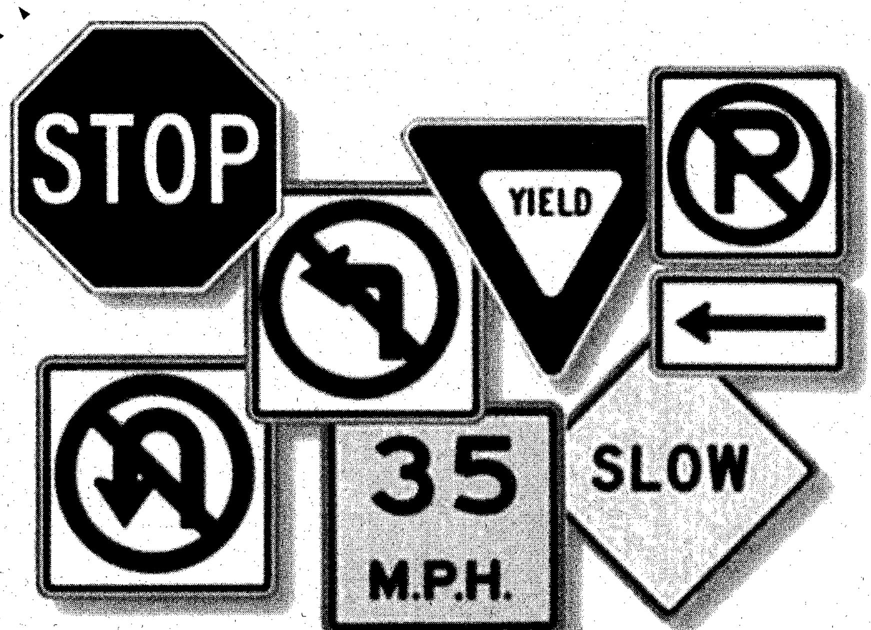
Report Number 94-33

Research



Human Factors Issues in Traffic Signing

UNIVERSITY OF MINNESOTA
CENTER FOR
TRANSPORTATION
STUDIES

Human Factors Issues In Traffic Signing

Final Report

Prepared by

P. A. Hancock

Human Factors Research Laboratory
University of Minnesota
141 Mariucci Arena Operations
1901 4th St. SE
Minneapolis, MN 55455

August 1994

Submitted to

Minnesota Department of Transportation
Office of Research Administration
200 Ford Building, 117 University Avenue
St. Paul, MN 55155

ACKNOWLEDGMENTS

I would like to thank Robert Stephens and Mark Coyle for their help in the completion of Work Task 1, Eric Arthur for all his contributions and Gayna Williams for the data collection on Work Task 2. I would further like to thank Christie Manning for her help on Work Task 3 and Stirling Stackhouse for comments and contributions to the present work. Gayna Williams' comments on an earlier draft of Work Task 3 and Douglas Wagner for his assistance with information on changeable message signs contributions are also much appreciated. I would especially like to thank Bob Dewar and Jeff Caird of the University of Calgary for their kind provision of references concerning changeable message signs.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This work reports results of an experimental program on human factors issues in traffic signing. The first task examines the problems associated with the programming of signs for evaluation of driver response in simulation. It is concluded that growing technical tools permit traffic engineers to test proposed signage, and avenues of implementation are given. The second task examines driver response in simulation to multiple real-world signs. It is concluded that while much effort is given to distinguishing the utility of individual signs, multiple signs in combination produce more complex decrements. Recommendations are made as to maximum sign density. The final task provides an assessment of signage in future IVHS driving environments. It points to the role of signage as one component of communication. A list of issues for future signage implementation is given for consideration as the Department moves to provide safe and efficient transport for the people of Minnesota into the 21st century.

SOFTWARE CREATION OF TRAFFIC SIGNS

EXECUTIVE OVERVIEW

The purpose of the first work task was the creation of simulation capability including signs to be evaluated. This work progressed upon a number of hardware platforms and through a number of software packages which were originally identified and in addition some more recent advanced graphics programming packages which are described. A sequence of routes were linked together. These represent routes within the Twin Cities Metropolitan area. This route system is described in more detail in work task two. Facilities were constructed which permitted the experimental sequence described in work task two. As the present work task was composed completely of programming, the present report is a descriptive overview of the hardware platforms and software packages used, together with a description of the signage made. Recommendations for future developments are advanced, including the adoption of more sophisticated commercial programs and the relative advantages of texturing as an approach to sign generation in driving simulation. **The contemporary status of simulation facilities developed under this work task means that Mn/DOT can test any combination of signage (existing or proposed) on any Minnesota roadway (existing or proposed). Thus the product of this work task is a valuable tool for all Mn/DOT planners and engineers to evaluate their designs and traffic-related signage questions.**

INTRODUCTION

The present work task was directed to the generation of road traffic signs for simulation. As this requires software development, the product of the present work is predominantly the generation of visible signs and other components of simulated environments as they appear in the Human Factors Research Laboratory's (HFRL) simulation facility. The present report, therefore, reflects a descriptive overview of that generation process. **The actual sign products and generated driving worlds may be viewed at HFRL.** They are also described in some detail in the procedural description of work task two below. The summary below presents the overall simulation facility, the hardware platforms upon which the sign environments are based, the software support for their construction, and graphic descriptions of generated signs.

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. This observation is of particular importance with respect to the generation of signage in a polygon-based system as is explained below. A schematic side-projection of the actual facility is shown in Figure 1. Subsequent sections describe the associated hardware.

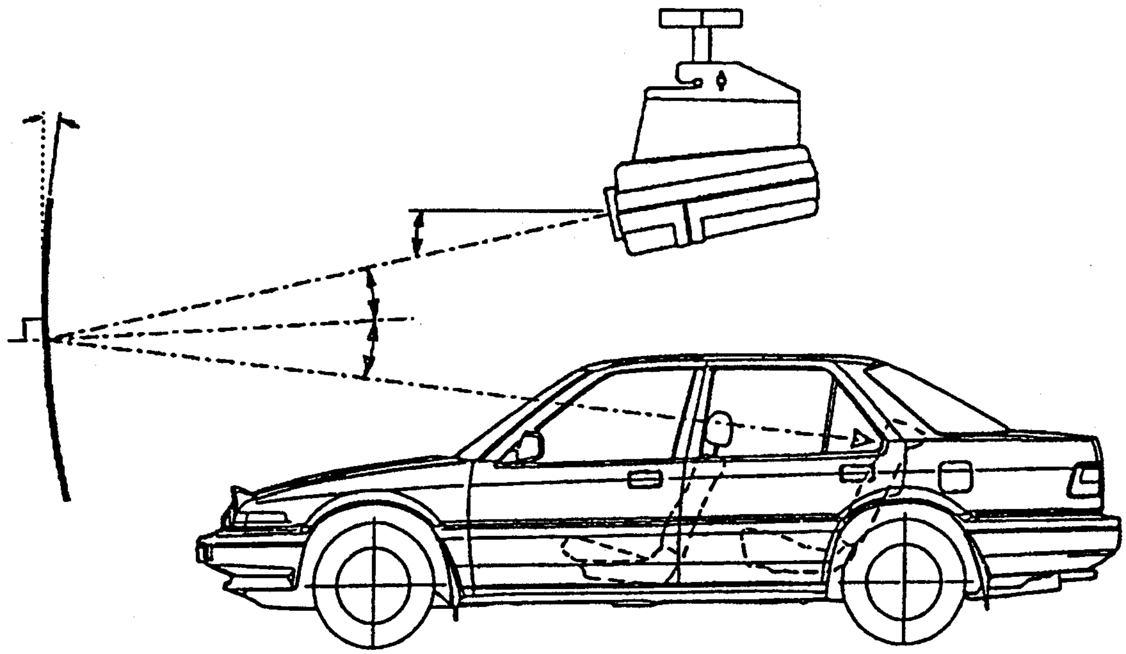


Figure 1. *Side projection view of the simulation facility illustrating the Honda 1990 fixed-position vehicle, the overhead projection system and the screen orientation and driver visual viewing angle.*

THE HARDWARE PLATFORMS

The XTAR System

In the present work, there are two hardware platforms for which software signs were created. The first of these was the XTAR system. This is a medium level graphics generation system based in a 33MHz 386 machine that attaches to the Electrahome ECP-3000 projection system. These system components are illustrated in Figures 2 and 3. Also contained in this loop is the actual vehicle itself, the Honda 1990 Accord and the associated A/D and D/A peripherals that allow interactive driving response on behalf of the experimental subject. As is noted below, the software package used in the present sign generation for this system is the AUTOCAD sequence (i.e., v.10 and v.11). 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

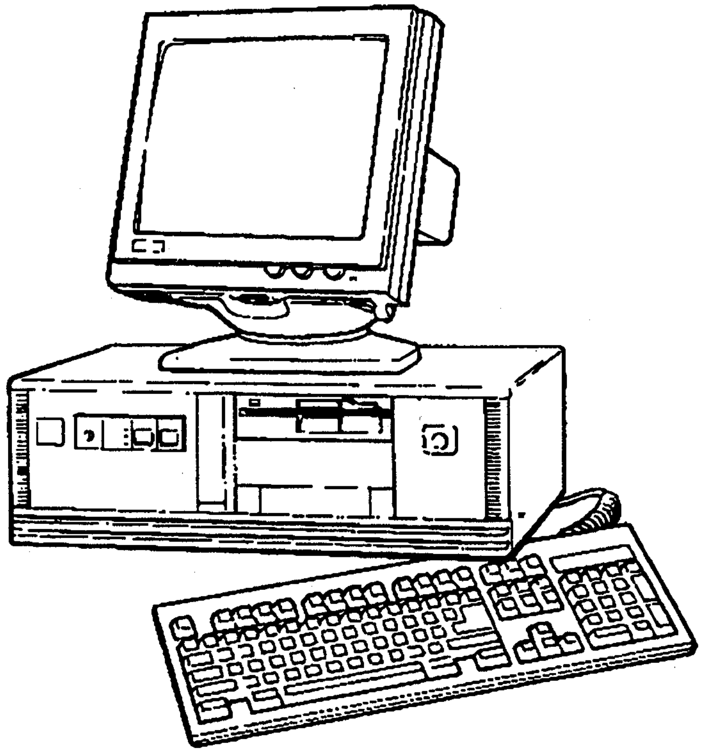


Figure 2. *Generic representation of the XTAR host computer system.*

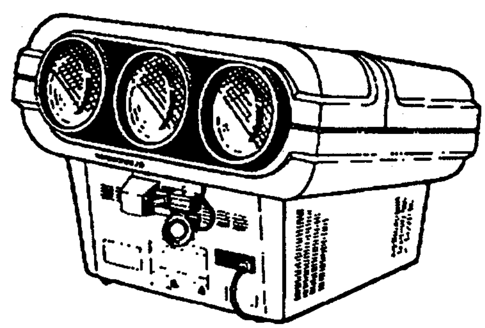


Figure 3. *Electrahome ECP-3000 Projection system.*

system is limited being able to calculate 2,000 flat-shaded polygons per second, where polygons are the currency of simulation fidelity in these forms of non-texturing system.

