to make efficient inferences. Since an IVHS domain is dynamic, the tight coupling approach is more realistic.

In an IVHS database domain, events such as traffic accidents, traffic congestion, safety envelope violation need to be persistently monitored. Since the occurrence of events are not predictable, it is more appropriate to model them as triggers rather than as queries. Triggers are more like persistent queries or demons existing in the database. Triggers are usually implemented as rules. A rule contains a condition part and an action part. The rule ``If collision with the self occurs, then report it and store all the colliding objects.", for example, can be defined as follows.

define rule collision_report is
on Collision_Detection (self.box)
do report_collision()

ACCESS METHODS FOR GEOGRAPHIC SEARCH AND MOTION

Access methods are data structures used to organize the data file on disk for efficient query processing. The access methods help in retrieving the data records of files in various sorted order to help answer interval queries efficiently. Recently a number of spatial data access methods, (for example, R-tree and Grid Files), have been proposed to retrieve objects which are n-dimensional points or solids. The spatial access methods optimize queries to retrieve all points or solids enclosed in or overlapping with a given search region. However, these access methods were designed with the assumption of static world with no moving objects. The update rates were assumed to be much smaller than the search query rate.

Motion distinguishes the IVHS database from the traditional geographic database. In the presence of high update rates due to moving objects, traditional methods incur very high overhead of maintaining the tree structured indices. We have proposed a new access method called **MoBiLe** Files (MOnotonic Bounded mapping In LEotard Files) to address these concerns. We utilize the population distribution function and time-average traffic density function to determine the disk space needed to store the geographic data. A contiguous area on disk (t consecutive tracks and identical s sectors/track) is chosen to store the object. The shape of disk region corresponds to the population distribution in the real world to preserve the geographic neighborhood relationship on the disk. The consecutive updates due to motion typically affect a common disk block unless the vehicle crosses over the block boundaries. Thus several update operations can be handled by updating a single disk block. The collision detection query is answered by examining the block containing the area occupied by the vehicle in question.

CONCLUSION

We have provided a representation of transportation data which is semantically rich in capturing the needs for the driver, traffic controller and researchers. Abstract data types and rules are created using Postgres' type definition and rule definition facilities. The use of these developments are widespread and can help researchers and traffic managers as well as providing a considerable challenge to computer scientists.

THE IMPROVEMENT OF SIMULATION FACILITIES

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Key Words: Equipment, Simulation Facilities

The Improvement of Simulation Facilities

INTRODUCTION

EXISTING FACILITY

The existing facility at the HFRL consisted of a flat screen projection system with an analog Honda vehicle attached to one 386 PC computer. The PC generates simulation images based on driver movements made by the steering wheel, accelerator, and brake. These movements are assessed by potentiometers attached to the steering wheel, speedometer, and brake pedal. The analog signals are converted at the computer into positional changes and the PC then calculates changes in position and generated the correct images. As the system was originally set up, this was a time consuming and therefore slow process. The human eye could not distinguish these changes as they occurred, but drivers could tell that when they turned the wheel the car did not move for a perceivable amount of time. This was probably in the "tenth of a second" range of a delay between starting a turn, and actually seeing it occur. The facility was dependent upon the computing system operating at optimal speed or participants would feel that the simulator was not "realistic".

A typical driving simulation study at the HFRL would consist of participants using our fixed based Honda Accord vehicle and a driving world consisting of three roadways. The hardware used included an XTAR graphics generation board in a 386 PC, and a torque motor and input 286 PC computer to collect information from the driver and relay changes to the XTAR system. To do this we employed the dynamic driving simulator at the HFRL (see Figure 1.) and used a simulated driving world.

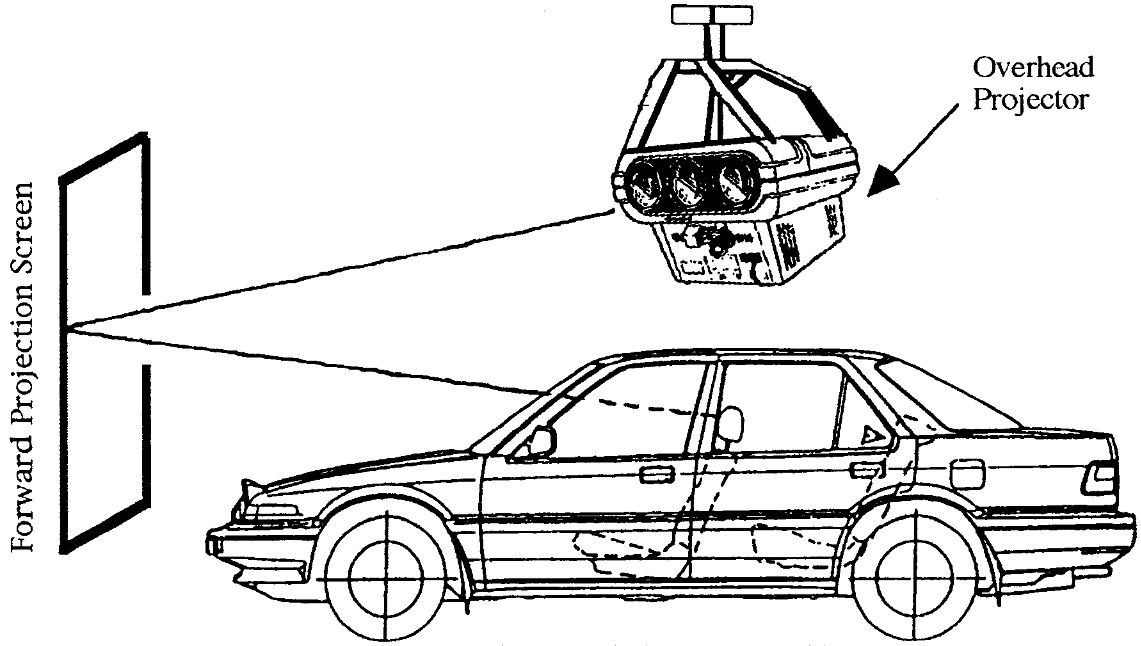


Figure 1 *Side projection view of the simulation facility illustrating the 1990 Honda fixed-position vehicle, the overhead projection system, the screen orientation and driver visual viewing angle.*

Inputs from the driver, in terms of accelerator and brake activation and steering are converted from analog to digital inputs at the PC. These are used as information which is fed to a computer model which approximates the equations of motion for the actual vehicle. Outputs from this model are then used to adjust the eye point of the driver in the environment in accord with the inputs given. The simulation changes to fit the orientation of the driver based on their driving actions. These changes are then displayed in real-time, constituting the dynamic driving world observed by the driver of the car.

This simulated driving world was programmed to be representative of the Twin Cities Metropolitan roadways, including driving with and against traffic and maneuvers typical of driving: merging into traffic, taking a left turn across traffic, and passing cars in front of the drivers. We called Segment One "Cedar Avenue" due to its representation of two lane bi-directional traffic. Segment Two we called "the Cross town" due to its East/West alignment and single directional traffic. The final segment, Segment Three, we referred to as "35W" due to its Southbound orientation and two lanes of like direction traffic, which is traveling at various speeds. These names are for illustration only and to give the drivers a semblance of the type of traffic they will encounter during simulation driving. (See Figure 2).

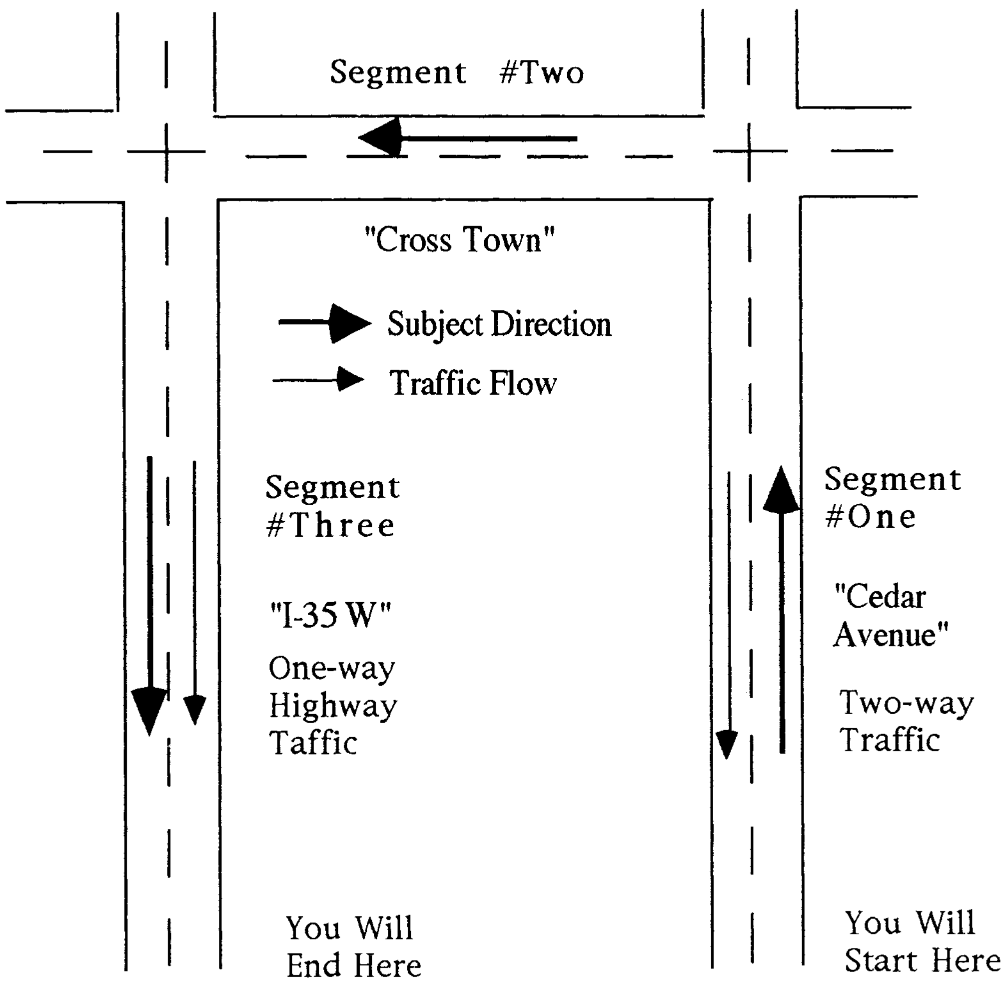


Figure 2. *Simulated driving world containing three segments of differing driving conditions. You will note that drivers cross traffic at the end of Segment One and pass other vehicle on Segment Three.*

The major variable studied is RMS (Root Mean Square) error, which is a measure of the vehicles position in relation to a center point. RMS error in this experiment was a function of the sampling rate and the frame rate of the simulation. This means that this variable is dependent upon the speed of the vehicle and the ability of the computing system to "redraw" the simulated world as seen by the driver. This is controlled by having participants drive at a constant 55 m.p.h. and designing a simulated world that the computer system can redraw faster than the human eye can perceive. RMS error can be measured by determining the area of participants' vehicles deviation from the center line of the simulated roadway and was collected every tenth of a second. The center line perpendicular to the viewing screen that passed through the Honda Accord is calibrated as the zero line. This is compared to the center lane of the simulated world's roadway. We would then collect data based on the simulator vehicles movement from the center of the lane they were driving in compared to the center lane of the entire roadway. Other variables noted were deceleration / acceleration changes, driving performance degradations, and braking changes when stopping.