Object creation in XTAR is performed in a number of steps, as is illustrated in the following diagram:

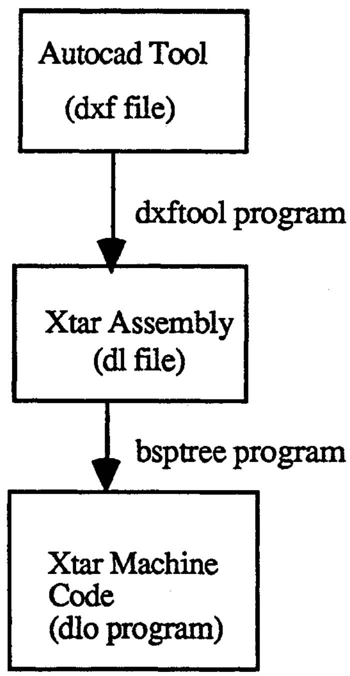


Figure 4. *Object creation procedure in the XTAR graphics simulation system.*

All objects seen in the XTAR system are designed using a very restricted subset of AUTOCAD. Although AUTOCAD is capable of creating very complex objects, only the command that draws a "3-D Face", i.e., a concave polygon, can be used by the XTAR system. Once the AUTOCAD file for a object is created, the file is saved in the "dxf" format. XTAR has provided a series of translation tools that convert this dxf file into a format that allows the object to be loaded at runtime. This procedure works adequately for objects such as houses, roads, etc. The creation of roadsigns, however, is at best difficult. The restricted subset of AUTOCAD requires designers to create the textual contents of the roadsigns using a large number of polygons. In addition, the spacing between elements of the sign is particularly problematic if they are to represent actual on-road signage as given in texts such as the Manual of Uniform Traffic Control Devices. Upon computation, it was found that inclusion of a small number of signs, i.e. no more than three, degraded the system making it impossible to perform real-time simulation experimentation.

Furthermore, the resolution provided by the XTAR system rendered the signs unreadable except at very close and therefore, unrealistic driving distances. Shortcomings of the XTAR system could be overcome by two strategies. The XTAR system could be upgraded to make use of newer technology from XTAR. However, even with the most advanced XTAR system, the simulation of sufficient road-signage and associated clutter could not be achieved for adequate simulation experimentation. The rapid change in graphics hardware and software, particularly Silicon Graphics provided different capabilities to begin building a new infrastructure of graphics hardware and software. The solution for current experimentation lay in the use of a technique used by FHWA for sign-simulation investigation as shown in work task 2.

The Silicon Graphics System

The second platform, more recently acquired, is the Silicon Graphics 4D310VGX(T) graphics mini-supercomputer. This system is considerably more sophisticated and powerful that the XTAR system. For a number of years, Silicon Graphics has been recognized as a superior graphics platform. However, until recently there have been few software support packages that enable simple programming on this system. This situation has changed dramatically with the introduction of packages such as VAPS, MULTIGEN, and more recently Designers Workbench. It is in these latter capabilities that a number of sign configurations have been developed for multiple usage in experimental procedures. The Silicon Graphics system is approximately two orders of magnitude more powerful than the XTAR system and in addition has the added capability to provide texturing options which significantly enhance the simulation fidelity.

Figure 5 illustrates the creation of signs in the SGI system:

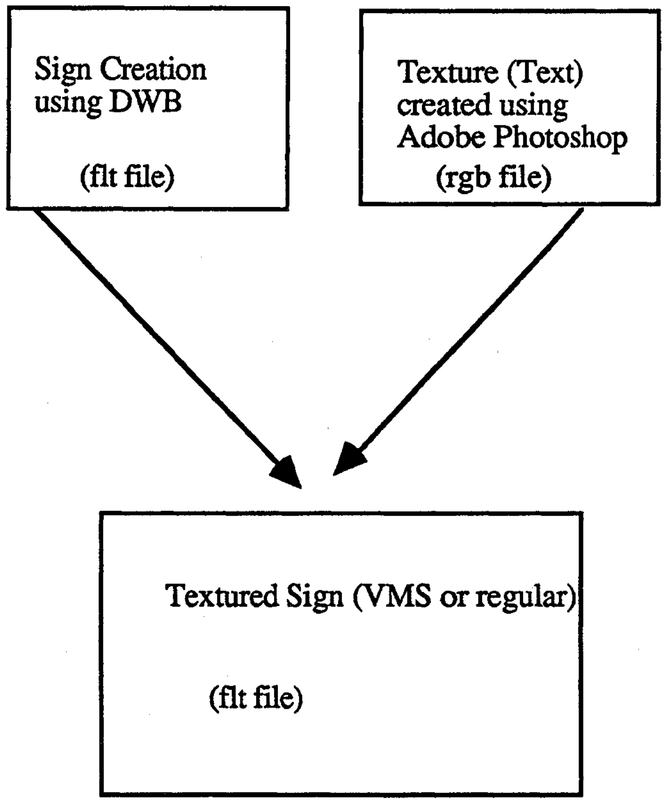


Figure 5. *Silicon Graphics sign creation path.*

We are able to create both regular and VMS type signs using the SGI system. First, the modeling tool, Designers Workbench, is used to create the backdrop for the sign (by backdrop, we mean the rectangular or diamond-shaped base). Adobe photoshop is used to create an rgb image of the sign itself (i.e. the image of a stopsign, including the red and white border colors as well as the textual message). Designers Workbench has a facility whereby we can "wrap" the image of the desired sign onto a backdrop, resulting in a roadsign. This is fundamentally different than the XTAR system, in which text for signs is made from polygons. The SGI method offers several advantages:

1) Faster Development of Prototype Signs.
2) Faster Rendering Producing More Realistic Simulation.
3) Higher Quality Signs.

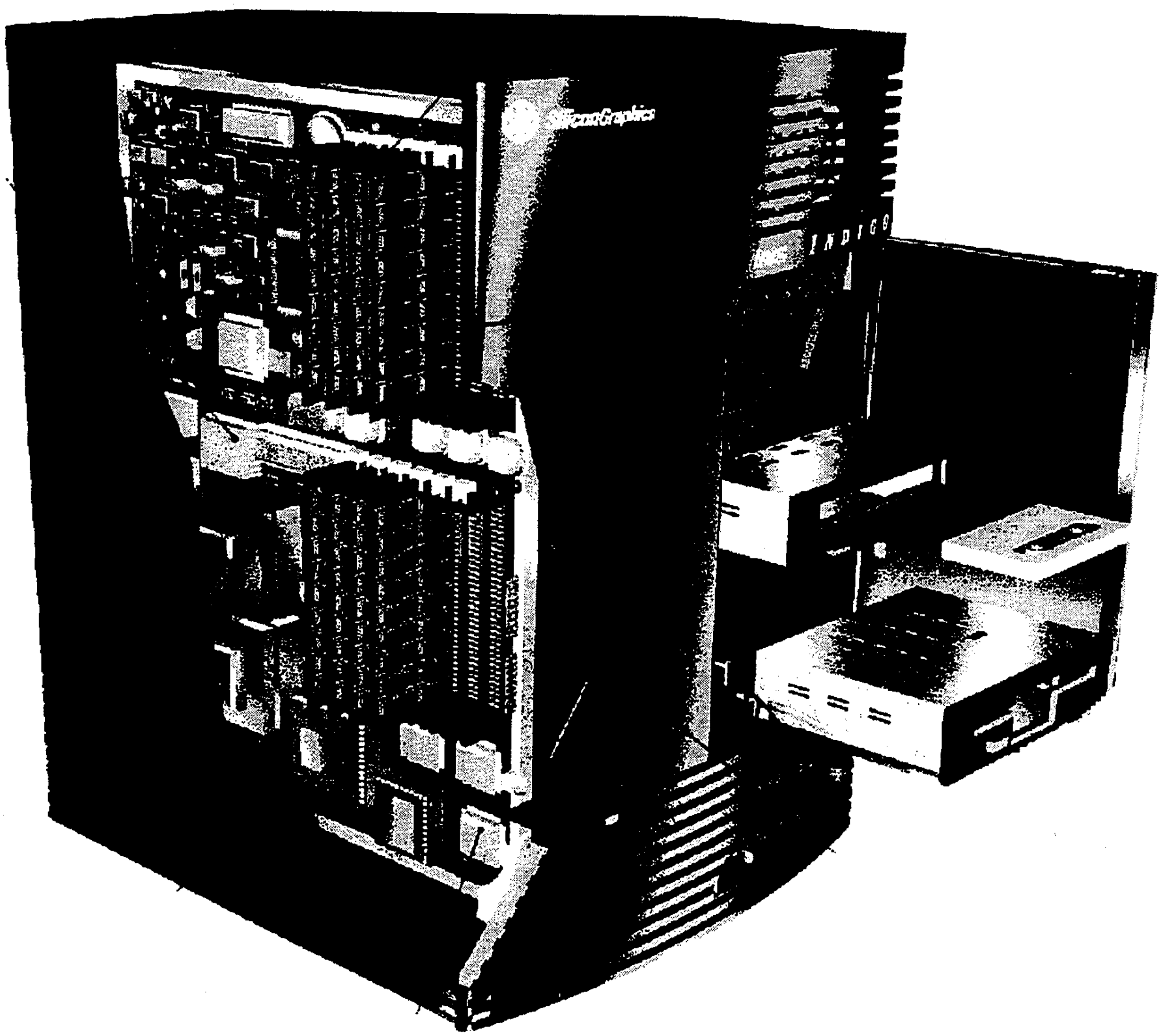


Figure 6. *Silicon Graphics 4D310 VGX(T) Computer System.*

SOFTWARE PROGRAMMING

The central problem with creating signs in a non-textured environment is the complexity of the object and the number of polygons signs take. In the present case, even simple signs such as a stop sign use a considerable portion of the available polygon count, which converts to real-time simulation capability. It is possible to create extensive, sophisticated and persuasive polygon worlds. However, because of the calculational load, such worlds cannot be interactive in real-time since they cannot be re-calculated for movement faster than fifteen times per second using the XTAR system, which is the minimum necessary for interactive simulation. Hence, in the present effort, we have generated a number of signs but could use only a limited number for experimentation. For the XTAR system, this fell below the number for signage and clutter which was eventually used in the simulation experiment described in work task two. In essence, an unlimited range of sign types can be created of an AUTOCAD type, however, as HFRL hardware is limited with respect to XTAR calculation, this strategy was not pursued. This approach has been pursued elsewhere in which the creation of differing roadway signs has been established as a small scale rule-based system in which actual dimensions are automatically calculated. This approach saves many hours of programming time. We recommend that for future developments this approach be given careful consideration (see Preston, 1994). To overcome the calculational problem in the present experimental environment, we used a technique which has been employed in the FHWA simulation facility in which the brief presentation of photographs of real signs is combined with simulated driving to evaluate driver response.

There is a better way of generating signs and signage for simulation which centers around the use of texturing options. The past several years has seen an explosion in both the quality of computer graphics as well as the reduction of prices for these systems. Graphics that were possible only with infrastructure investments in the millions is now possible for often much less than one-tenth the price. One of the largest advances in graphics hardware and software is in the use of texture to increase the realism of graphic scenes. At the Human Factors Research Laboratory we are now using textures for two main purposes, that of terrain generation and signage construction. The remainder of this section discusses the HFRL's use of texture for the creation of roadsigns for projects related to the Intelligent Highway Vehicle Systems.