We used the XTAR hardware platform to generate the driving worlds. This is a medium level graphics generation system based in a 33MHz 386 PC that attaches to an Electrohome ECP-3000 projection system. Also contained in this loop is the actual vehicle itself, the Honda 1990 Accord and the associated analog to digital conversion peripherals that allow interactive driving responses on behalf of the experimental subject. As noted below, the software package used in the present project for the generation of objects for this system is the AUTOCAD design aid system. The XTAR system has been used extensively at HFRL for experiments in which look-ahead driving maneuvers predominate (e.g., left-turns). In terms of computational power, the XTAR system can calculate 2,000 flat-shaded polygons per second, where polygons are the currency of simulation fidelity. This represents a refresh or redraw rate of greater than thirty screens per second. Object creation in XTAR is performed in a number of steps, as is illustrated in the following diagram: (Fig. 3).

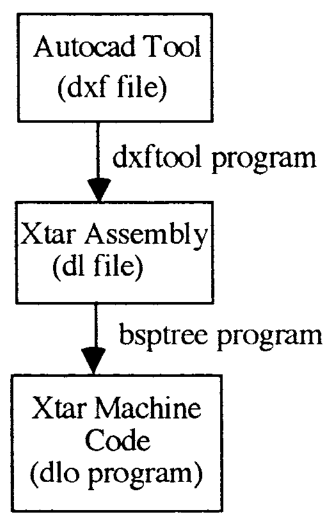


Figure 3. *Object creation procedure in the XTAR graphics simulation system.*

Once the AUTOCAD file for a object is created, the file is saved in the "dxf" format. XTAR has its own series of translation tools that convert this dxf file into a format that allows the object to be loaded at runtime.

It is this dependency upon the XTAR's ability to load changes at runtime that causes the simulation to react slowly and to feel unrealistic. To improve upon this we have refitted the car and changed the basic computing system of our simulator. To provide enhanced viewing we are constructing a wrap-around projection system to promote realism.

IMPROVED FACILITIES

A three step approach to improving the simulation was completed with this task: the first involved improving the existing flat screen wrap-around simulator; the second was the purchase of a Silicone Graphics reality engine and related software to be used for graphics generation; and the final step was planning and beginning the construction of a 360° wrap-around visual field dynamic driving simulator.

Changes to the existing simulator:

Several changes were made to the existing wrap around simulator. The first step was to add an analog to digital converter to the vehicle and allow full processing of all digital data to be completed by a PC installed in the rear of the car. This was completed by adding separate distribution circuitry to each of the feedback systems. This meant adding a digital throttle, steering, and brake interface connected by an interface distribution circuit and powered by continuos 5 volt DC power. (See Appendix A. Car Circuitry). This fully processed data is then sent to the XTAR generation system for simulation world modeling. To simulate the "feel" of real steering motion, there is a feedback control which sends turning information to the PC in the rear. Information on the speed and direction of the turn are sent back to a servo motor (Torque motor) which counteracts the turns with a calculated opposing force. In other words if you turn to the right, your speed and steering wheel degrees turned is calculated, and a counter force to the left is applied to the wheel. This provides the realistic "feel" of the road pushing back against the tires as you turn in one direction or the other. To facilitate this feedback to the XTAR system we have installed a servo amplifier circuit to feed digital information matron to the PC in the rear and to the torque motor which connects to the steering to add force to the steering wheel. (See Appendix B. Feedback Control Circuitry). This means the data can be relayed as real-time information and there is no perceived slow down between starting an action and seeing the result. To further speed up the process we have added a Compaq Presario and an IBM PS-1 486 Computer to enhance the flat screen simulation design. We now use two PCs to generate and respond to driver input in the driving world. (one computer draws the world, the other processes incoming information and data collection). This speeds up the simulation to make movements appear more real time without delays. In essence the Compaq computer acts as large data collector saving all data that needs to be analyzed, the other PC receive only driver information ready to be calculated for graphics generation and the output is almost instantaneous. Previously, the XTAR computer received all information, processed it, stored data for analysis, and generated the driving scene. Now the data is collected for analysis at one computer, the other processes the data for graphics, and the XTAR simply draws and generates the driving world. This has increased the speed of the simulator from 30 frames per second to 100 frames per second.

To promote realism a second driver's side screen and projection system has been installed to project side views of passing cars and scenery. This aids in the ability of the driver to see when to make turns and when to change lanes. (See Figure 4). This is extremely helpful in creating a feeling of seeing in three dimensions instead of watching a movie or operating a video game. Participants can now observe what is happening on a perpendicular road before turning down that road.

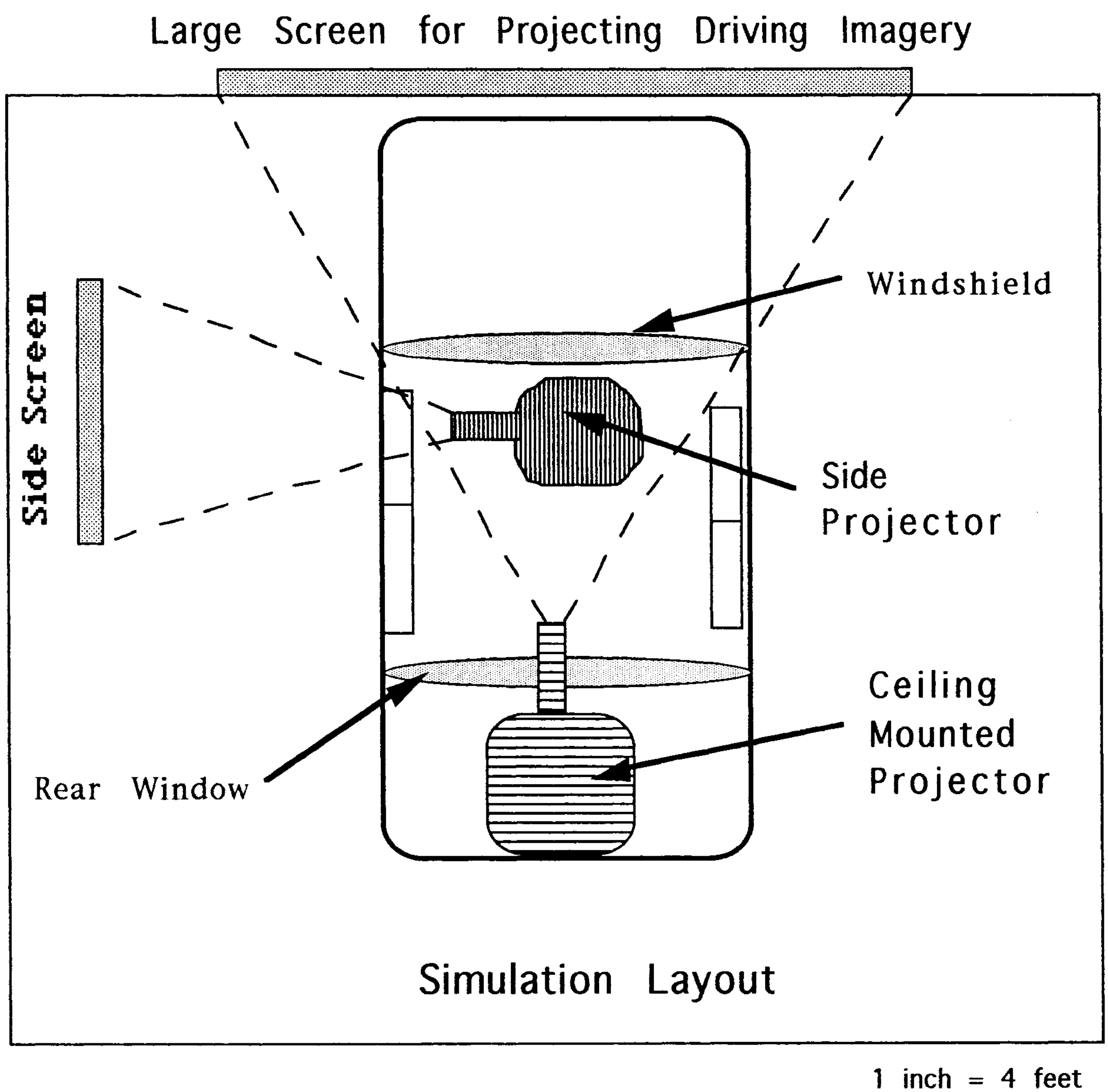


Figure 4. *Overhead view of side projection system.*

To enhance communication a "hands free" two way audio system has been installed which would allow for the experimenter to communicate with the participant during trials and vice versa, while both are stationed at their respective positions behind computer terminals and the wheel of the car. The required the purchase of PA equipment and microphones that were mounted in the car and at the experimenter's stations. The participant hears through the cars audio speakers, while the experimenter has head phones to listen through.

Silicone Graphics Simulation

The proposed wrap around driving simulator will employ a Silicon Graphics 4D 310 VGXT Iris workstation driving four Electrohome projector displays, a Harris Nighthawk 4402 for host communication to the simulator, a VMIC 4100 Analog/Digital (A/D) board for input from the car, and a sound generation system. The first goal is simultaneous projection from three projectors on a wrap-around screen which will provide a 210^{o} field of view. We will obtain this increase in field of view while *increasing* the resolution of the display of the driving world. The Silicon Graphics computer will drive all of the displays at 1024 x 1024 at a 30 Hz refresh rate. The Silicone Graphics can use a dual video buffer, projecting one field while simultaneously generating the next field in sequence. It has the largest frame buffer rate on today's market. The frame buffer rate is a measure of the write per bit frequency which this system can draw at 160 million pixels per second, meaning the screen can be refilled 203 times per second compared to roughly 30 per second for the XTAR system. Because of the high frame buffer, effects like fog, rain, or transparency can be added real-time. The Silicon Graphics will enable us to provide texture to the driving environment, thereby adding more realism.

The Harris Nighthawk will provide host computing facilities for the simulator and increase the experimental capability of the lab by providing faster input from the car, greater resolution of operator response times, and, in the future, with the addition of a Digital/Analog board, output to the car for the gauges in the instrument panel. The VMIC A/D board is required for getting operator input from the steering wheel, brake and gas pedals, transmission, etc. The VMIC 4100 board is a 64 channel auto scanning device which polls each channel two times per millisecond, which eliminates the need to actively poll devices in the car. The combination of the Harris Nighthawk and the VMIC A/D board will allow data acquisition of the simulation facilities to be very close to real-time. With specific respect to the I/O Communications unit, the Harris 4402 we have purchased has the best real-time system processing on the market today. The Nighthawk runs a multi-processor, multi-threaded preemptive Unix. The Nighthawk has excellent input/output capabilities coupled with the operating system that make it the system of choice for real-time simulation. By using the Harris, we will be able to extract the maximum capability from the existing Silicon Graphics 4D 310 VGXT in terms of rendering speed. The Nighthawk will enable us to provide better resolution on the timing of operator responses because several clocks are built into the architecture. The utility of this system is attested to by the fact that. The Harris Nighthawk is being used as the host computer for the Driving Simulator at the University of Iowa and Ford uses one for their real-time driving simulations.

To further increase realism a 12 channel audio system is being installed which will use a dual sound feature. The first feature will be realistic automobile sounds for the driver's vehicle. Turning the key will send a digital signal to a 16 bit sound board activating a car start sound. Once the car has been started a low engine drone will be continuos until ignition is cut or the experiment is concluded. Feedback form the accelerator and the steering will be used to add acceleration noise and tire/roadway noise when turning. To further increase the sound capability there will programmed sounds added into the simulated world. Cars the are passed or that pass the driver's car will have sound which will use a Doppler equation to simulate the change in tone of a passing vehicle. Included in this programming will be effects for when curbs are struck by tires or even when accidents or "standing on the brakes" occur.

This sound enhancement has been shown to be very effective in providing a realistic driving environment, where participant's believe they actually feel movement even in fixed based simulation. (McCauley, Clarke, Sharkey, & Dingus, 1994.)

To assist in programming driving worlds on the Silicone Graphics system we have purchased two software packages; Designer's Workbench™ and EZ Scene™. Both of these packages allow multiple level programming of different angles of the same scene and can be integrated in easy to set up and execute files for real time downloading and simulation world development. The lab currently has two full time programmers creating simulation scenarios using both programming tools.

Wrap-around Screen Simulation System

Finally, we have begun construction of a 360° Wrap-around Dynamic Driving Simulator which will use the capabilities of the Silicone Graphics and Harris Night-Hawk real time computers that we have to draw a full circular driving world. This will allow the driver to see cars approaching from behind, to use all of their mirrors, to see cars pass by form the front, sides, and to the rear, and allow full realism in the simulated world. As such the vehicle in the simulator is also being outfitted with the same measures and systems as the flat screen vehicle. In addition full quadraphonic sound will be employed to add car noise, ignition sounds, the sounds of passing cars, and the sounds of tire to road contact. Further we will be connecting the two simulators together so that someone driving in the flat screen simulator (experimenter, other subject, or control vehicle) can be projected into the wrap around world and interact with the driver of the wrap around vehicle. Each vehicle will be projected real time onto the simulated world of the other, therefore, allowing experimental design where true interactions between two drivers can be measured. It will be possible to have an experimenter in the flat screen car perform a dangerous maneuver which is translated to the simulated world of the driver of the wrap around vehicle. We the can observe the reaction of the driver to an emergency situation, near miss accident, or full contact accident. As such this will make the HFRL one of the only laboratories in the world to have interactive simulators.

The wrap around is being constructed as a geocircular dome around an Acura Legend automobile. The walls of the wrap around will be formed material that is projection grade with no apparent cracks visible, giving true depth perception to the simulation world. The end of the simulator opens to allow entry and exit and forms a seal when closed. Four projectors are mounted above the vehicle with three projecting a circle approximately 210° from the front, and a rear camera projecting on the rear 90° of the screen. This is not a complete 360° projection but the sides are the perceived blind spots of the car and drivers can not see that the projection is not complete. To their perception it appears as a full 360° . (See Figure 5). The frame is wooden with cast steel sides and can be taken down and reassembled within a 48 hour period. The four projectors are hung from above on a connecting harness attached to the top of the dome, to allow full clearance under the car. This also eliminates the ability of the participant to see the projectors when inside the simulation vehicle.

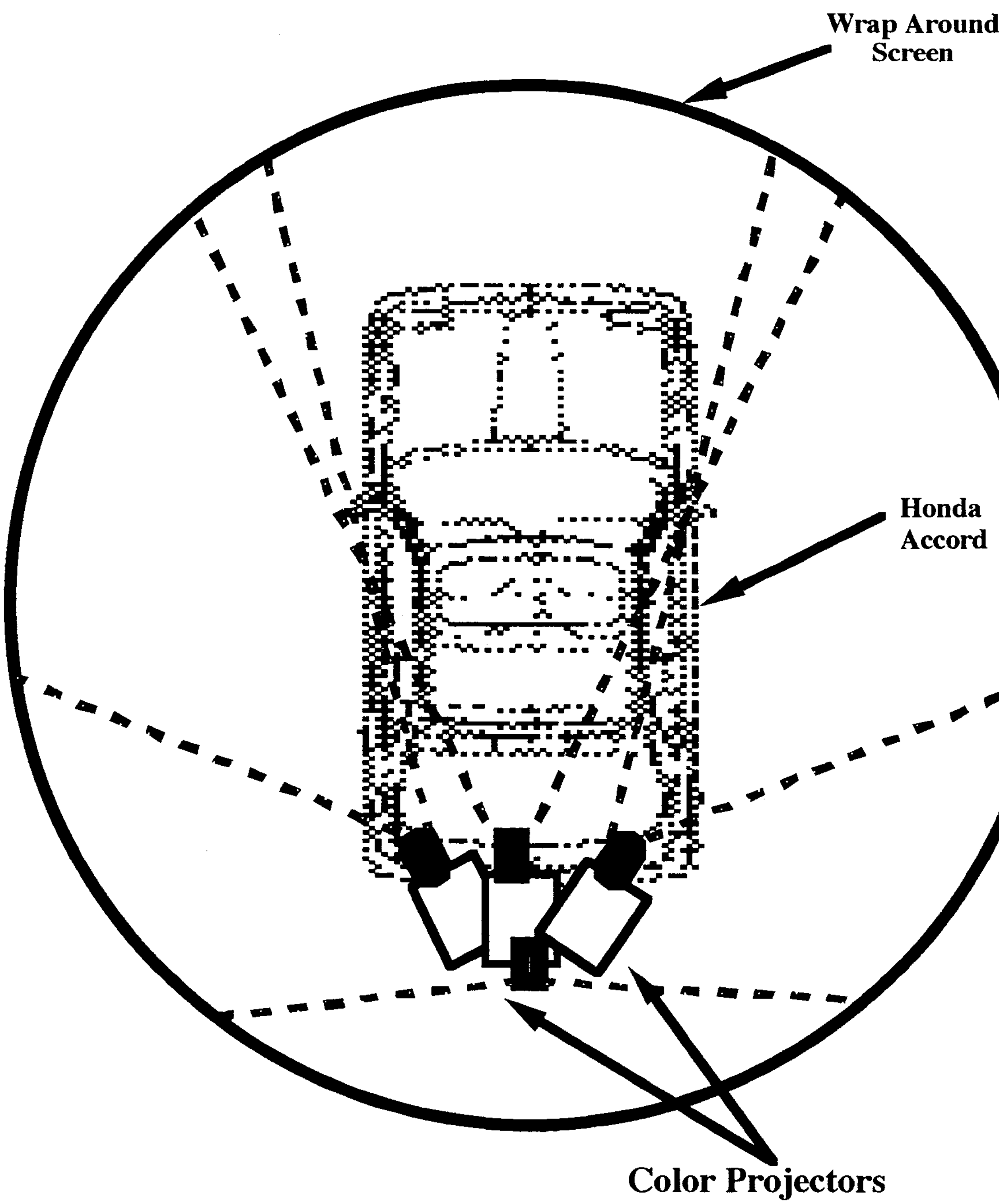
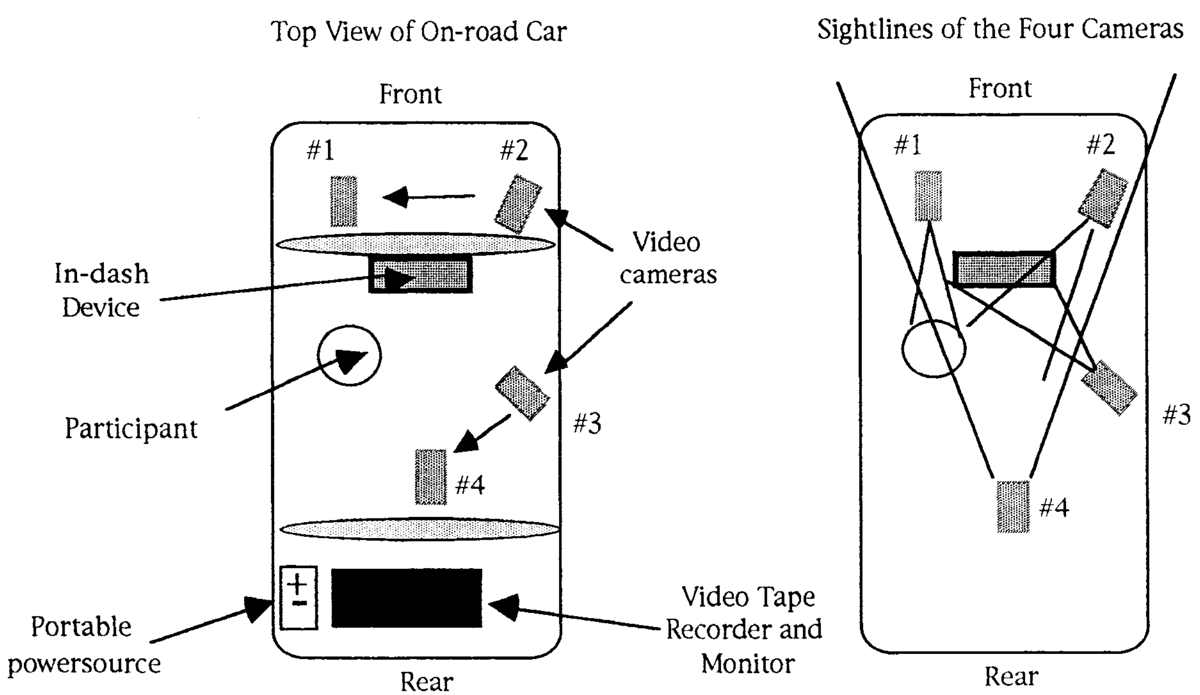


Figure 5. *Wrap-Around Screen, Associated Projection System, And Simulator Vehicle.*

Four CCD video cameras will be installed inside the vehicle to give the experimenter full view of the driver's reactions while inside the simulator vehicle. This common method of evaluation is often used in evaluating in-vehicle devices focusing on the driver's interaction with the devices. These cameras are connected to an outside monitor and VCR which record the split screen images of all four cameras. Many recent studies on ATIS and ATNS use video data collection from multiple vantage points. (McCauley, Clarke, Sharkey, & Dingus, 1994; Akamatsu, Yoshioka, Imacho, & Kawashima, 1994; Srinivasan, Jovanis, Yang & Kitamura, 1994; and Sperling & Reeves, 1980). The most common positions of video cameras correlate to the actions of the driver with these devices. Cameras are mounted to observe the driver's eye, head movements, interaction (hands) with the devices, and the overall driving scene from behind. This arrangement of cameras has produced the most interesting data (See Figure 6).

Figure 6. *Video camera placement in a simulation vehicle and the associated sight lines from each camera.*



This simulator is scheduled for full completion and operational status by June of 1995. Preliminary testing and pilot experimentation is expected by December of 1994.

Assessing Driver Behavior

A critical component of IVHS is the understanding of how drivers' behave. In particular, we want to know how they react in normal driving conditions and how they react in the presence of advanced systems as proposed in a variety of IVHS programs. There are many different strategies through which to obtain such knowledge. At a simple level, we can ask drivers for their subjective reaction. That is, how difficult did they think a particular system was to operate. Subjective response provides an important window on behavior since it is a major factor in issues such as user acceptance. However, subjective report is often misleading, especially about such critical elements as actual performance. In short, people are often poor judges of their own abilities. Were we all the same in our mis-perceptions it might in fact be reasonable to draw performance conclusions from subjective report. Unfortunately, however, some individuals over-estimate their abilities while others under-estimate their abilities just as radically.