The Silicon Graphics VGXT used by the HFRL has software and hardware support for texture. Texture differs from traditional graphics in a number of ways. In traditional graphics, objects are created by specifying vertex points that describe the objects. For example, a cube is described by eight vertex points and concomitant color information. One problem in this approach is the difficulty in obtaining a complete list of vertex points that accurately describe a complex object. This is particularly true of objects such as road signs. These objects have a property that make them difficult to create using traditional graphics techniques, which is the incorporation of text of differing size. Text may be implemented as points and polygons, but this approach is inefficient and non-flexible for quick prototyping. Each letter can be composed of a number of polygons, for example an "A" can be made from three polygons.

GRAPHICS TEXTURING

Texture is simply "wrapping" an image around a polygon. This approach provides a graphical picture in a convenient format (e.g., rgb or tiff format). It instructs the computer that this picture is to be pasted onto a polygon. The difference between this approach and the previous approach is that in this approach there is no vertex information. The image is described by the picture alone without regard to any points inside the image. The image consists only of pixels and color information. The Silicon Graphics system has a built-in support in both hardware and software to process efficiently textured objects. At the Human Factors Research Laboratory we are using textures as roadsigns to create a dynamically reconfigurable testbed for roadsign construction and evaluation. The system for advanced sign generation could work as follows. Initial signage design is completed by a graphic artist. A photograph is taken of this design and scanned into a color scanner for use in the simulator. Once the color software image is available, it can be incorporated it into a roadsign for the driving simulator in a minimal amount of time. This provides a quick and inexpensive method of evaluating road signs for a wide variety of applications.

GENERATED SIGNS

In the present work task, we have generated a number of signs. These have been used in association with a number of experiments. This section describes the process of Sign creation under both the XTAR and SGI systems. In the first section, we discuss the process of creating signs in XTAR, and we discuss the performance problems that precipitated our move to the SGI system. The second section discusses sign creation under the SGI system. The generated signs, embedded in simulation can be viewed at HFRL. As the signs react and respond in dynamic environments, e.g., variable message signs, static representations do not illustrate their primary characteristics. However, software copies of specific signs are portable at the request of Mn/DOT. These signs have been demonstrated to Mn/DOT personnel including Commissioner Denn and his colleagues. They are available for inspection at HFRL.

SUMMARY

The contemporary status of simulation facilities developed under this work task means that Mn/DOT can test any combination of signage (existing or proposed) on any Minnesota roadway (existing or proposed). Thus the product of this work task is a valuable tool for all Mn/DOT planners and engineers to evaluate their designs and traffic-related signage questions. This tool is available at the Human Factors Research Laboratory to be configured and employed as appropriate.

RELEVANCE TO THE MINNESOTA DEPARTMENT OF TRANSPORTATION

- Signs generated for non-textured environments are computationally costly and are not the most efficient or practical method for simulation.

- Sign generation in accordance with contemporary standards is a costly process. Contemporary, purpose built, small-scale expert system sign generators are the preferred method of production, particularly when compared to individual software generation.

- An alternative method, used by FHWA, is the projection of sign photographs alongside simulated driving. This approach is recommended and used in current simulation experimentation.

- Texturing provides an opportunity to project complex objects such as signs in simulation. It is a recommended approach for future signage experimentation.

- The approach via texturing can also use artificially generated signs by photographing and "wrapping" such representations onto single polygons sign shapes.

- The latter approach can be used in wrap-around simulation and is the recommended procedure for future use in which perspective signage can be evaluated.
- The contemporary status of simulation facilities developed under this work task means that Mn/DOT can test any combination of signage (existing or proposed) on any Minnesota roadway (existing or proposed). Thus the product of this work task is a valuable tool for all Mn/DOT planners and engineers to evaluate their designs and traffic-related signage questions.

AN EXPERIMENTAL EVALUATION OF TRAFFIC SIGN DENSITY

EXECUTIVE OVERVIEW

Twenty, licensed Minnesota drivers performed a sign detection and recognition test while driving in a driving simulation facility. Specifically, participants were asked to navigate a straight driving course as safely as possible by keeping a constant lane position and a constant velocity of 30mph. Drivers received an initial practice session in which the procedure was explained. There followed four separate session in which different number of signs were presented for driver recognition. They were displayed at the edge of the simulated roadway as they would appear in actual driving. In each session, there were twelve scenes presented, thus a total of forty-eight scenes in all were encountered by the participant. In twelve of the scenes there was one traffic control sign, in another twelve of the scenes there were two traffic control signs, and in another twelve of the scenes there were three traffic control signs. The remaining twelve scenes showed no traffic control signs. Order of presentation was randomized within and across sessions. Participants were asked to detect traffic control signs and to report what actions they mandated. Scenes were manipulated to provide differing levels of potential distraction. Subjects performance was scored in terms of percentage correct response to sign presentation and in terms of vehicle control in the form of lane and velocity deviation. Results showed that the percentage of correct detections decreased systematically with the number of signs at any single location. This decrement in performance ability was apparently not reflected in vehicle control. The evidence provides support for the contention of a diminishment in returns for signs added at single locations and for potential driver problems when attempting to assimilate multiple sign information.

INTRODUCTION

The driving environment of tomorrow promises to be a progressively more complex and demanding one, especially in high traffic density, urban areas. The sheer amount of information that can potentially be presented to the driver is daunting. With the innovations promised by Intelligent Vehicle-Highway Systems (IVHS), this information avalanche threatens to be even more extensive. In the face of these startling changes, the drivers' task remains essentially the same, the safe and efficient control of their vehicle. Yet superimposed upon this task will soon be the abilities for world-wide communication in the car, the ability to perform heads-down map navigation in unknown driving areas, and the threat of automatic take-over if automated highways become a reality.

What will remain constant is the need for any vehicle under driver control to obey traffic control devices. However, how drivers will react to traditional traffic control in the face of information overload is not known. There are anecdotal reports from Japanese experiences that drivers with advanced in-vehicle information systems follow advice from those systems over traditional traffic control. Specifically, a voice-command system advised a driver to "go straight ahead," a command the driver proceeded to comply with. Unfortunately, the traffic lights at the time were red and the driver went through the intersection. This situation typifies circumstances in which advanced technology is added to the vehicle, yet the driver does not know the level of sophistication. As a result, the driver assumes the technology is "intelligent" and knows that it is all right to proceed through a red light, in this case an incorrect assumption.

Such voice commands bring up further issues. There is a tendency to obey the proximal voice command over the distal visual and more passive command of a traffic control device or sign. In-vehicle systems provide novelty which is a strong attractor of attention. Hence, even if the in-vehicle device does not provide contradictive information, it may well distract the driver so that they "miss" the less novel but still important control devices, such as a stop light. Finally, as external signage proliferates, it becomes progressively more difficult to distinguish critical information from distracting information such as advertising. For each of these reasons, we need to know much more about driver behavior in the face of increasing information load, especially when some of that information is mandatory traffic control. The present experiment is directed to this question and presents an initial approach in which simple increase in signage density is evaluated against driver performance in the form of momentary control, sign detection, and sign recognition.

METHOD

Experimental Participants

20 participants were solicited as experimental subjects. Each was a licensed Minnesota driver and volunteered their time to contribute to this work. Each had 20/20 vision or corrected to 20/20 vision except where noted. All subjects were in professed good health at the time of testing and any individual medications, whether prescription or over-the-counter, were noted in the survey component. Subject consent forms and instructions for subjects are appended to this report.

Experimental Task and Apparatus

The experiments were performed in the Human Factors Research Laboratory (HFRL) front-view simulation facility. An illustration of the facility is shown in Figure 1. The computational element of the simulation is performed by an XTAR graphic acceleration system embedded in a 33MHz 486 Computer. The graphics for the displayed driving scene is projected through an Electrahome ECP-3000 System to a single, flat-screen display. The model for the driving vehicle has recently been updated to provide a more detailed representation of the vehicle and thus a higher fidelity simulation. The principle measure derived from the simulation facility was root mean square error (RMSE) around the center-line of the road lane illustrated. This measure indicates road drift and is a primary measure of driver vehicle control. Displayed scenes were projected on a screen located six feet to the right of the forward-screen display. The presentation of these scenes lasted two seconds and were located in the appropriate position with respect to drivers' viewing side of the road signage.

Experimental Procedure

Participants began the experimental procedure by completing an informed consent form which described the experimental procedure. They completed a driving survey questionnaire which included questions on demographics and past driving behavior. They were also presented with an open-ended question which allowed them to express their concerns about contemporary signage. They then entered the simulation facility and were given a brief practice session to familiarize them with the simulator. The experimenter read the specific instructions with respect to the experiment, emphasizing the importance of safe driving and the necessity to perform the sign detection and recognition tasks. The driver then proceeded along the preset course, reporting the messages on the sign to the experimenter.

There were five experimental sessions. The first session was a practice one and was not included in analysis. In the practice session, the procedure was introduced to the subject. They were asked to drive a straight course and keep the vehicle in the same location in the lane in order to drive safely. They were also asked to keep the vehicle's velocity at 30mph which they could monitor on the operational speedometer. During each session, twelve slides were presented. These could contain zero, one, two, or three signs. The ordering of these presentations with different signs was randomized both within and across sessions. Subjects faced with these presentations had to identify the signs shown.

The experimenter recorded driver responses and noted errors and correct detection's of the control devices. Analysis was also performed on the percentage of correct detection's and percentage of correct actions taken in response to the differing sign load conditions. At the same time as the scenes were displayed to the driver, the computer recorded change in lane position as a reflection of driving performance. These data were also subjected to analysis. Analysis compared driving ability in the presence and absence of concurrently displayed scenes. It further compared driving ability as the information load increased as a function of the number of signs shown in any one single location. It is these results which are examined below.

RESULTS

Sign Recognition and Identification

The sign recognition data were reduced in the following manner. Each participant's observations were classed as correct or incorrect for each presentation. These produced a percentage correct score for each number of signs, 0, 1, 2, 3, across twelve replications in the four sessions. These raw scores, which are given in Table 1, were subjected to an analysis of variance procedure. This analysis indicated significant effects for the number of presented signs $F(1, 19) = 150.53$, $p<0.0001$. This highly significant effect was

Table 1. Mean Percentage Correct by Individual Subject.

Subjects #	No signs	One sign	Two signs	Three signs
1	1	0.875	0.8461538	0.6666667
2	1	0.875	0.8461538	0.6666667
3	1	0.875	0.7692308	0.4666667
4	1	0.8125	0.8461538	0.6666667
5	1	0.875	0.4615385	0.6
6	1	0.875	0.8461538	0.6
7	0.75	0.8125	0.7692308	0.8
8	1	0.8125	0.9230769	0.5333333
9	1	0.9375	0.6153846	0.5333333
10	1	0.875	0.6923077	0.6
11	1	0.9375	0.8461538	0.6666667
12	1	0.9375	0.8461538	0.7333333
13	1	0.9375	0.7692308	0.6
14	1	0.9375	0.8461538	0.6666667
15	1	0.75	0.5384615	0.5333333
16	1	0.6875	0.6153846	0.6666667
17	1	0.875	0.7692308	0.5333333
18	1	0.9375	0.7692308	0.6
19	1	0.9375	0.7692308	0.6
20	1	0.8125	0.5384615	0.6666667

Means	No signs	One sign	Two signs	Three signs
	0.9875	0.886875	0.7461538	0.61

subjected to post hoc analysis which distinguished significant differences between each of the sign conditions. These data are illustrated in Figure 7.

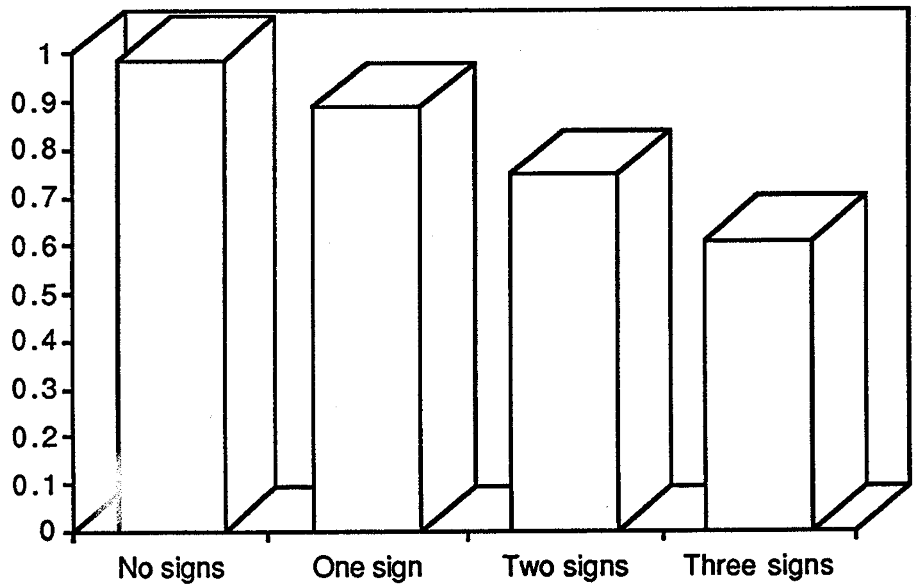


Figure 7. *Mean Percentage Correct by Number of Signs.*

As can be seen, the driver's were almost ubiquitously correct in identifying the zero sign condition. In reality only one driver out of twenty reported seeing signs when they were not there. However, drivers' recognition of the number of signs present fell off as a function of the signs presented. That is, in answering the question, "how many signs are present?" the participants accuracy in identification was reduced systematically with the number appearing in the scene. With respect to identification, there were several characteristics of individual signs which drew attention. In particular, color was frequently reported by drivers as a salient cue. In several cases, signs which could not be recognized by alpha-numeric content were identified by color constituents. This aspect of recognition is a fertile are for future research.

Vehicle Control

As well as sign detection, the ability of the individual driver to control the vehicle while performing the sign recognition task was recorded. This was accomplished in terms of lane position and controlled velocity. For the purpose of analysis, rms error (a measure of lane drift) and velocity error, were compared for the five seconds before the sign was presented with the five seconds after the sign was presented. These results produced no significant differences between the periods evaluated. The tenor of these findings, which are undergoing further evaluation, is that the presence of signs did not affect vehicle control behavior in a substantive manner. It is advised that this preliminary finding be treated most cautiously at the present.

DISCUSSION

The use and effectiveness of signage is a perennial question in driving safety (Johansson & Backlund, 1970). It has become a particular problem as the density of signage and vehicle speed interact to create viewing conditions that defeat the recognition capabilities of even the most attentive driver. It is clear that increasing viewing time increases recognition (see for example Spijkers, 1991) but it is also the case that a number of additional factors such as sign conspicuity and driver expectation also have a substantial impact (Summala & Hietamaeki, 1984; van Norren, 1981). Evaluating signage can be accomplished in a number of ways. Some methods (Spijkers, 1991) require subjects to view signs from a stationary vehicle and seek ecological validity from the context in which they are set. Others use recordings of driver behavior on the road and these tend to be both extensive and expensive forms of evaluation (see Luoma, 1991). The more traditional engineering approach manipulates facets of the roadway and the signage whilst observing driver behavior. Such experimental evaluations require the sanction and cooperation of many judiciaries (see Donald, 1994). A compromise between static work and real-world manipulations is evaluation in simulation. Considerable evidence has been gleaned from such environments (see Hall, McDonald, & Rutley, 1991) and this is the approach that has been adopted in the present work.

What was evident in the present data was the diminishment of returns in co-locating signs together. That is, the addition of signs to one location inhibits the identification of the number of signs present, let alone their specific content. The results further suggest that there must be much redundancy and familiarity in sign perception for such signage to work in the real-world environment. However, there is a paradox here in that the more familiar a driver is with an area, the less they rely on informational signs, and arguably upon traffic control devices which also become subject to 'automated perception (Schneider & Shiffrin, 1977).

RELEVANCE TO THE MINNESOTA DEPARTMENT OF TRANSPORTATION

- The imposition of an increasing number of signs at any single location inhibits the recognition of the number of signs present.
- There is evidence that color coding is given prominence in sign recognition.
- The introduction of distracting signage, such as advertising, might also inhibit traffic sign recognition. This potentiality needs further research efforts.
- There is evidence that vehicle control is largely unaffected by the informational demands of sign recognition. This conclusion should be treated most cautiously since further evaluation of this finding is proceeding.
- There is a strong rationale for further research investment in signage given its importance in IVHS implementation schemes.

TRAFFIC SIGNING ISSUES IN AN INTELLIGENT VEHICLE-HIGHWAY SYSTEM (IVHS) ENVIRONMENT

EXECUTIVE OVERVIEW

This work examines the nature of road signage in the evolving IVHS environment. It is clear that the traditional role of signage as either warning and/or advisory will change and expand in response to the technology intrinsic to IVHS implementations. It is also clear that many road users will initially have no access to these advanced technical systems but there will remain a responsibility to increase the safety and efficiency of signage for all road users. This complex weave of advanced and vestigial functions for signage is examined in the present work. We evaluate various human factors features of present signage as a basis for projection for implementation of advanced systems. We include a brief examination of the contemporary driver population and the restrictions and constraints that the knowledge of such users places upon designers and traffic engineers. Further, we examine how advanced approaches such as AVCS, IVNS, and ATMS will influence future instantiation of signs. Our human factors emphasis is safety as reflected in the swift, uninterrupted flow of vehicles within the roadway system. The report concludes with a synopsis for our customers in the Minnesota Department of Transportation (Mn/DOT). An extended reference listing is provided as a basis for continuing work in both signage and IVHS implementations.

INTRODUCTION

The Purpose of Traffic Signs

Traffic signs provide the public with the vast majority of their present information about route guidance, hazard identification, and warnings and rules of the road. This information is designed to allow the safe and efficient passage of vehicles on crowded freeways, arterioles, and other roadways. There is a tradition of research on traffic signage (cf., Mitchell & Fortes, 1942) and there have been many useful reviews of the existing literature including critiques of poor designs and implementations (see Dewar, 1989, 1993). The purpose of the present work is to build upon these syntheses and evaluations. To use and integrate this knowledge in an overview which is designed to provide our customer (Mn/DOT) with information upon the potential for changes in signage that will accompany Intelligent Vehicle Highway Systems (IVHS) implementation. As such, this work draws on knowledge distilled from companion efforts that are in progress on variable message (or changeable message) signs, and other IVHS implementations (e.g., RDS systems). The work adopts a *systems* approach to integrated signage for projected IVHS environments as they are planned for the Metro and rural areas of the State of Minnesota. It is hoped that our synopsis is also beneficial to others considering this information aspect of IVHS development.

Traffic signs are an important and necessary method of conveying information to road users. Throughout their history they have depicted alphanumeric, pictorial, shape and color information. They warn and direct the driver or traveler about conditions which affect safe and efficient navigation of the vehicle. As they exist today, traffic signs are largely static. In most cases they display non-variable, location specific information. Today's traffic signs have evolved from the early Greek and Roman stone distance markers. Signs have evolved with maps to provide progressively more accurate location and direction information. However, conditions on the roadway have rapidly evolved and signage must change in the face of these new conditions. Thus today's signage may often be rendered ineffective by the rapid change of local conditions or by the speed of the passing traveler to whom the information is directed. The capability of automobile has increased, and the number of cars on the road has also increased, each causing conditions less conducive to the success of traffic signs. Added to this is the overwhelming amount of information which city planners and advertisers want to convey to drivers via signs. The situation has quickly becomes one of information overload, meaning essentially no information at all. Another problem of ever increasing information load is in the driving task itself. Driving takes attention (Brown, 1962; Hancock, Wulf, Thom, & Fassnacht, 1990). The addition of information on hazards, navigation, and vehicle and road status have a tendency to overload even the most vigilant driver (O'Hanlon & Mackie, 1977). Road signs are generally built for the young and fit individual with perfect vision and optimal information processing capabilities (Dewar, 1988). Many road users don't fit this profile and find the combination of demands placed upon them in trying to read and understand signs while driving frustrating and therefore potentially dangerous. In order for a sign's message to be conveyed the sign must first be detected, and then the message processed and understood (Mace, 1988). Sometimes both things must happen in time to permit some sort of vehicle maneuver. In the case of warning signs, distraction of the driver can seriously compromise safety (Brown & Poulton, 1961).

Certainly, extreme cases of inadequate signage are not the rule. However even the examples of better real-world signs are not yet optimal The task of driving today is fairly complex by itself and it does not take considerable extra information complexity on the part of a traffic sign to overextend the information processing capabilities of the driver. The sources of distraction and added complexity are many. For example, the volume of vehicles on the road, driving speeds, passengers, additional information services, and emergencies and hazards. Drivers' attention is drawn to the information contained not only in traffic signs but also displayed on billboards and advertisements, to the song playing on the car radio, tape player, CD player, or to the adjustment of one of the many dashboard controls, or conversation with passengers or on a car phone. The limitations of the human information processing capacities may possibly be exceeded by complicated configurations of traffic signage when coupled with one or more of the above conditions

(Hancock & Parasuraman, 1992). While we do not, as yet, have definitive understanding of the relationship between information overload and safety, it is frequently assumed that the two covary in some non-trivial manner.

An example of overload signing can be found on a commonly traveled route in Boston. Boston's Logan airport has five separate terminals, A through E. Upon entering the loop of road which runs from The highway to the airport the driver is presented with five overhead signs in quick succession, each naming a terminal letter and all the airlines located at that terminal.. There can be as many as 12 or 13 different airlines at a terminal, and it is impossible to scan all the airline names on each sign and process the information to determine which terminal is the correct one at the same time as navigating the car on the three-lane road. Here, signage changes from a pure informational function to one of potential distraction, and therefore, is a hazard in and of itself.

Signage and Roadway Accidents

According to Dewar (1989) the problem of information overload on the part of the driver "points out the need for drivers to make intelligent trip plans". Unfortunately, this policy represents an admission that signs can frequently overload unprepared drivers. Norman (1991) encourages designers to design for error by understanding the causes of errors and trying to minimize their occurrence and maximize the recovery from them (see also Reason, 1990). The case of the driver either missing or not understanding the sign could be ameliorated by either removing external distractions, such as other signs or billboards, or making the sign message more conspicuous and easier to understand. Advance notice may also be given and repetition provides greater sign information redundancy. It is important to consider all the factors which influence the traffic sign's effectiveness, and design the sign to work well within the worst case combination of as many of these factors as possible, see Table 2.