The Importance of Context

What we have found from the past three decades of human performance research is how important context is. For example, many organizations such as the military use batteries of tests to try to predict an individuals reaction to a specific situation. The rationale is that performance on the battery relates directly to actual operational conditions. As we learn more about human behavior, we realize that this assumption frequently does not hold. In past psychological experimentation, the individual was confined to a small, often darkened room and show stimuli through a device (a tachistoscope) which presented simple number or letter displays for a matter of milliseconds (thousandths of a second). The assumption was that if more could be known about basic human-information processing capabilities, then this knowledge would transfer to the outside world where performance would become predictable. Unfortunately, this assumption is poorly founded and can, and has, led to many mistakes. For example, reaction times of drivers used by traffic engineers comes directly from this form of testing. The arbitrary 1.5 second reaction time is clearly a poor compromise since reaction time, as is all driver behavior, is critically dependent upon context.

Context refers to behavior embedded in the actual performance environment and leans heavily on a newer area of psychological investigation called ecological psychology (see Flach, Hancock, Caird, & Vicente, 1994; Hancock, Flach, Caird, & Vicente, 1994). In this approach, every effort is made to ensure that the behavior of interest is studied in the actual context in which it occurs. Inherent in this approach is a trade-off. The trade-off is critical to the present comparison of simulation versus video systems and it is this. The more context-free the environment (i.e., the old laboratory conditions) the more control the experimenter has of the situation. The more context-dependent the environment, the less control the experimenter has of the situation. In past research, control was seen as a critical factor since the emphasis was on main-effects or simple cause-effect relationships between independent variables and dependent variables (e.g., how does changing the color of a road sign affect recognition rate). In highly controlled conditions, it was hoped that each of these single relationships could be mapped and then assembled to provide a predictive picture of what happens in the real world. What defeated this aspiration was interactions. That is, factors in the real-world do not have simple, 1:1 causal relationships with specific outcomes, or more succinctly, it depends. That is, the recognition rate of signs doesn't just depend upon color, but also on size, on viewing angle, on glare in fact it depends directly upon context.

How then is the human factors researcher to provide the traffic engineer with reasonable assessments of human behavior if the answer is always, it depends. This has been a source of continued frustration of those who interact with cautious human factors specialists who are always aware of potential interactive effects. The answer lies in a different approach to experimentation. In the past, all the human factors researcher could present the driver with was one of two conditions. Either the sparse and uninformative single stimulus display, or the field study of on-road driving. In the hands of imaginative and informed individuals much useful insight came from each of these approaches but they always suffered under the handicap articulated above. However, recent developments in computing have allowed human factors researchers to investigate a compromise in the form of high-fidelity simulation. In this approach, scenes are presented which represent the real-world. However, unlike the real-world they are controllable. That is, the researcher has direct control of all that is displayed to the driver. This control is critical since it permits specification of relationships rather than speculation as occurs in uncontrolled conditions.

Comparison of Investigative Techniques

The purpose of the present comparison is for the utility of split-screen video against high-fidelity simulation. However, prior to such a comparison it should be noted that each of the methods are, in their own right, legitimate avenues of driver behavior investigation. It may well be that there are circumstances in which only one or the other can be used (such as in the collision-avoidance work presented later in this report). Therefore, the comparison does not seek to reject one or the other method but rather seeks to compare the two as potential strategies in HFRL. We have engaged split-screen video before in previous experimentation (Hancock et al, 1989). In this procedure, one video camera is trained on the forward view of the roadway ahead while the second camera views the driver. The two video images are (gen) locked together on a common time base. The expectation is to provide a view which links driver reactions such as eye movements, etc., with events that happen on-road. The link is tenuous for the following reasons. First, the fields of view of the cameras is often limited and use of view expanding technologies such as fish-eye lenses distorts the image to the extent that post-processing is problematic. More simply, the more panoramic the camera system the more difficult it is to tell where the driver is actually looking. Various technologies have been developed to address this issue and in particular eye-track systems are now more widespread and well-known. Unfortunately, the problem goes deeper than simply tracking the eyes. It is the case that knowing where the driver places their eyes is not to know where the driver places their attention. It is often assumed by advocates of eye-tracking that attention and visual placement overlap. However, it is those very occasions in which they don't, e.g., day-dreaming, that knowledge of where 'attention' is becomes so-important. Like all technologies, eye-tracking is becoming more sophisticated, small and more manageable for the subject and within the coming several years is liable to provide useful insights into driver behavior. However, the present assessment is that current technologies are costly and the inference drawn from the data they provide problematic. Should the issue of eye-tracking re-emerge, considerable thought has to be directed to the use to which data from these systems is to be put.

Without sophisticated eye-tracking equipment it is exceptionally time-consuming to attempt to posit where drivers' eye-positions are located and accuracy is always a concern. Hence, split screen video for eye movements is an emerging but costly technology with potential problems. It is the case, however, that split-screen video can provide a number of other insights into behavior. For example, we can observe interaction with in-vehicle devices and other behavioral responses, e.g., eye-blink rate, can be recorded and post-processed easily. One undoubted advantage is that of serendipity. In simple terms, luck. Split-screen video, as a real-world, on-road technology can sometimes catch happenings and events which the experimenter would never predict for simulation purposes. Hence, the use of video alone, rather than split-screen, is one that is advocated for on-road work and is one we have consequently pursued at HFRL. However, luck by its nature cannot be predicted and considerable frustration may be experienced in its pursuit. The alternative we have followed is progressively higher-fidelity simulation.

In its earliest form, HFRL presented a low-level simulation which was generated in a square polygon-world. While the driving environment was somewhat limited, it did provide the opportunity to examine driver responses in maneuvers such as the left-turn where the display of concern was primarily straight-ahead. Partly as a result of this assessment, we have begun to engage wrap-around high-fidelity capabilities. The reasons for this are many. However, principally, such simulation provides the appropriate contemporary compromise between context and control. We are able to set context and so can test drivers in 'worst case' scenarios which can consequently provide traffic engineers with numerical bounds and limits to the systems and roadway configurations that they have designed. Further, we can evaluate roadways that have yet to be built and as a result of the present contract have already done so (see Carmody from vita).

World-Wide Simulation Facilities

At HFRL, we are not alone in this decision. The Australian Research Team in Victoria, with whom we have had interaction, have also decided to pursue this strategy. They have commissioned a simulation facility from a North-American company to achieve aims consistent with those at HFRL. Through our mutual interaction, the basic computational facilities are also common such that software environments are interchangeable. This system is commercially available at over $1 million, however, the system at HFRL has been assembled for less than one-third of this cost, of which the present contract has played a direct role. We further expect to be able to share interactive facilities with several other national and international under this strategy. In addition, this decision allows HFRL to interact with the University of Iowa in simulation and has been directly influential in a teaming agreement with the University of Michigan for sharing simulation facilities. In summary, while video technologies clearly have a place in the future of transportation research and will, in all probability be used by HFRL in the future, split-screen video still does not provide the control to evaluate IVHS systems in the manner expected by the Minnesota Department of Transportation. It is a result of this collective synthesis that high-fidelity simulation is the preferred experimental strategy in HFRL at present.

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IN-VEHICLE COLLISION AVOIDANCE WARNING SYSTEMS FOR IVHS

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Key Words: Driver Response, IVHS Technologies, Collision Avoidance

INTRODUCTION

It is perhaps the major selling point of IVHS that it promises improved road transportation safety. Some critics have doubted whether this improvement can or will occur (Insurance Institute for Highway Safety, 1994). The principal way in which high-technology promises to help reduce accident frequency is through the use if In-Vehicle Collision Avoidance Warning Systems (IVCAWS). These systems promise to provide the driver with timely information about the potential for imminent collision. Put in this way, the problem seems reasonable and somewhat straightforward. However, such a perspective is particularly misleading. The first efforts at in-vehicle information systems in IVHS have been directed toward navigation aids that provide the driver with map information and more recently, dynamic, real-time information about the status of congestion in the immediate area. (Hancock & Parasuraman, 1992; Hancock, Dewing, & Parasuraman, 1992) Founded on this information, intelligent aids can provide on-line recommendations about preferred route guidance and the appropriate ways in which to avoid stoppage and slow down. In a fundamental way, collision-avoidance warning systems perform exactly the same function, except that the time constraint provides a quantitatively different challenge. In many IVHS arenas, e.g., advanced traffic management systems, it is possible to use technology transfer to import solutions that have been developed in other areas such as aviation. However, this technology transfer does not appear to be viable for in road-vehicle collision-avoidance systems. For example, the comparable systems in aviation are the various configurations of the Traffic Collision Avoidance System (TCAS). Here the time window falls into the range of minutes, not the millisecond range that constrains road-vehicle operations. There are perhaps comparable technologies in the robotics realm in which robot vehicles have been asked to perform navigation tasks in which obstacle avoidance is a critical concern. But such systems represent totally automated functions and this raises perhaps the central design issue in IVCAWS development. That is how are the component elements of the collision avoidance task to be delegated.

One simple answer is to delegate all control to the automated systems upon detection of a collision situation. (see Bekey, 1970; Fitts, 1951) As one facet of the automated utopia (autopia), this solution has much appeal to the engineer who can then 'reduce' the problem, apparently, to one of algorithmic solution. It is this form of investigation which underlies current efforts at rear-end collision avoidance (e.g. Farber, 1992). One concern with such systems is the question of signal to noise ratio, such that we must consider what is the cost of a miss with respect to a false alarm. Missed signals (collisions) have a phenomenally high cost, yet their potential frequency is relatively low. Indeed some drivers may drive for decades without taking the sort of evasive action mandated of such a system. However, if great gain is focused on not missing signals, the problem of frequent false alarms is immediately encountered. It is well known from operation in other vehicles, e.g., single seat high-performance aircraft, that false alarms in warnings are highly distractive and disturbing to the operator. There is at present no simple solution to the trade-off that such a ratio implies other than the simple and simplistic affirmation of deriving a perfect detection algorithm.

Given an actual imminent collision situation, how is the automated vehicle expected to respond. It is probable that for the alert driver, a number of options open themselves up, such as running off the road onto a soft-shoulder, and this may be considered a preferred action given the expected cost of collision. However, given the myriad of environmental contingencies, how is an automated decision expected to perform the task of detection, evaluation, and action initiation within the available time frame? The computational power presently required to accomplish such action, were it actually possible, would certainly cost many orders of magnitude more than the value of the car, which we cannot forget is manufactured in a competitive financial environment. Hopefully, such capabilities will become real within the coming years and the computational capability to support such action will drop in cost at rates comparable to today's logarithmic acceleration. However, absent such availability, we need to keep the driver in the loop as we can assert that drivers currently are well able to avoid most obstacles set in their path.