Table 2. Factors Determining The Effectiveness Of Traffic Signs:

- **Driver characteristics**
  - *Age*
  - *Amount of driving experience*
  - *Vision*
  - *Information processing abilities*
  - *Route familiarity*
  - *Attention/motivation*
  - *Drunk driving*
- **Sign design characteristics**
  - *Size*
  - *Placement*
  - *Visual angle*
  - *Materials*
  - *Luminance*
  - *Message content/complexity*
  - *Message size*
  - *Message coding and symbols*
  - *Frequency of occurrence of sign*
- **Environmental Factors**
  - *Visual scene complexity/clutter*
  - *Weather*

There is a sparsity of empirical data which examines any relationship between traffic accidents and inadequate signage. However, signs clearly play a part in the complexity of the overall driving task. Inadequate signing was frequently named as a leading cause in a survey of 920 motorists nationwide who had experienced an accident or a near-miss situation (Midwest Research Institute, 1982). Thus, increasing the complexity of the driving task via complicated sign configurations may further contribute to the already high accident rate. Shinar and Schieber (1991) state that most accidents have multiple causes rather than one specific human impairment and that the most frequently cited human causes of accidents are either attentional or higher-order perceptual failings such as misjudgment, improper lookout, or distraction (see also Bawden, 1900). The cause of an accident may never be attributed solely to a missed exit due to an overly complex or unreadable sign. However, if signs were well placed and well designed, containing an easily processed, informative message, perhaps the dangerous action undertaken by the driver, which was the catalyst of the accident, could have been avoided. Thus some of the underlying elements upon which an accident is based may be removed from the roadway.

Possible Improvements in Today's Traffic Signage

What can designers do to improve today's traffic signs? There are many possibilities. The first question for the designer is: what is the population I am designing for? In this case, the answer is clearly the older driver (see also Burwell, 1993, on general uses of IVHS). Older drivers are making up an increasing proportion of the driving population (TRB, 1988), and older drivers on average have more stringent legibility and conspicuity requirements (Mace, 1988). By designing for the older population, and meeting their greater needs, one is more than adequately providing for the younger population, with their less rigorous visual needs. Though the concentration of suggested improvements discussed here will be on information processing, there are some physical characteristics which could help to improve the effectiveness of traffic signs. Youngblood (1976) found that signs constructed out of high performance retro-reflective sheeting were more conspicuous as well as legible at greater distances. Mace (1988) has shown that increasing letter size improves the legibility of signs, and spacing between letters also makes a difference, (see also Mitchell & Forbes, 1942).

Table 3. Problems in Freeway Use as Seen by Older Drivers (Lerner & Rattle, 1991)

Group Mean Rankings Of Factors Contributing To Dislike of Freeways

	mean rank
Large Trucks	*3.3*
Rudeness or Dangerous Actions of Others	*3.6*
High Speed of Travel	*4.0*
Difficult/Confusing Signs	*4.3*
Difficulty Merging	*4.4*
Difficulty Maneuvering in Traffic	*6.4*
Getting Lost	*6.7*
Things Happen Too Quickly	*6.8*
Exiting	*6.9*
Boring View	*8.6*

An improved traffic sign system would be one which simplified the structure of the information processing task. The changes in the design of traffic signs which would enable better information processing are: avoidance of information overload by reduction of visual scene complexity and use of simple word messages, the use of symbols and codes, and the presence of redundant information to reduce memory load (Deutsch & Deutsch, 1963). Information overload can be avoided by dispersal of signs in either time, space, or both. Complicated or long word messages, such as the Logan airport entrance signs mentioned earlier, can also cause information overload, and should be avoided. Sign message content can sometimes be simplified using salient characteristics as codes. Traffic signs today do use coding quite effectively, for example, color codes, discernible in both day and night driving conditions, tell the driver what kind of information is displayed on the sign well before the driver is able to read the information (Shinar & Drory, 1983). Shape codes can alert the driver as to what the message is. Internationally, there is some variation in color and shape codes and a world-wide standard in association with IVHS implementation is advocated.

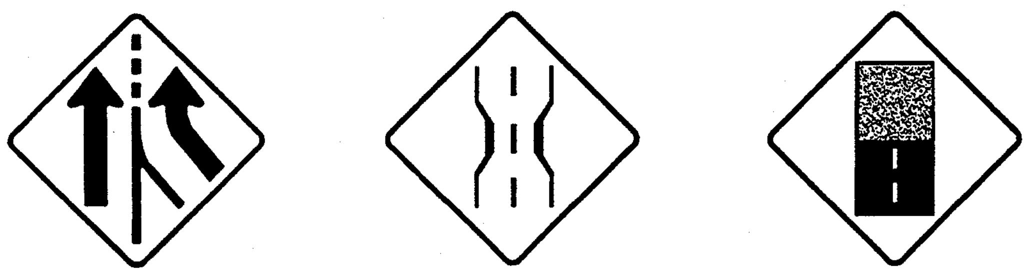


Figure 8: *Differing design of signs and symbolic representations (After Dewar, 1993).*

Simple graphic symbols are also used on traffic signs today; however, they are used less effectively than codes (Dewar, 1989). Symbols on traffic signs are standard icon representations of roadway conditions, warnings, or rules. If properly designed, symbols can be recognized and understood more quickly than word messages on signs, as shown in Figure 8. Dewar (1989) referred to an Australian campaign for signs which can be easily comprehended. These signs contain symbols which are good pictorial representations of real world traffic sign messages Signs can contain abstract symbols also, but it takes time for the driving population to learn the meaning of the abstract symbol. Norman (1988) considers this process of standardization a necessary one in some cases of design improvement. The United States has been relatively slow in incorporating symbols into their traffic sign system (Dewar, 1988). Though upon the introduction of new symbols there would be an adjustment and learning phase, it would be worth the long term investment to start using symbols, if IVHS does not radically alter all of signage environment. Information processing requirements for signs containing symbols would be noticeably reduced as the symbols took on their proper meaning, provided the symbols were easy to learn and remember. This is a critical design challenge in a nascent IVHS environment.

Redundancy of information is another significant way to reduce the information processing requirements placed on the driver. Advance notice sign would improve the overall effectiveness of all signs by alerting drivers to upcoming messages and reminding them of previous messages (this tactic is used in stop ahead signs in present environments). There is one trade-off associated with the use of redundant signs, and that is the possible increase in visual scene complexity. Consequently, in crowded areas (such as metropolitan areas) redundancy is a lesser preferred tactic. Redundancy may also refer to the presence of both sign information and information in the world, for example often crosswalk signs are placed within sight of the crosswalk to which they refer. The implementation of the above suggestions promises improvement in traditional forms of signage.

Consider the STOP sign, a ubiquitous feature of the roadway. It is immediately recognizable, even in poor weather and traffic conditions, by the near-sighted older driver who forgot her glasses, while she drives alone engrossed in a conversation and playing music. The STOP sign is a well-designed sign. It has both color and shape coding, it's message is clear and simple. Most often it is the only sign at it's location. All of these features combined make it an easily recognized and responded to roadway sign.

An Overview of Important Issues

We suggest that IVHS implementations will radically affect signage in general. Hence, attempts to improve traditional signs, while laudable and important, represent only a small element of what the traffic engineer can achieve with signage in the foreseeable future. IVHS promises to change signage so that it no longer relies on two-dimensional, static, non-interactive, visual stimuli to convey location-specific information to drivers. In what follows we present an examination of signage as it will be influenced by each major facet of IVHS. First, we identify critical issues and then present a brief synopsis of the history of signage as a basis for our overview on IVHS signing impacts.

Therefore, the overall goal of this work is to examine the questions associated with and problems with traffic signage today, and the potential issues to be dealt with considering traffic signs on the roadway of the near future. IVHS technology is rapidly being implemented on European and American highways. Such technology demands a re-evaluation of the aims of traffic signage. Evolution of complex IVHS systems may eventually make traffic signs as they exist today, obsolete. As the current signage system changes to meet the needs of the driver in an IVHS environment, consideration must be given to the human factors issues involved in the iterative re-design of signage. IVHS does indeed promise to revolutionize signage by technological fractionation of the traditional constraints imposed upon traffic signs. Signage within an IVHS environment need not be stationary nor static in terms of information provided. Thus, space, time, and content are no longer restrictions on driver information availability. This transition from today's signage to signage appropriate to an IVHS environment will have a potentially great impact on safety and efficiency of roadway signage. Where will signs fit in IVHS? What will be the important parameters to consider when building signs?

The nature of the problem with signage, and the transition to signage in an IVHS environment, implies the need to understand human-machine interaction issues such as the capabilities of the driver and the amount and configuration of the signage provided. The specific objectives of this project are to identify the flaws in the current signage system with respect to human information processing limitations and perceptual capabilities, and the application of this information to aid in the transition to signage in the evolving roadway environment.

HISTORICAL FUNCTIONS OF SIGNAGE

Traffic signs subsume several functions. They are devices used to convey location-specific information to road users and are designed specifically to attract the attention of the driver. Their history comes from early attempts to provide guidance across large distances. For example, in Europe, "milestones" were literally small stones placed at the side of a road to provide just that function. The early Romans and Greeks used stone markers along their highways as map or distance markers. Many early signs occurred at crossroads or meeting places where directions were provided between settlements that represented islands of civilization in the then wilderness. Track signs between towns and villages were the basis of early map-making and several early forms of mapping were "coaching" maps which provided the driver with a dead-reckoning pathway rather than the area coverage which is used in today's maps. Given the speed of early vehicles and the marginal uncertainty of drivers (who basically knew the routes they were traveling), problems such a legibility and comprehension did not arise. Other functions of signs have also grown from contemporary constraints. For example, we can imagine the absurdity of a stagecoach "collision warning" device, as the density of traffic was such that one meeting between two vehicles in a day would have been considered quite unusual.

Despite the intervening centuries, the evolution of the traffic sign really began with the popularity of the early automobile in the early 20th century. At the Traffic Control Materials Division of 3M Corporation in Woodbury, Minnesota, one can see a demonstration of sign changes since the early 20th century road signs. Changes which have occurred in road signs since these early signs include things such as improvement of materials for retro-reflectivity of colors at night and in adverse weather conditions, improved legibility of messages, and some standardization of coding. In spite of this evolution and improvement in signage, there are still improvements that can be made.

The process of guidance for signage is one then that has historical primacy and is perhaps still a major impetus for providing these facilities. However, this process of providing information has become vastly more complex as the potential number of driver decisions has increased and the time for such decisions has also decreased as well. Primarily, the drivers' decision is whether to continue upon the same course or to change to an alternate route. Hence, decision complexity increases directly with the number of alternatives that are presented. The epitome of this complexity is in our major conurbations. Perhaps the most daunting of all of these is Los Angeles. While perhaps not having the intimidation factor of Dallas or New York, Los Angeles has a greater mileage of freeway system than any comparable conurbation in the United States or beyond. The problem of signage is manifest in Los Angeles. The first and most interesting of observations is that the driver needs to "know" their route before they are able to find any novel location. In essence, the driver needs a map of the freeway system in their head in order to get to a place that they have no familiarity with whatsoever. Little wonder that this system proves so intimidating to novices in the area. An example may suffice. At various points, the 110 Freeway can also be called the Harbor Freeway of the 11, depending upon who is consulted and where they are consulted. In order to navigate this freeway, it is necessary to know direction and the location of the town toward which the freeway is headed (e.g., the Harbor Freeway can go to Long Beach but there is also a Long Beach Freeway [which does not necessarily need to end in Long Beach]). In such cases, signage can become so confusing that not only is it non-informational, it can become positively distracting and impair the safe operation of the vehicle (see Hancock & Caird, 1992; Hancock, Dewing, & Parasuraman, 1993). The message is clear, there must be a balance in signage so that it performs its function without concomitant problems of confusion and overload. This is a potential problem for IVHS implementations since there will be much more information available to the driver through multi-media displays. Distal navigation (i.e., transition between origin and destination) is therefore a primary and traditional function of signage. An additional function is proximal route guidance. That is guidance in the near-term. Among such applications are signs for immediate compliance, i.e., traffic control devices, and signage for temporary routes, i.e., workzone guidance.