DRIVER-IN-THE-LOOP COLLSION AVOIDANCE SYSTEMS

We cannot but wonder at the relative infrequency of collision given the number of opportunities on an everyday basis. Some may assert that this is especially true given their perceptions of the capabilities of other road users. It is difficult to speculate on the numerical potential for collisions in contemporary driving but from this perspective, it is clear that human controlled vehicles are able to navigate current road systems and avoid the vast majority of such events. In light of these observations, At the recent IVHS America Meeting, Eugene Farber speculated upon this frequency for one particular scenario which was rear-end collisions. By bounding the operational space to this one configuration he was able to derive the figure of approximately 0.5 million 'slow-downs' associated with the actions of a single driver for a lifetime of operation. Given the respective reliability of the "average" driver he further suggested some potential ways in which to consider the additive nature of a warning aid reliability with this estimate of human reliability. Despite the inherent problems of integrating machine and human reliability (see Adams, 1987), the approach advocated by Farber was one of shared actions which I put here under the title of a hybrid warning systems. It should also be noted that based on daylight driving, there is approximately one fatality per 77, 519, 380 miles of driving (see National Safety Council, 1991, and Owens, Helmers, & Sivak, 1992). All of these observations attest to the current capability of the driving population for safe vehicle operation. It is important not to remove human capabilities prior to the unequivocal establishment of a proven superior system. The combination of human response augmented by machine information or action falls under a heading of a type of system that I have previously referred to as hybrid systems. The use of hybrid systems allows the retention of flexible actions as compared to the highly constrained environment that has to be enacted in early stages of automation. In hybrid architecture, proximal warning systems have to act as information augmentation and decision support and this is one role advocated in human-centered automation design.

The idea of retaining driver-in-the-loop architecture, with the expectation of the final arbitration of avoidance action remaining with the human component is predicated upon a human-centered approach to IVHS system design made explicit in the work of Hancock, Dewing, and Parasuraman (1992) (see also Owens, Helmers, & Sivak, 1992). While the human-centered approach presents numerous human factors related problems, the alternative systems architectures founded principally upon engineering conceptions hope to solve the problem via automation techniques with relatively little direct concern for the proximal user of the system, the driver. While such 'control' strategies have always had their appeal to the design engineer, it has been shown with nauseating frequency that such design approaches are almost always doomed to failure as a result of the intrinsic assumptions that form their basic premise and foundation. As indicated earlier, the state-of-the-art in automated collision detection and avoidance is certainly not well enough advanced at present to subsume such a function, hence the notion of a hybrid approach is probably the preferred if not the only viable contemporary strategy.

Having said this, we cannot adopt the design principles that have been enacted elsewhere in many complex systems of automating all that it is possible to automate and to leave the human as the "backup system of last resort." Indeed, the lessons from aviation, aerospace, process control and similar domains have taught the flaws and fallacies of such a strategy. This is particularly true of driving where the driver is liable to retain active control of steering, at least in the immediate future. We should note here that there are a number of active research efforts that seek to provide automated steering for the driver such that active guidance is not required. If and when such systems are installed into IVHS environments, the evolving role of the driver will converge rapidly with many other operators to whom management and decision-making have replaced active control. How such a change in role and demand will be greeted and faced by the vast range of skills and capabilities in the driving public is essentially unknown. How drivers will respond in conditions where differing proportions of vehicles are equipped with such capabilities is also uncertain. Such human factors questions again emphasize the necessity for using a human-centered approach. Thus, if task allocation is not to become a default approach (Chapanis, 1965, 1970) as outlined above, or based simply on descriptive, machine-oriented comparisons (Bekey, 1970; Fitts, 1951; McCormick & Sanders, 1982; Meister, 1971), we must seek new approaches that will stand up to the rigors of fast, real-time application that are the leitmotif of IVCAWS.

One potential solution lies in the application of adaptive systems through the medium of intelligent interfaces (Hancock & Chignell, 1989). Adaptive human-machine systems (Hancock & Chignell, 1987), which represent a particular subset of hybrid systems, emphasize the use of mutual adaptive capability on behalf of both human and machine to promote flexible and rapid response to uncertain conditions and unusual task demands. As such their major usage are focused on transient, unstable, emergency conditions as typified by the imminent collision scenario. Adaptive human-machine systems are facilitated by the use of intelligent interfaces which act as a translation intermediary between human and machine framing and managing respective queries and actions of both human and machine in the language and format which is appropriate to each element. The use of intelligent interfaces as envisaged by Hancock and Chignell (1989), has been suggested for application to numerous human factors problems raised by IVHS development (Verwey, 1990), and IVCAWS appears to be perhaps the prime example where such development could be immediately evaluated. As the full range of questions and problems concerning such application cannot be fully aired in the present brief space, it is perhaps best to consider a way in which the problem of collision avoidance warning can be approached.

However, much of the discussion concerning different strategic approaches to collision avoidance are premature. This is because much of the basic experimental data upon which design decisions must be founded has yet to be recorded. In more simple terms, we don not have enough information about how drivers currently react to predict how they would react to different collision-avoidance systems. This lack of data is a particular drawback and therefore, the present experiment is directed to an evaluation of driver response to vehicle proximity warnings at an intersection. The specific purpose is to evaluate the influence of modality of warnings and latency of warnings upon turn decisions.

METHODOLOGY

As noted there is insufficient understanding about the way in which purely manual collision avoidance actions are initiated. We have only dim evidence provided by epidemiological data and impoverished evidence that come from accident reconstructions as to the behavioral sequence of actions in collision or near-collision circumstances. Our lack of knowledge about the dynamics involved in collisions and near misses is such that the design of collision avoidance warnings is a hazardous endeavor and may potentially heighten rather than diminish collision risk. If a loud warning is issued it may startle drivers into unforeseen response. Likewise if the threshold for warnings is distance, what if the distance is too short for drivers to complete effective actions. Likewise, if the distance threshold is too high and drivers receive constant warnings, they will not trust the system and may disregard warnings in critical situations. Also, with a user-centered approach, we may very well attempt technological solutions to vestigial problems which themselves might be more easily defeated by a careful analysis of what the driver is trying to achieve (see Owens, Helmers, & Sivak, 1992). While each of these cautions may be valid, it is still the case that dynamic collision avoidance engenders rapid vehicle maneuvers in which the response of the driver is, most probably, critically dependent upon the interaction of visual and motion cues which they are receiving. That alone justifies the creation and use of high-fidelity simulation testing environments. We observe that the use of an integrated motion base, that is one that produces true dynamic response as compared to random ride motion, is the differentiate between medium and high-fidelity simulation. Thus while a fixed-base environment can provide strong visual cues as to motion, the full scale integration with a motion base, as typified by commercial flight simulators for pilot training, are those which begin to approach and surpass the Turing test for artificial realism. We have yet to reach this level in all but one or two simulators world-wide. In consequence, the present experiment is conducted in a fixed-base simulator and focuses on decisions rather than proximal avoidance actions. Therefore, we have designed a collision avoidance experiment based on a simulation program where drivers make left turns across traffic with varying gap size between cars. The experimenter randomized the sequence in which five collision warning modalities (no warning to continuos) were presented to the driver and randomized the gap size between cars approaching the intersection during each of the trials. The design is such that no driver receives the same order of warnings. The dependent variable in the present experiment was the success rate of completing the turn which was recorded by the experimenter. It was this data that was subjected to analysis.

Experimental Procedure

As illustrated in Figure 1, participants began the experiment parked at a stop sign at a four way intersection. Participants were instructed that cars would approach from the opposite lane of traffic (on a two lane road) and when the gap between cars appeared large enough for them to complete a safe left turn they were to do so. The gap between cars was varied by the experimenter to a time interval of either two or four seconds. There was only one four second interval presented within each trial, that is, only one four second gap appeared in the on-coming traffic stream. In all of the trials, six vehicles crossed the intersection with, as noted, all but one inter-vehicle gap being two seconds. The presentation of the four second interval was randomized within the five gaps provided.

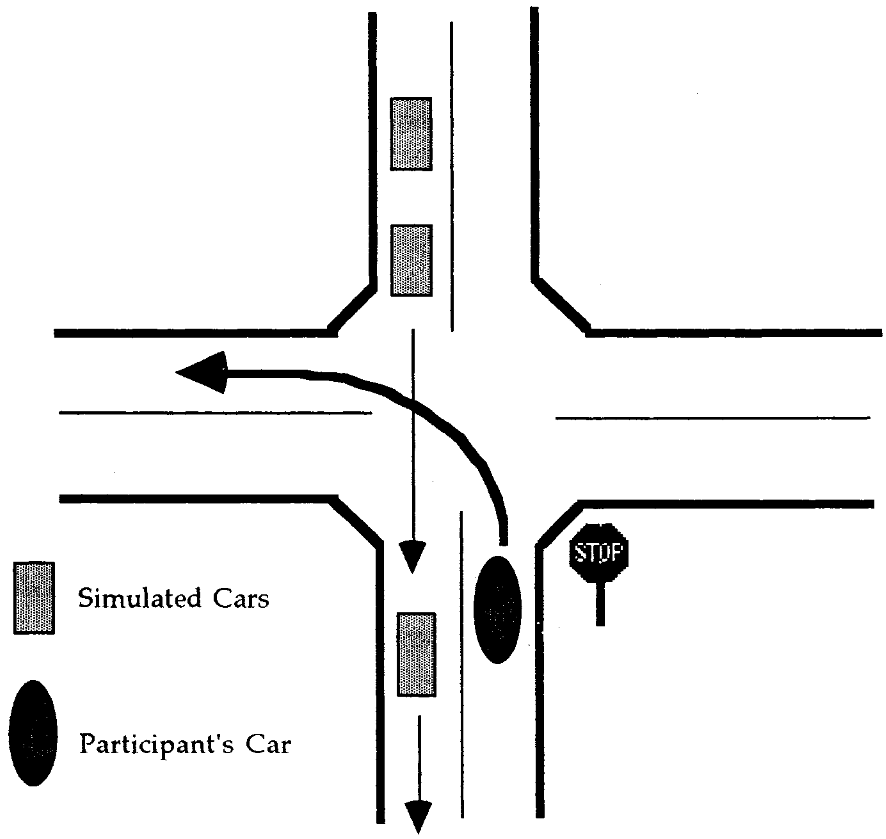

Figure 1. *Simulation scenario for collision avoidance.*

Each trial lasted until the driver turned or the last car in the sequence passed the intersection, which occurred in an elapsed time of three minutes. If the participants had not turned by the time the last car passed, they were allowed to turn after the final vehicle had passed. This was scored as an incorrect interval completed turn. Participant's were purposely not told that waiting for the stream to pass or turning during the two second intervals was an incorrect choice, but were allowed to decide whether the intervals presented were acceptable to them for a safe turn. This is a critical point since it is very easy to bias a participant's turn decisions by providing an arbitrary external criterion. This was purposely avoided here. The procedures thus provided a range of gap sizes that could be used as a means of determining natural driver behavior in making left-turns. This could then be compared to how participants changed their turning behavior with aural and visual warnings.

The participants had three levels of warning: No warning, an audible tone, and a colored light. The warnings themselves each had two levels with the tone being presented as a single beep at 250 feet before the on-coming vehicle crossed the intersection and a continuous beep when the on-coming vehicle was within 100 feet before crossing the intersection. The light presented as a warning was yellow at 250 feet and red at 100 feet. These levels of warning were presented as either level one (single beep or yellow light) or as level one followed by level two (single beep to continuous, yellow light to red light). Hence, there was a chance to observe sequence effects of ascending warning intensity in the present experiment.