PURPOSE OF INTELLIGENT VEHICLE HIGHWAY SYSTEMS (IVHS)

There is an acknowledged problem with the transportation systems of the world. This is not confined to the developed world but is perhaps even greater a problem in the developing and third world countries where infrastructure development has evolved at differing rates. The problem is simply stated. There are too many vehicles that are attempting to occupy too little roadway space. This results in congestion, when vehicle density exceeds road carrying capacity. It results in pollution when those same vehicles produce waste that has, in some way, to be absorbed by the environment. Finally, it results in death and injury, when vehicles are placed in close proximity and travel at speeds sufficient to result in damage to drivers and passengers. It is a paradox of congestion that it may potentially reduce injury through reduction of collect vehicle speed. This collective state of affairs of a dirty, dangerous, and delayed roadway system costs each individual country considerable and mounting resources. The United States alone is projected to lose $100 Billion in lost time productivity (TRB, 1991) from road congestion per year. In Europe, where the roadway system is founded upon earlier horse and wagon paths, there is literally no space for expansion in many regions of differing countries. In the United States, where land is more plentiful, this is not an insurmountable problem in rural areas. However, in major conurbations, there is simply not the room to continue to add lanes to existing routeways. In any eventuality, such plans inevitably appear as patching the present systems and frequently additions are overwhelmed as soon as construction is finished.

The problem is not a new one. Hancock, Dewing, and Parasuraman (1993) quote Flink (1975) who paraphrased the observation made by Brownell in 1923:

> *"'The ultimate failure to significantly ease the impact of the automobile occurred even though the responses of city governments and local leaders to the automotive challenge was in the best American pragmatic tradition. As the numbers of automobiles mounted, so did the governmental response: new taxes, improved roads, expanded parking facilities, extensive surveys, and a vast system of regulations enacted to guarantee the auto's operation in the public interest and welfare.' Thus, instead of attempting to discourage the use of private passenger cars in cities, politicians and city planners adopted the expensive and ultimately unworkable policy of unlimited accommodation of the motorcar."*

The question for contemporary society appears to be the same. Are we still attempting to foster an unworkable policy?

The answer appears to be, perhaps not. First and foremost, there is a revolution in the nature of work such that the transportation of information is growing in importance to the level of the transportation of physical material (included in the latter group is human commuters). In the days of the telephone, the FAX, the computer, and video-conferencing, it is now no longer imperative to be physically present in order to accomplish one's business for all purposes. There remain many functions at which it is either vital or preferable to be actually present at some remote site but with the advent of technology such as virtual reality (VR) the frequency of these attendance imperatives is further decreased. However, while technology provides alternatives, a differing strategy argues for the improvement of the roadway system presently in place. Engineering and mathematical studies of roadways expose their inefficiencies which, if reduced or eliminated, could free the present roads that we have. The major effort to accomplish this latter aim is through a program of applications of advanced technologies to questions of transportation. In Europe this program is variously called PROMETHEUS/DRIVE, in the United States the effort is now referred to under the generic title IVHS. IVHS stands for Intelligent-Vehicle Highway Systems, a phrase coined by Kam Chen of the University of Michigan. The organization that now represent IVHS in the United States is IVHS AMERICA.

IVHS grew out of Mobility 2000 which was a group of individuals principally concerned with improving highway transportation (Saxton, 1993). This group defined differential areas of interest such as Commercial Vehicle Operations (CVO), Advanced Traffic Management Systems (ATMS), Advanced Vehicular Control Systems (AVCS), and Advanced Driver Information Systems (ADIS), since divided into Advanced Traveler Information Systems (ATIS) and Advanced Rural Transportation Systems (ARTS). These formed the basis of IVHS concerns which has broadened interest to include all travelers and has engendered additional focus on Advanced Rural Transportation Systems (ARTS). IVHS was supported largely by appropriations under the Inter-Modal Surface Transportation Efficiency Act (ISTEA) of 1991. Since that time, IVHS America has grown substantively and Federal Agencies such as the Federal Highway Administration (FHWA) and the National Highways Traffic Safety Administration (NHTSA) have begun to administer grants and contracts designed to advance knowledge in this general area. In particular, there has been a conscious effort to promote collaboration between Government, States, Industry, and Academe as evidenced in major demonstration projects (Brown, 1993). In Minnesota, this effort has been spearheaded by the GUIDESTAR program and associated demonstration projects such as GENESIS and TRAVLINK. Each of these collective and individual projects has the overall aim of improving the safety and efficiency of transportation. While IVHS is directly particularly to ground transportation, ISTEA mandates a clear effort on Intermodality, that is the relationship between transportation systems. As such ISTEA seeks to enervate the whole infrastructure of the country. What is becoming apparent is that the questions of IVHS are particularly linked to those of information and advanced communications. In particular, the Minnesota demonstration projects are directly concerned with passing traffic information to commuters. However, the partners in those projects are clearly concerned with transmission of more that traffic information. This question of communication of appropriate information is directly bound up with that of signage. Historically, signage has been bounded to fixed spatial locations, especially for route guidance purposes. It is the case that advanced systems make it feasible to present information that is not spatially fixed. The problem is that the wide broadcast of information means that any individual driver or traveler is deluged with information and has the excessively difficult problem of distinguishing appropriate information from inappropriate messages, occasionally while going 55 mph in the middle of rush-hour. The manifest safety problems of such conditions are obvious. What is not obvious is how to present an integrated information system of which signage is one essential component. In particular, targeting information that is context contingent and specifically useful to individual travelers is a considerable challenge. This challenge is articulated here with respect to major IVHS components and some potential systems-based solutions are discussed in summary sections.

SIGNAGE FOR AUTOMATED VEHICLE CONTROL SYSTEMS (AVCS)

One of the major efforts in IVHS is the attempt to convert vehicles from purely driver (manual) control to some form of automation. It is envisaged that under such automatic control numerous strategies can be enacted that would make much more efficient usage of the existing roadways, especially freeways. The present strategy that is receiving the greatest attention is the concept of "platooning." This approach requires the assembly of a sequence of vehicles that travel, train-like, down the freeway. Vehicles then enter and leave the platoon dependent upon individual origin and destination. While ingress and egress generates a number of particular problems, even minor improvements in overall flow promises to have a substantive impact on the problems of congestion. Automated vehicle systems are being aggressively pursued in IVHS and represent a large investment in terms of time and technology. Among the major promises of AVCS is the opportunity to use Defense related work on autonomous vehicles as a basis for advanced systems.

While the promise is great, AVCS is not without a number of potential drawbacks. Safety is a major central issue in IVHS and no facet of the overall development concerns lay individuals than that of relinquishing control of the vehicle (see Sobeleski, in Hancock, Dewing, & Parasuraman, 1993). Can we ensure that such automated systems are 100% reliable. Experience with previous high technology systems would suggest not and some theoretical stances would deny that any system can be guaranteed 100% safe (Perrow, 1984). Consequently, a major concern for AVCS implementation is how to handle system-induced accidents both in terms of litigation and in terms of remedial action. Therefore, while hardware safety is a primary focus for the technologist, software safety is becoming an important concern. At present, few efforts appear to be directly related to safety per se, in IVHS and even fewer are directed to software. How we initiate and indemnify these new systems is a major question for those in IVHS. While all technologies have their potential advantages and drawbacks, the promise of an automated utopia (autopia) has been offered before. In each of the realms in which pure automation has been advanced as the "answer" the problems posed, it has failed. It has failed because it has failed to understand the human role in systems, even when they appear to be minimally involved. Aviation took many years and many mishaps to learn this lesson and only recently has the concept of human-centered automation been clarified (Billings, 1989, see also Oborne, Branton, Leal, Shipley, & Stewart, 1993). The function of technology transfer is to communicate ideas so that lessons learned in one area can be useful in others. There are hopeful signs such that more recent AVCS proposals have begun to incorporate such human factors considerations.

A central question for the present report is on how advanced and current signage could interacts with AVCS systems. This of course directly depends upon the type of AVCS system under consideration and the type of signage envisaged. As a gross generalization, we might divide AVCS systems into those which are free-standing, vehicle-based autonomous systems which rely minimally on roadway features, e.g., machine vision systems which process information about roadways as they present appear. A second group would be those that rely on a strong interaction between features of the roadway and systems within the vehicle itself. An example here might be the magnetic trackway in which vehicle sensors specifically respond to constructed additions in the roadway. A final group might be controls that are principally roadway based and provide control envelopes for vehicles that pass through that envelope, where the control function resides outside the vehicle. This is, of course, an arbitrary distinction and there is no reason why an actual system would not incorporate features from each of these three design alternatives. It is important to examine how signage, broadly defined, might interact with each of these alternatives. The broad definition of signage here implies the provision of information, although this information need not necessarily be communicated to the driver but could be linked to sensors in the vehicle.

Clearly, signage applies most vigorously to systems in which control resides outside the vehicle. In this circumstance, signage can be said to be the controlling system and hence this tactic represents an AVCS technology. The traditional embodiment of signage is for the control of the vehicle to distal sites. Consequently, even with this basic function there must be some interaction between the vehicle and the roadway since the driver must specify desired destination. However, we can easily envisage conditions in which the majority of destinations are pre-programmed, e.g., shopping, school, or as also time pre-programmed, e.g., Monday to Friday 7:30 a.m. drive to work. In these conditions the driver merely enters exception cases and even these can be done at a high level such as, find the nearest hardware store with 3/4′ nails on sale. Given the information flow in the Travtek demonstration environment, the information support for such programming is almost available in existing systems. In these circumstances, the overall system, presumably under larger computer control, programs origin-passageway-destinations for all such equipped vehicles in order to optimize travel time given prevailing conditions. We do not examine here the question of residual signage for those vehicles without access to IVHS systems technology as represented in the present example. We have presented below, a whole section on the question of signage in such mixed environments where some vehicles possess advanced capability and others do not.

Where control resides outside the vehicle in AVCS applications, signage becomes an automated control function between origin and destination. Presumably, this could also be instantiated for local control. That is traffic control devices would be substituted with an embedded knowledge of the roadway and the appropriate behavior. Thus the vehicle would be controlled to stop at all stop signs etc. Actual physical signs would have to remain for transitional environments since there would be many other vehicles on the road that would not have such capability. Given a total IVHS environment, however, such things as traffic lights and stop signs would be redundant since the system would possess exact knowledge as to where each vehicle is at any time and could program movement accordingly. The latter assumes that the question of breakdowns and failures could be also overcome. Therefore, if this design strategy for AVCS were adopted and eventually results in the total IVHS environment, signage as it is presently conceived would cease to exist. However, it is unlikely that this approach would be adopted for social and fiscal reasons, in particular the desire to retain independence of action by each individual traveler. If the vision of autopia cannot be supported it is reasonable to consider systems which focus on vehicle roadway interaction, especially because many of the contemporary demonstration projects in AVCS have adopted this tactic.