Experimental Participants

There were twelve participants all of whom were licensed drivers. This pool consisted of six males between the ages of 22 and 62, and six females between 22 and 61. All subjects had participated in previous simulation studies at the Human Factors Research Laboratory or were given adequate practice in order to become familiar and comfortable with the simulator. All participants were given a description of the experiment and signed a participant consent form. Participants were not told how long the intervals would be that were presented nor were they told about what modality of warning would be presented in each trial. Participants were told only that there may or may not be warnings during each trial and that they should turn at any time that they felt that the interval was large enough for a safe turn. Participants were given an example of each warning and of no warning before starting the experiment and were then tested on five trials consisting of a random order of presentation of the five scenarios.

RESULTS

During each trial, the participant's data was recorded by the experimenter and is represented as the precise behavior of each driver. (see Appendix 1 at the end of this document). This raw data included if the correct turns were made, whether the participant's completed the turns safely (no accidents or near misses), and the warning stimulus which was presented. The raw data collected was scored and a point scale was established following the criteria in Table 1. The point total was transformed into a raw percentage based on the point total achieved out of a possible total score of 15 points.

Percent correct was calculated by scoring the points accumulated from three criteria; all correct turns during four second interval warnings or no warnings, turns made when warned by distance, and turns made at any interval but completed safely (no collision or near misses). The following scoring rules were applied. A correct turn refers to turning during a four second gap, all other turns (during a two second gap or at the end of the trial) were referred to as "not correct" turns. A safe turn, is any turn in any gap interval that was completed safely without any accidents or near misses. Participants who "floored" the accelerator ("unsafe driver activity") and completed a turn without mishap were given zero points for safety as this is considered an unfavorable response. Finally, the distance measure taken from the on-coming car as it approached the participant vehicle was used as a measure of whether the participant turned early or late within the gap interval provided. These were used to form point totals for each type of turn. A correct turn during the four second interval (with or without warning) was awarded 10 points. A turn completed safely at any gap interval was scored as 3 points, while having an accident was scored as - 3 points. A turn after the last car had crossed the intersection was scored as 2 points. If a turn was attempted when warned of a car approaching at greater than 200 feet of distance or when receiving no warnings the participant was scored with 2 points. If a participant attempted a turn when receiving a warning when a vehicle was within 100 feet of the intersection, the participant had 5 points deducted as this was considered an unfavorable response. Finally, if a turn was attempted when warned of a vehicle approaching within 100 feet and the turn resulted in an accident was scored as -8 points as this was the worst response to the warnings. Individual scores are combinations of these point totals. For example, if a participant was warned of a car within 100 feet and they still turned and completed the turn safely they would receive three (+3) points for completing a turn safely and would have five (-5) points deducted due to ignoring the 100 feet warning. This would result in a score of -2 total (3 - 5 points). If a participant made a safe turn within the four second interval but did so late in the gap interval (or after being warned of 250 feet distance but before the 100 feet distance) they would receive 10 points for the correct interval and 3 points for turning safely, for a total of 13 points. If they completed the safe turn during the four second gap and did so before the on-coming car approached closer than 200 feet they were awarded the maximum number of points, fifteen. In contrast, if a participant made the correct turn in the four second interval (10 points) but had a collision or near miss (-3 points) while being warned of an approaching car within 100 feet (-5 points) would receive a total of 2 points.

The raw data collected by the experimenter was recorded as the following outcomes. A correct turn was any turn made during the four second interval presented during the trial. A turn was either completed safely or precipitated an accident or collision with an oncoming car. Turns were calculated as either occurring early within the gap interval presented or as a late turn within the interval. This implies that initiation of the turn began early in the four second or two second gap intervals (200 feet or greater) or late in the gap interval (less than 100 feet before the next oncoming car). Combinations of these observations, lead to a tabulation of possible outcomes and their scores (Table 1).

Table 1. *Criteria For Scaling Raw Data*

Criteria	Points Awarded	Raw Percentage
Four Second Interval Completed Safely Greater Than 200 Feet	15	100
Four Second Interval Completed Safely Range of 200-100 Feet	13	91
Four Second Interval Unsafe Driver Activity	10	78
Four Second Interval Mishap or Accident	7	65
Four Second Interval Under 100 Feet Unsafe Driver Activity	5	57
Safe Turn Completed Two Second Interval Greater Than 200 Feet	5	57
Turn at End of Trial Completed Safely	5	57
Safe Turn Completed Two Second Interval Range of 200-100 Feet	3	48
Four Second Interval Mishap or Accident Within 100 Feet	2	44
Safe Turn Two Second Interval Under 100 Feet	-2	26
Mishap or Accident Within 100 Feet	-8	4

This scoring system favors correct turns, completed safely, and performed during times of informed warning. If a participant turned safely during a four second interval while seeing no warning or at the start of a 250 feet distance warning they could earn 15 points. Participants were penalized if they turned within the four second time zone but attempted the turn when being warned of a car approaching within 100 feet or if they initiated the turn late. In this way, participants who turned at the safest times and who used the collision warnings to their advantage would received the highest scores.

Raw scores were collected for each participant in each of the five scenarios. The observations recorded by the experimenter were applied to the scoring criteria above and a raw score for each participant's trial was calculated. The participant's data was tabulated and compared across the five scenarios; no warning, single beep (250 feet), yellow light (250 feet), single beep followed by continuos tone (100 feet), and yellow light followed by red light (100 feet). These scores can be meaningful on there own and are presented below. The raw scores were calculated from the criteria above to yield the scores tabulated in Table 2 and depicted in Figure 2.

Table 2. *Raw Scores Taken From Criteria Table 1.*

Participant #	Percent Correct Turn Rate : Raw Scores				
	No Warning	Single Beep (250 ft)	Yellow Light (250 ft)	Continuos Tone (100 ft)	Red Light (100 ft)
1 (M)	-2	3	3	10	7
2 (M)	2	3	3	7	5
3 (M)	3	5	5	7	13
4 (M)	2	5	5	13	7
5 (M)	-2	3	3	7	5
6 (M)	-2	3	7	7	10
7 (F)	2	3	5	10	10
8 (F)	2	3	5	13	13
9 (F)	2	3	7	13	13
10 (F)	2	3	5	7	10
11 (F)	-8	2	3	5	7
12 (F)	-2	3	7	10	10

This data table can be represented graphically by using the raw scores or each participant and comparing it against each of the five scenarios. In this way we can view the individual performance of the participants against the type of warning scenario that they received. The warnings are arranged with no warning at the bottom, 250 feet warnings (single beep and yellow light) next and the top consist of the 100 feet warnings (single beep at 250 feet followed by continuos tone at 100 feet and yellow light at 250 feet followed by a red light at 100 feet of distance). This graph will allow us to see the progression of scores of each participant when receiving no warnings or the four warnings.

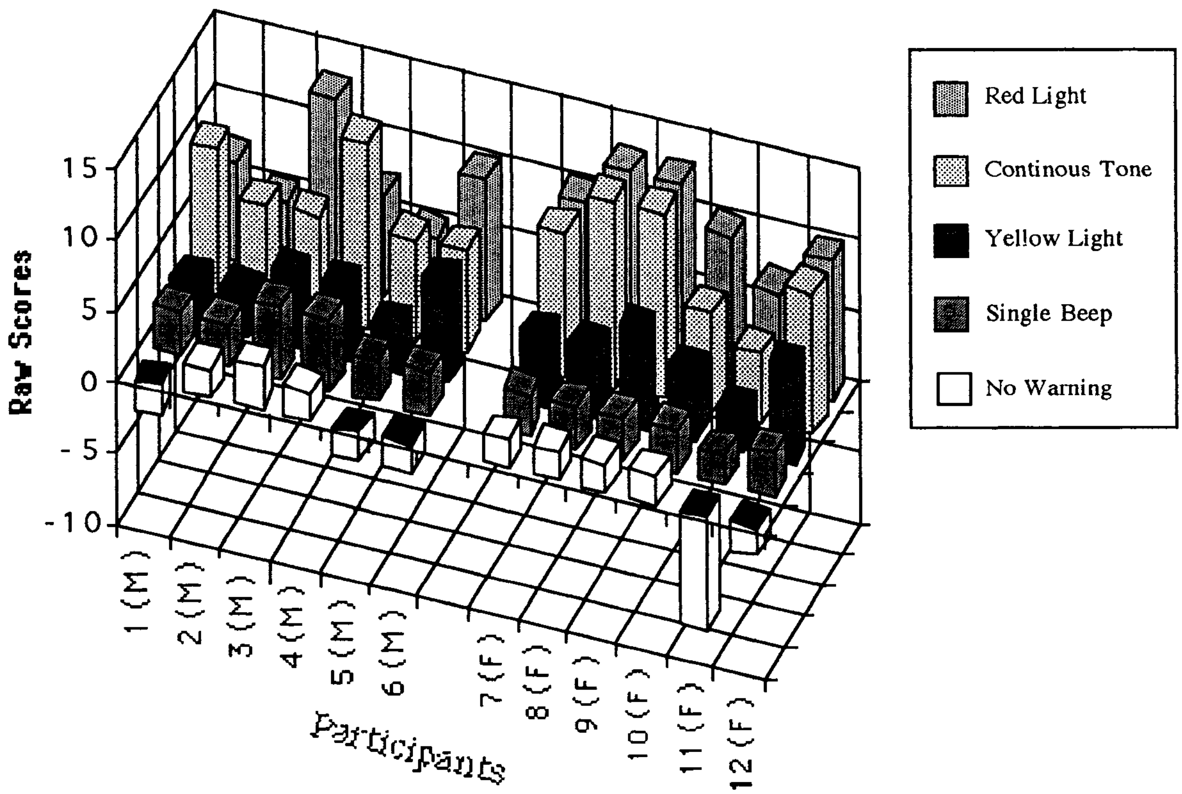

Figure 2. *Raw Scores Compared By Warning Scenarios For All Twelve Participants.*

The raw scores given in Table 2 were used to determine a percentage rank against a perfect 100 percent score of 15. This method of standardization allows all participants to be scored against each other across all five warning scenarios. These data are given in table 3 and shown graphically in figure 3.

Table 3. *Scores Of Driver Turn Behavior Translated Into Percentage Values For The Different Turn Conditions.*

Participant #	Percent Correct Turn Rate (Raw Percentages from Raw Scores)				
	No Warning	Single Beep (250 ft)	Yellow Light (250 ft)	Continuos Tone (100 ft)	Red Light (100 ft)
1 (M)	26	48	48	78	65
2 (M)	44	48	48	65	57
3 (M)	48	57	57	65	91
4 (M)	44	57	57	91	65
5 (M)	26	48	48	65	57
6 (M)	26	48	65	65	78
7 (F)	44	48	57	78	78
8 (F)	44	48	57	91	91
9 (F)	44	48	65	91	91
10 (F)	44	48	57	65	78
11 (F)	4	44	48	57	65
12 (F)	26	48	65	78	78

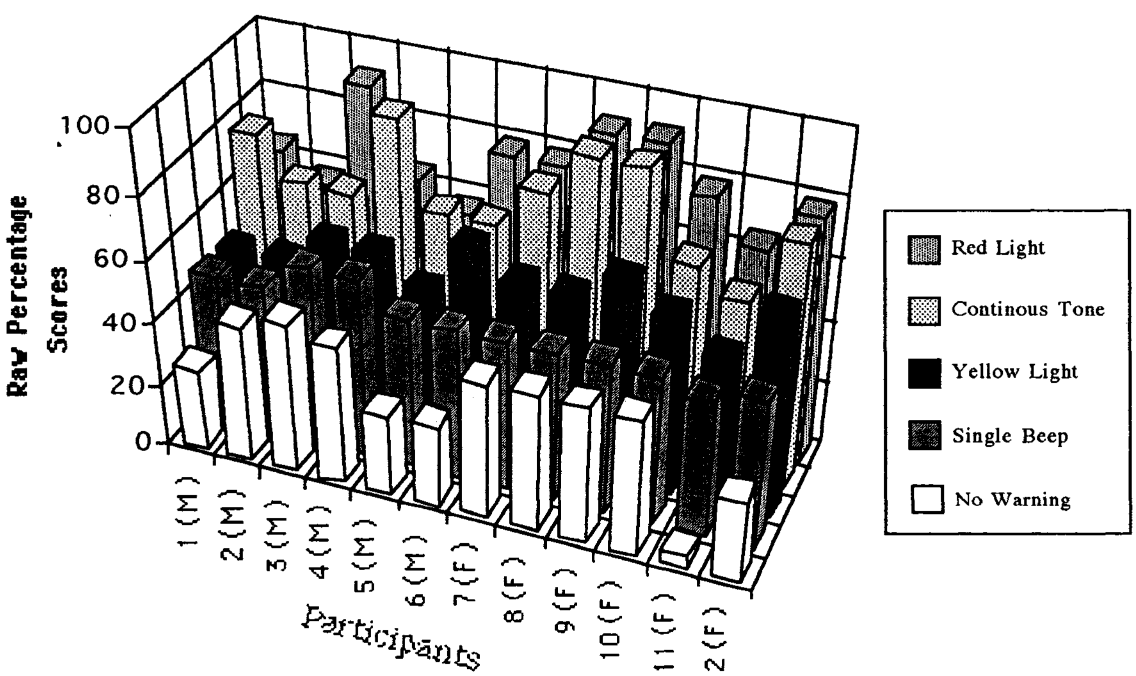

Figure 3. *Percentage Scores Derived From Raw Data. Percentage calculated from the total number of points allowed twenty-three (23), which was derived from a interval of negative eight (-8) to positive fifteen (+15) for a total interval of twenty-three points.*

There is a natural bias created by the point distribution, which can distort the graphical data. The data does not allow comparison across all participants by all trials. A participant who consistently scores lower on all trials can not be compared fairly to a non-consistent participant. Likewise, the percentages can make an extreme score appear lower or higher than another participants data due to the point spread between raw scores. A raw score of negative eight provides a raw percentage of 4% while the next level score of negative two represents 26 percent. To eliminate this bias the data is rescored as a percentage based on the individual participants data across all five of their trials. This rescaled the data to provide a comparison across each subject based on individual trial performances. The rescored data is reflected in Table and Graph 4.

Table 4. *Experimental Re-Scored Data*

Participant	Percent Correct Turn Rate (Scored as a scaled score across individual participants utilizing the simulation scoring criteria)				
	No Warning	Single Beep (250 ft)	Yellow Light (250 ft)	Continuous Tone (100 ft)	Red Light (100 ft)
1 (M 22)	53	60	62	78	75
2 (M 27)	62	64	65	75	73
3 (M 30)	67	69	70	75	81
4 (M 31)	64	72	69	81	75
5 (M 55)	52	62	64	74	70
6 (M 62)	53	62	71	76	76
7 (F 25)	61	63	68	79	76
8 (F 26)	58	60	68	81	82
9 (F 22)	59	64	71	82	82
10 (F 30)	58	66	69	75	79
11 (F 50)	49	55	63	70	72
12 (F 51)	50	60	71	79	76

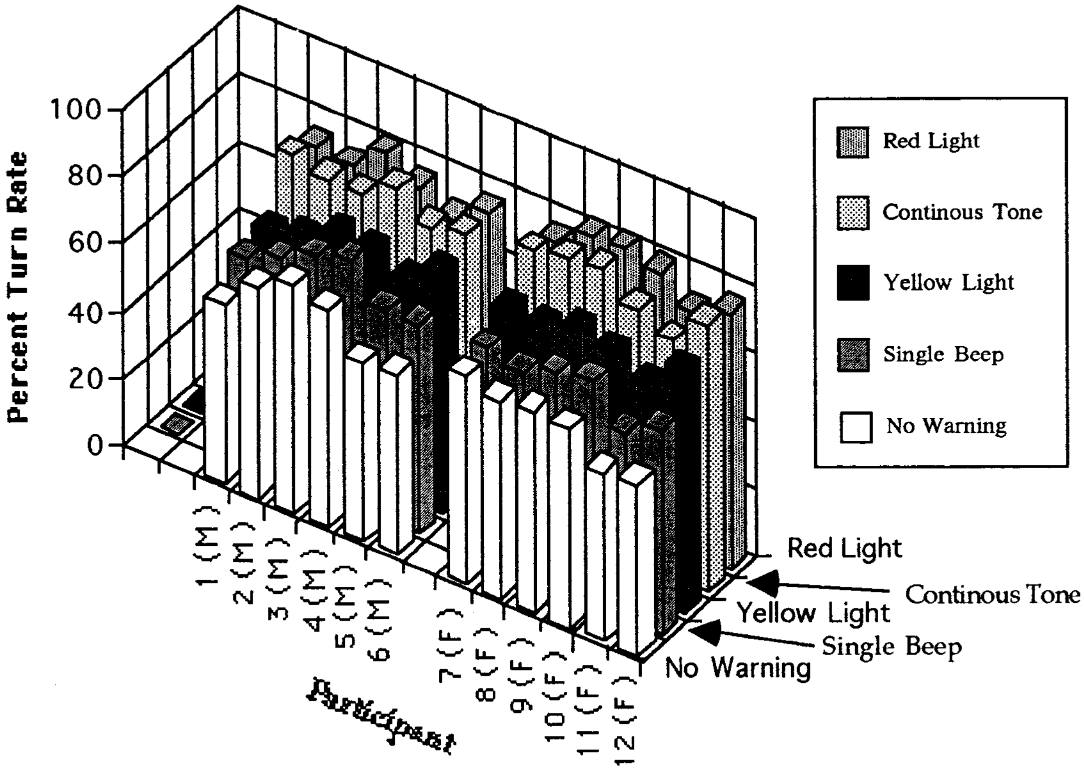

Figure 4. *Turn Rate By Warning Modality Scored Using the Individual Trials of Each Participant.*

As can be seen from this extrapolated picture, each manipulation has the effect of improving the participant's score, which reflects the overall safety of turning. This was the case across the group and in comparison to their own performance in the control condition.

It is also important to examine individual components of the data. We are interested in whether receiving a warning or not receiving a warning has an effect on each individual making correct turn decisions. To do this we separated the data into categories which include all warnings and no warnings, and whether turns were performed in the four second or two second intervals. Also, we separated turns into those completed successfully and those resulting in accidents or near misses. This data was examined in two ways; First we looked at all turn data including those resulting in accidents as a function of choosing the correct interval or not. (i.e. four seconds verses two seconds). Secondly, we examined only data where safe turns were completed. These are illustrated in tables 5 and 6 and figures 5 and 6 respectively.

Table 5. *All turns compared by interval and warning or no warnings.*

All turns during 4 or 2 second intervals against warnings / no warnings		
	Warnings	No Warnings
Correct	62.5	41.7
Not Correct	37.5	58.3

Adjusted by taking total chances for each category and calculating percentages from raw scores.

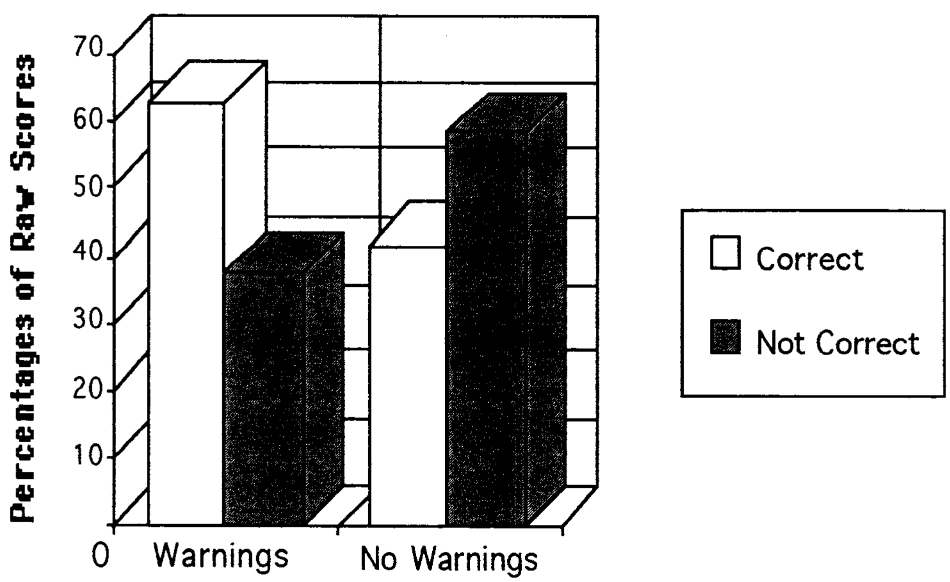

Figure 5. *Percentage of all turns completed graphed against whether warnings were received or not.*

Table 6. *Safe turns compared by interval and warning.*

Turns during 4 or 2 second intervals against warnings / no warnings (safely completed turns only).		
	Warnings	No Warnings
Correct	33.33	0
Not Correct	31.25	50

Adjusted by taking total chances for each category and calculating percentages.

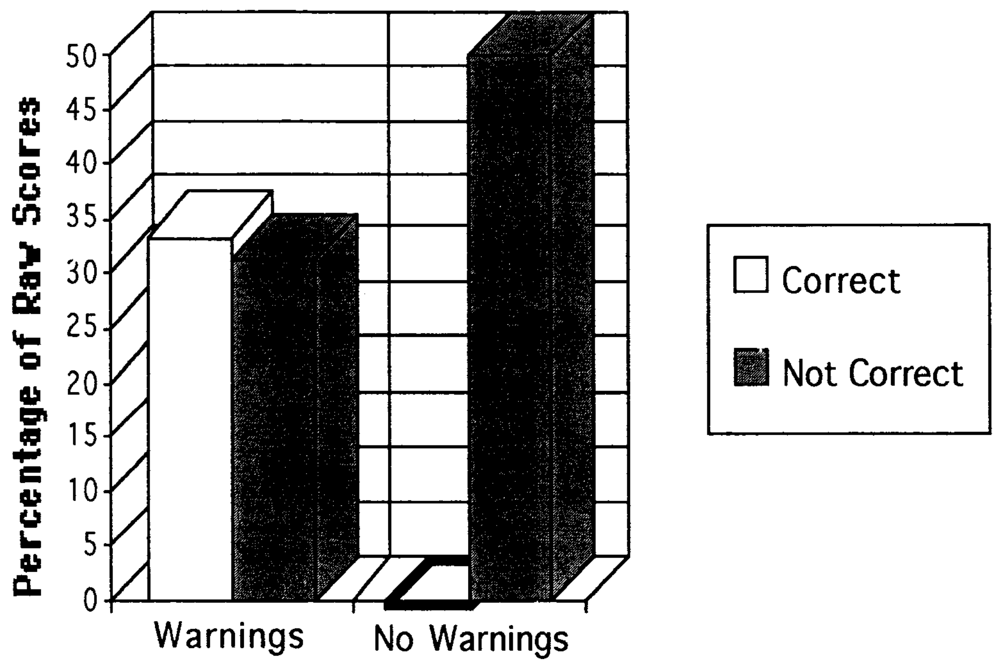

Figure 6. *Percentage of safe turns completed graphed against whether warnings were received or not.*

Further we wish to examine the effect that warnings at 250 feet and those with 100 feet distance have on driving decisions. To do this we abstract the data reflecting when warnings were issued and examine whether safe turns were completed in the correct gap interval.