When vehicle and roadway interact, treating each vehicle as a separate unit it remains necessary to communicate much information to the driver. This is especially true when only part of the system, e.g., freeways, offer the capability for control assistance. In this form of design, there is no "giant controller in the sky" to work on the problem of overall integration and local autonomy is given to each unit. It is an interesting aside to consider these design strategies with the development of theories on brain organization (Wooley, 1993). Under these conditions, there will be an interchange of control between driver and automatic system. Relief from the continual demands of steering will allow the driver additional time for other tasks such as route navigation. Unfortunately, the progress appears to be that automated control will be available on freeways which are typically the location where navigation is least taxing. In contrast, it does not appear that automation will be available when the driver is on arterials or city streets which is frequently the time when most support is needed. This might be a case of recurrence of a theme that has appeared in aviation automation for some years. That is, that automation reduces the load on the operator when the load is already low, e.g., high altitude cruise (freeway driving) and increases the load on the pilot when the load is already high, e.g., landing (Weiner & Curry, 1980; Weiner & Nagel, 1989). Hopefully, IVHS designers can avoid the latter trend.

Given the avoidance of these problems of automation, navigation problems which are informed by signage can be solved during periods when the driver is offloaded. This begs a central question in signage in general. How much do people use signs anyway? It is acknowledged that the vast majority of miles driven by any one individual is over routes with which they are intimately familiar. This is especially true for the local commuter and two car family but less true for the specialist driver such as trucking and haulage and other services like taxis and delivery. Therefore, the use of signage is directly proportional to one's familiarity with the traveled route. In essence, few people use signage to remote locations when proceeding to work. Traffic control devices are slightly less redundant for frequent users, but it is still the case that drivers are familiar with their routes and stop signs and traffic lights arranged along them. Dynamic signage, such as traffic lights, which present information that changes within the display are less redundant. This is the case since one cannot say that if one arrives at a certain intersection at exactly a certain time that the light will be either precisely red, green, or amber. This is so since changes in lights can be remotely programmed. These assertions about sign redundancy only hold for those directly familiar with an area. Strangers to an area would be unable to navigate or follow road rules without their presence. (It is pertinent to note that during the Second World War, signs were removed from roads in the southern part of England. The result was that many of the English got lost!) Therefore, AVCS strategies which include direct interaction between vehicle and roadway promise much in terms of control but with respect to signage such systems will certainly have less impact on the family of signage than AVCS systems based upon external roadway control. This may seem a restricted discussion since many of the innovations for in-vehicle navigation seem pertinent also. However, we examine IVNS technologies in a separate section. As becomes rapidly clear, IVHS does indeed mean system and any consideration of communications and information flow in that system becomes most confused if a systems approach is not adopted. Hence, although our present focus is on signage, the systems integration also assumes a significant role.

When considering systems integration, we can begin to see how developments such as "smart" pavement markings begin to interact with elements such as AVCS control devices. For example, on present roadways there are forms of signage on the road itself. These can take many forms. Typically direction arrows, center stripes and edge striping are examples. At present, these are passive materials than can help guide the driver in terms of control directives and actual steering assistance. It is often the case that drivers "drive the white line" in poor weather, relying upon the enhanced conspicuity to provide augmented information as to roadway status. It is the case that these markings also inform automated control systems. Present machine vision systems can use the information intrinsic to the conspicuity differences to decide the location of the edge of the roadway. Given this information autonomous vehicles such as the NAVVAN can proceed unaided down a marked road. However, this occurs when the "smartness" all resides in the vehicle on-board detection systems. It is equally possible for the roadway markings to become more active elements in this interchange process. Transmission of more than light might inform an array of detectors on-board a vehicle to provide navigation assistance. Indeed, it is possible that such marking become a backup form of information for all extant traffic control devices. The active versus passive argument is one that engages many areas within IVHS and this depends directly upon the relative role of Industry and Government in the development of systems. However, it is technically feasible to accomplish either in the vehicle or on the road and, as said before, so much depends on the systems integration and how it either evolves or is legislated.

The final AVCS strategy we have identified is a free-standing vehicle. It relies on no external aids and could thus operate on roadways as they presently exist. Given that, it would have to use the family of signage as it presently exists. The interaction with the roadway in this case entails no additions. The only advantage of this system with respect to signage is the "hands-off" time provided to peruse present signs, broadly defined as on-road materials and broadcast information. This can well appear to be a palimpsestual function since it implies a need to make up for the shortfall of the present signing. In the case of a non-trivial percentage of the driving public, e.g., older drivers, this is true. It is the case since the present assemblage of signage does not specifically cater to the capabilities of that and other disadvantaged groups. In conclusion, the next generation of signage can have a considerable impact upon AVCS, including how systems integration might occur in an overall IVHS architecture. It is further clear that differing approaches to AVCS imply this integration to differing degrees. Precisely what strategy is adopted is to be decided in the near future as the collective architecture is defined by Federal agencies in association with contractors. We deal with this issue in more detail on the section specifically directed to IVHS architecture.

SIGNAGE FOR IN-VEHICLE NAVIGATION SYSTEMS (IVNS).

In-vehicle navigation systems (IVNS) are a perhaps the highest profile element of IVHS since it is the component that is most readily apparent to the driver. IVNS is a multifaceted concept beyond simple in-vehicle navigation systems (Dingus & Hulse, 1993; Perez & Mast, 1992). It is envisaged that drivers will be provided with such capabilities in order to facilitate navigation and avoid congestion. These aims are identical with contemporary on-road signage. Hence, IVNS and signage come within the same purview and each represent methods of supplying pertinent information to the driver. The clear difference is the innovation of IVNS and the presence of some high-tech "gadget" within the vehicle with which the driver can interact. However, we cannot forget that in essence, signage and IVNS subsume the same function. There are, however, non subtle differences. The major one of these is the individuality that one's own system provides. Signage is presented for all, IVNS are for the exclusive use of the driver. Further, IVNS is omni-present. That is, while a sign goes by, be it variable message or fixed signage, the IVNS system is always resident and therefore should always, in theory, be able to provide pertinent information. In their present forms, e.g., TRAVTEK, IVNS systems do not provide information about proximal traffic controls such as stop signs or traffic lights. Therefore, in current demonstration projects, drivers have to divide their attention between out of the window views for immediate control and in-vehicle views for navigation cues. This division has been the subject of contention (Andre, Hancock, & Smith, 1993; Hancock & Caird, 1993) since divided attention is one of the few facets of capability that has been linked to eventual driver efficiency.

The advocates of IVNS rightly reply that many drivers attempt to navigate using cumbersome paper maps and their is no essential difference in this division of attention. However, the mere transcription of information from a paper to an electronic medium is insufficient rationale. Rather, IVNS systems provide momentary information on present position updating location and direction dependent upon the specifics of the technical system involved. There is a distinct advantage in knowing one's current location, especially if expressed in terms of a differential between present position and desired goal. However, transcription to electronic media has taken advantage of extensive technology transfer from military systems which have used such technology for an extended period. However, this transcription has been, for obvious financial reasons, direct. What has been the subject of concern is that most people are not familiar with direct map navigation. That is, many individuals navigate using landmarks as compared to map items such as road names or numbers. There are examples of this form of navigation which abound. "Turn left where the old Turner house used to be then sharp right where the county took away the oak that got struck by lightning last year," might work well for individuals with local knowledge but for a stranger it provides no information whatsoever. What it does illustrate is how people code environments for navigation, an area of extensive experimental study. IVNS systems that neglect these styles are liable to be of limited use or at worst reject outright by the majority of potential users.

The advantages of IVNS systems are several fold. First, the systems can store considerable amounts of on-board information so that this information can be supplied during travel rather than be elicited before or force stops during travel. This is particularly the case for stable information that does not change dramatically over short time periods. The location of shops, restaurants, bars and businesses in general can be coded into databases and periodically updated with minor changes. We should note that the more extensive the database the more frequently that it has to be updated since the greater the propensity for some individual item in the database to change. So, while information for a small county may not change significantly in a year, databases for the whole of the United States would probably have to be updated daily. This breadth versus updated accuracy of information is a critical one for IVNS, although at present systems are typically limited to the on-board storage size. This coverage versus accuracy question is raised again in the second great advantage of IVNS, namely the ability to present updated traffic information.

In the present realm of signage, information about traffic conditions can be had via three major avenues. The first is simple, the driver sees illuminated brake lights and realizes that some form of backup is occurring. The second, and more recent form of information is given via changeable message signs that, at fixed locations on the roadway, provide a short message about dynamic conditions. The bandwidth of possible information here is limited but it does have the advantage of reaching the vast majority of individuals traveling on that freeway. It has some disadvantage in terms of causing slow-downs in and of itself (sui generis). However, we do not discuss these full nuances here. The final source of present information is via radio broadcast. The latter source has the advantage of being able to warn individuals well in advance such that they may be able to alter their travel plans. However, radio reaches only a limited number of travelers and their are a percentage of vehicles that do not posses a radio in any form. The difference between the three sources is then the preview time they provide, the range of coverage and hence essentially, the impact each can make upon the traffic flow. All of these have to be considered within the range of the traditional "armory" of signage. IVNS on the other hand offers the potential to reach all so equipped individuals. It provides omni-present information (when switched on and working) and therefore avoids the problem of location bound sources, e.g., variable message signs. Consequently, it provides a greater opportunity to influence traffic flow. IVNS systems also can provide alternative routes, a very important consideration since many who receive information about congestion may not react to it through concern of traveling a new and uncertain route. Re-routing for IVNS is a demonstrated capability, re-routing without such augmented information is an option that only a percentage of drivers would adopt. Clearly then, IVNS adds to the spectrum of signage not in a fundamentally differing way, but by providing enhanced services in a timely manner. The unique element about IVNS is the individuality and therefore context specific information it provides.

The aim of the traffic system is the safe and efficient passage of vehicles between origin and destination. The problem is that virtually all involved vehicles have differing origins and destinations. Traditional signage ignores this individuality and provides information about stable (e.g., road names) and dynamic (e.g., traffic radio broadcasts) conditions independent of these individual concerns. The influences are always exerted at a macro-level of traffic flow. However, attempts to optimize systems-wide traffic flow may well sub-optimize the passage of many individuals who will clearly seek to improve their own travel time. IVNS promises to close this gap between the macroscopic and microscopic, especially where the individual vehicle is not just a passive receiver of widely broadcast information but is also an active source of information within that system. Such knowledge will reduce transit time and might well obviate individual journeys through information, e.g., this store is out of the item you require. The ability to custom tailor traffic information to the individual traveler is the key expectation here an is not confined to IVNS alone. Indeed, major demonstration projects, e.g., GENESIS are directed to exploring how such systems can be made independent of the vehicle and become part of an individually integrated information system.