Table 7. *Safe turns compared by interval and distance when warning was issued.*

Warning distance against 4 or 2 second intervals for safe completion of turns		
	100 Feet	250 Feet
Correct	31.2	6.3
Not Correct	4.2	29.2

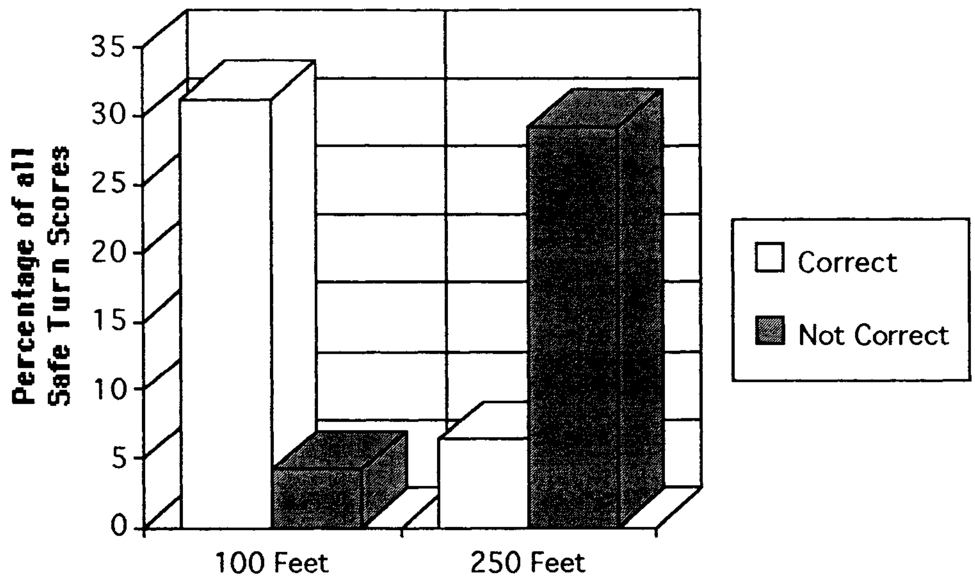

Figure 7. *Percentage of safe turns completed graphed against distance of on-coming car when warning was issued.*

Finally, we want to examine whether participants initiated turns early or late in the gap intervals measured by their decision to choose a four or two second interval. This will be graphed against the resultant outcome of safely completing the turn or having an accident or near miss. Participants may choose to turn before receiving warnings (early turn) or when receiving first warning of a sequence (early turn at 250 feet). Likewise, participants may decide at the last minute to turn. This could be caused be receiving the 100 foot warning or by their belief that the interval is still safe for turning in spite of the warning of on-coming cars. This data is represented in table and figure 8.

Table 8. *Type Of Turn Completed Based On Early Or Late Initiation.*

Type of turn against early or late initiation of turns during each warning distance				
	Early Turn 250 Feet	Early Turn 100 Feet	Late Turn 250 Feet	Late Turn 100 Feet
Correct/Safe	0	20.8	4.2	8.3
Correct/Mishap	2.1	6.3	6.3	10.4
Not Correct/Safe	22.9	0	8.3	2.1
Not Correct/Mishap	0	0	2.1	0

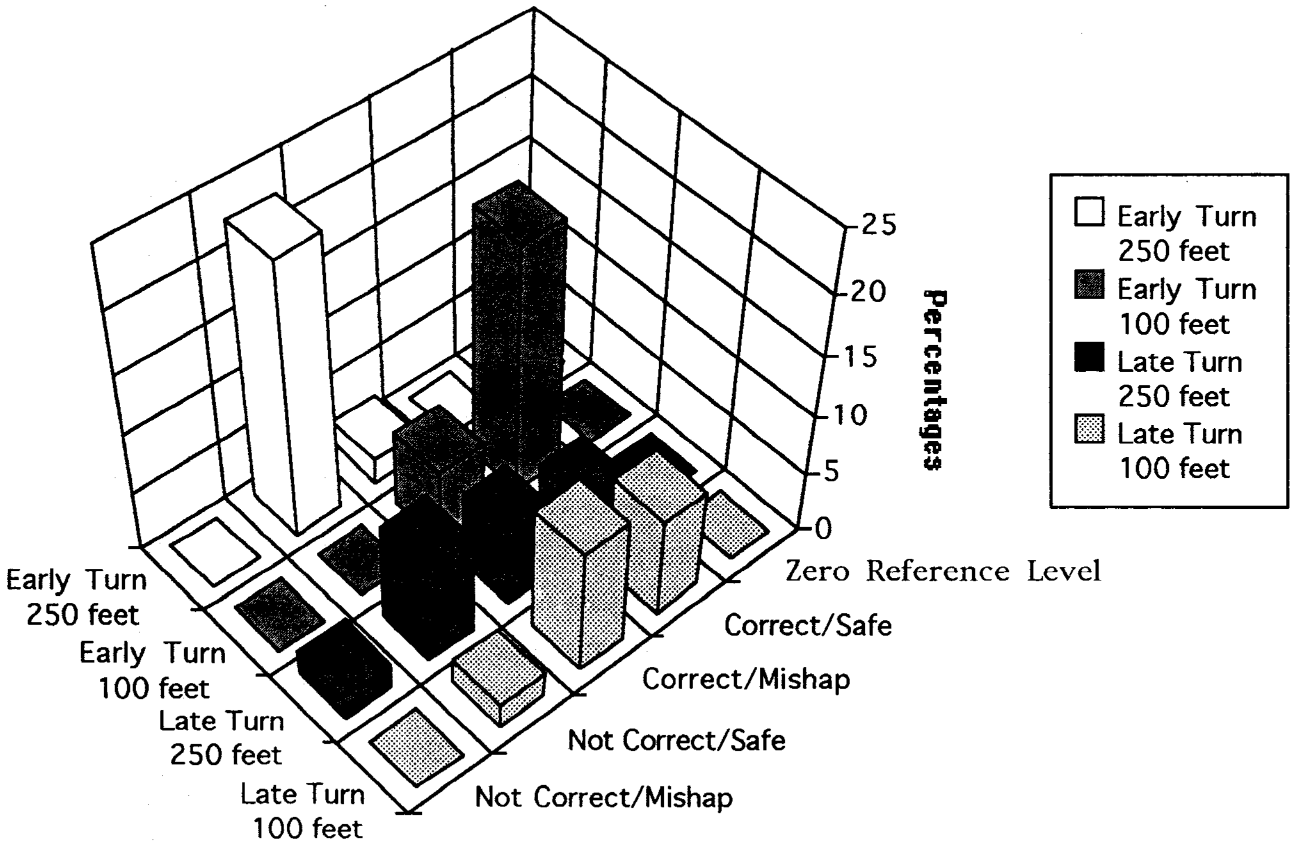

Figure 8. *Type of turn completed graphed against initiation of turns.*

DISCUSSION

There are several major points to note from the presented data. First, the presence of warnings in general appear to have an impact on turn behavior which apparently improved under such manipulation. As can be seen from Figure 5, warnings facilitated acceptance of larger gap intervals (four seconds) and depressed the acceptance of smaller gap size (two seconds). This was true for turn behavior, regardless of the outcome in terms of safe turns or near misses and accidents (see Figure 6). The sequential effect of increased warning intensity also had an effect. The added warnings of continuos tone or changing light color facilitated the selection of the larger gap interval and depressed selection of the smaller gap size (see Figure 7).

However, several cautions need to be added to this positive picture of warnings. First, there is evidence, as shown ion Figure 8, that several drivers took the warnings as advice to turn rather than information solely indicative of the proximity of on-coming vehicles. Thus warnings can be subject to misinterpretation. This is a critical caution. As individuals interpret displays and warnings differently, it may be problematic if a two second warning is taken as an imperative cue to turn. In essence, the driver is attributing more intelligence and authority to the system than it deserves and this can be especially dangerous (see Hancock & Parasuraman, 1992). Indeed, some of the present evidence suggest that this cue overrides an individual's own judgment. That is, "I don't think it is safe but the system must know best!" This division between displays being advisories versus imperative commands has to be resolved.

There are, of course, many cautions with respect to the methodology of the present work. Clearly, this is simulation-based study, with a limited number of subjects. The Laboratory was preparing to move to a new facility, which limited the time available to run participants. To accommodate for time, participants were only tested once on each warning scenario. Hence, our recommendation is for a further follow-up on this work with a wider spectrum and greater number of participants and an increase in trial frequency. However, the central points of the work remain. They are that proximity warnings do strongly influence turn behavior and that such warnings are occasionally treated as mandatory rather than simply advisory. These results are most encouraging with respect to the potential impact of warnings and indicate the usefulness of further experimental evaluation.

Contemporary investment in the transportation infrastructure mandates not only improved efficiency in moving people and goods and a reduction in associated pollution, but also a critical focus on safety. Such a focus recognizes the insupportable burden currently imposed by safety failures in road transportation. For IVHS, a major avenue through which safety improvement are expected to occur is through the use of proximity warning systems that can be generically referred to as In-Vehicle Collision-Avoidance Warning Systems (IVCAWS). Such systems are unlikely, at least in their early stages of development, to be purely automated systems which usurp control from the driver. Indeed, this design approach, in general, is flawed and contains a number of inherent fallacies that have been exposed in other realms of technological development. Intelligent interfaces should be of direct use in developing hybrid collision avoidance warning systems that seek to integrate the proven capabilities of human drivers with the nascent capabilities of proximal detection systems. However, the way in which humans currently accomplish such actions, and by extension how augmented information might be presented to them, might be better approached from an understanding of the tenets of ecological psychology, one approach to which, albeit from an older work, is given in some detail.

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APPENDICES

The following is an example data sheet used in Task Five. The original data sheets can be attained from Dr. Hancock at the Human Factors Research Laboratory by written request to the address listed in the beginning of this paper or by calling (612) 626-7521.

DATA SHEET

Trial Number __________

Subject Number _______

Warning Type:

1 No warning   2 Single Tone   3 Single Tone and Continuous

4 Yellow Light   5 Yellow Light and Red Light

Simulated car presentation:

Bike/2secs / Car/2secs / Car/2secs / Truck/ secs / Car/ **4secs** / Truck/End

Correct Turn?   YES   NO

Comments ____

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