In sum, IVNS appears to hold several forms of promise related to individual drivers. However, there are some critical questions to be answered here. How often do everyday drivers drive in circumstances where they need navigation information to their destination. The suggestion is very infrequently. Hence, IVNS systems seem to be directed to market penetration in drivers who are required to find unknown locations, e.g., delivery, taxis etc. Further, are IVNS systems justified on the basis of congestion information. There are already existing forms of congestion alerting but IVNS does appear to hold an edge on these current systems. But what is the marginal utility of these systems, what is the cost the driver would bear in order to acquire one? This question has yet to be asked of the market. This is a vital question since hand-held devices are already planned and resident IVNS devices that could go no further than the car might have restricted utility for the average driver. Of course, we might choose to place hand-held devices under the domain of IVNS and consider them all of one package. However, hand-held systems certainly promise expanded temporal coverage and are planned to be linked to other services beyond traffic alone. In sum, there is a complex interplay between the differing envisaged forms of IVNS and traditional signage. Again, in the architectural sense, we need to specify the spatio-temporal ranges we wish to cover and the depth of that coverage that is acceptable, from individual information for all individuals at all times to widespread coverage without individuality to restricted coverage for selected individual. Each of these strategies are possible and might represent and evolutionary sequence. However, the eventual goals of IVHS and the "milestones" along the way represent the guiding principles which will direct how current signage and planned IVNS systems will interact.

SIGNAGE FOR ADVANCED TRAFFIC MANAGEMENT SYSTEMS

There is a direct parallel between the air-traffic controller and the pilot and the traffic manager and the driver. The pilot or driver is trying to get themselves (and their passengers) from A to B. The air-traffic controller or traffic manager is trying to facilitate getting everyone (and their passengers) from A to B. Therefore, while the goals of each appear to be at least similar, their respective strategies can bring them into direct conflict. The parallel between air-traffic control and traffic management is tempting. Initially, there appear to be many similarities, as indeed there are. The locations in which each work are both examples of process control with all the specifics that go with transportation management. However, there are distinct differences. Air-traffic controller manage a certain air-space and have their duties divided between en-route and terminal control areas (TCA). Terminal control area controllers have to bring all vehicles to a single location, a very different process from traffic management. Thus if parallels are drawn they are much more pertinent to en-route air-traffic controllers who have planes "pass" through their space. The major difference is in how control is effected and upon who. For example, Air-traffic control is actively directing vehicles, traffic management is directed to keeping clear space on the freeways and not individual vehicle control. Consequently, in air-traffic control, there is direct contact between the controller and the pilot. There has evolved an unambiguous set of commands which allow much of the interaction to be stereotyped for fast communication. Further, both pilot and controller are highly skilled and practiced. Also, there are not that many planes in the sky and they do not often come into close proximity. As a consequence, there are few major incidents to be managed and no planes parked off to the side in the air awaiting some for of breakdown crew. Hence, the air-traffic controllers job is intense and stressful to be sure, but it is the volume of individual traffic that makes it so, not frequent incident management procedures.

In contrast, the present traffic manager is faced with a similar problem, yet the tools to accomplish this function are not so well refined. The traffic manager cannot contact each individual driver to provide instruction. Even if they could, it is most doubtful if air-traffic control type strategies could work in such an environment with an unselected population of hundreds of thousands of drivers many of whom may occupy the roadway at any one time. In any case, this would alter the presently declared goal of traffic management. Hence, momentary control and navigation strategy has always resided with the driver and promises to remain there for some time. The traffic manager does have an armory of tools which represent forms of information or driver signage. As different cities and towns have different capabilities we cannot discuss all such forms exhaustively. However, the Twin Cities has one of the most advanced traffic management centers in the United States and hence examples from the Mn/DOT TMC may be illustrative. The traffic manager of the TMC has many sensors, being a complement of loop detectors and video cameras giving measures of roadway occupancy. In the case of Minnesota, this is based on real time information from monitors and algorithmic data from loop detectors. Thus the TMC is dominated by visual displays of the information being received. Other forms of sensors are available but for the present purpose we concentrate on vision. Like any organism that has to respond dynamically and adaptively to the environment, TMC must have sensors, decision-making capability, and effectors in order to function successfully. In the TMC after eyeing traffic conditions, decision-making is performed by resident managers. They can influence traffic in an number of ways. They are the source of radio information via KBEM 88.5, the Mn/DOT purpose station. While ramp-meters are automatically controlled, the traffic manager has an override capability for control in exceptional conditions. These forms of signage are used as access controls to the freeway system and for the driver appear as traditional traffic control devices. These are not advisory but are mandatory. However, like all control devices, they are not ubiquitously obeyed. Hence, the manager exerts probabilistic not deterministic control on any vehicle and is engaged in macroscopic management of the system.

At several locations on the Metro area freeways, driver can receive information from Changeable Message Signs (CMS). These signs are typically electronically controlled and dependent upon the level of their sophistication can provide more or less information. In the Twin Cities, the traffic controller can provide very limited information about traffic incidents and subsequent directions as to the actions that drivers should take. The messages on present CMS systems therefore represent only warnings and advisories. During a peak shift in the Traffic Management Center (TMC) the most frequent use of the CMS is to notify drivers to tune to KBEM 88.5 for momentary traffic news. The appearance of this sign coincides with broadcast traffic reports, although the traveling public may not be aware of this linkage.

SIGNAGE FOR ADVANCED RURAL TRANSPORTATION SYSTEMS (ARTS)

One of the more recent thrusts of IVHS is a focus on the impact in rural areas of the United States. This has become known under the collective name of advanced rural transportation systems or ARTS. It grows from a natural concern that much of the focus of IVHS has been directed to the high-tech solution of urban problems and relatively little has been done to serve the many travelers who reside outside of these areas. The problems of rural communities are not a diluted case of those of Metropolitan areas. They face radically different challenges and therefore require differing solutions. This is as true for signage as it is for any other aspect of the roadway system. First, we should note that solutions for ARTS type question do not ubiquitously have to be "high-tech." Questions such as warning signs for rural workzones can be answered with existing technologies as well as the application of upcoming and innovative technologies. The basic functions of signage, advisories and warnings, still pertain to rural environments. As ARTS is a new development, it is useful at the present to consider examples of how advanced signage might be applied. The first example is one that Finkelstein has noted about traffic fatalities. It is well documented that over 50% of fatalities in traffic accidents occur in the window between the event itself and the time at which the individual can be rendered a first form of aid (i.e., paramedics) and a more substantive form of aid (i.e., trauma centers). The period following an accident is known as "the golden hour." It is the activity that happens within this critical period which can be the difference between life and death. Finkelstein has indicated that for rural accidents there is an *average* period of 25 minutes before first line help is rendered to the injured individual. In essence, in a rural accident almost half of the golden hour is wasted in the process of discovery and communication. Therefore, one of the important issues for ARTS signing actually pertains to the vehicle rather than the roadway. If there were some beacon that were initiated by a crash event, there is the promise of considerable savings of time and therefore lives. How these beacons might interact with local communications facilities, such as those in the cellular systems, is a critical issue for future ARTS consideration.

Since the density of vehicles is much less in rural areas and such areas present intrinsically less attention demanding environments, much of the safety problems are related to single vehicle, run off the road type accidents. While this might seem to suggest some form of driver alertness warning system, the possibility of adding intelligent road-markings, especially to interstate highways is an appealing one. As discussed in terms of Advanced Vehicle Control Systems, the provision of interactive information is an important one. At present we have some form of warning in terms of visual marks but they do not prevent excursion from the rural freeway. In the past, sequences of roadside bumps and/or roadway bumps have been used for alerting individuals. Given that a frequency of 4-6 Hz is most uncomfortable for human experience (see Hancock, 1984), roadside bumps can be constructed to provide maximal alerting effects to a driver who is leaving the freeway. However, this is a remedial approach rather than a preventative approach. Prevention might imply automated take-over from fatigued or drowsy driver. These questions are beginning to be addressed in the Mn/DOT ROADSTAR program.

CHANGEABLE MESSAGE SIGNS

Changeable message signs are a relatively new innovation (early 1970's in Europe) on the roadways. They represent the tacit recognition that traditional signs which presented only a single, unchanging message are not flexible enough for the evolving transportation system. Various traffic management systems both nationally and internationally have employed changeable message signs. In the United States for example, Information for Motorists (INFORM) has been implemented to improve the throughput along a highway corridor in New York. Changeable message signs provide information of traffic congestion and delays, which allows drivers to make appropriate route diversion decisions. In Germany the Aichelberg Congestion Warning System was designed to optimize flow of traffic and reduce the number of rear-end collisions. Changeable message signs were employed in this system to provide congestion warnings and speed advisories (Bolte, 1984).

There are several varieties of changeable message signs. They range from the small, portable, limited-content, limited variability signs that may be typically used in workzone environments - through permanent signs with a limited "vocabulary" - to the totally flexible electronic systems which can convey unlimited information at the discretion of the traffic manager. The flexibility of these signs tend to covary directly with their cost. This ranges from several thousands of dollars - through hundreds of thousands - to even the million dollar range. As with all resource investments, the traffic engineer and the traffic management executives have to weigh the cost of these facilities and the on-going maintenance and infrastructure of them versus their effect and the effect of alternatives to these forms of signing. Among these alternatives are RDS systems, expansion of traditional signs, and radio broadcast facilities. Against these decisions are set the background of additional IVHS developments such as personal, hand-held devices to provide traffic information and enhanced Mass-Transit with other roadway innovations such as high-occupancy vehicle lanes.

Thus investment considerations of changeable message signs must be made with a systems perspective that is informed as to technical alternatives and existing local facilities. As with many other IVHS technologies, implementation will most probably be CONTEXT specific. That is, differing solutions will be appropriate for differing questions and circumstances. Initially, it can be envisaged that changeable message signs will be a critical component of the "intelligent" workzone. This is because preview information is critical for the driver to help anticipate the uncertainties of the roadway associated with workzones. As with many new technologies, it is expected that the changeable message sign will be only one of several tools in the armory of the intelligent workzone.

Fixed-location, limited vocabulary message signs are those presently available in the Twin Cities-Metro area. In response to traffic conditions, operators at the TMC can alter the message to warn and advise travelers. Most frequently, the advice given is to tune to KBEM for much more detailed advisories. This is a good strategy since it maximizes the bandwidth of information and is one that will be adopted in early RDS programs. An obvious question is how far penetration of RDS systems into the driving market will obviate the need for limited capability changeable message signs. With respect to all signs, but especially changeable message signs is trust.

Traditional signs are both spatially and temporally static. That is, they stay in the same place and say the same things all the time. If such signs are initially well placed and relevant to that roadway location or configuration, they tend to retain their utility over time. This is not true for changeable message signs. They convey time-dependent information. For this reason, they provide warning of roadway change and congestion to a much greater degree than they provide routing information. The question is, how timely is that information? This is critical since experimental evidence indicates that an individual's trust of a system is easily fractured and recovers only very slowly. This is especially troubling since in early phases of operation, bugs, failures, and operational and procedural problems can mean that information is not as timely as desired and drivers and travelers may dismiss all information on such signs as irrelevant or incorrect. Hence, early phases of development are critical with respect to this form of technology.

IVHS SYSTEMS ARCHITECTURE ISSUES

One of the critical questions in any overall system design is the nature of the agreed architecture for that design. This is a particularly pertinent question at the present since arguable the most important contemporary IVHS program is focused specifically on this issue (Klein, Rantowich, Jacoby, & Mingrone, 1993). The recent Federal impetus for funded work on this issue confirms its centrality and importance. Elsewhere, we have discussed the importance of considering a driver-centered systems architecture for IVHS (Hancock, Dewing, & Parasuraman, 1993). We do not repeat these issues in detail here except to note that the fundamental acceptance of IVHS is with the users. Design in the absence of knowledge about use is a sterile and eventually self-defeating exercise. However, our work focused specifically on the driver and we can generalize this even more to serving the traveler as well as specific intensive users such as the traffic manager. The main thrust of the driver argument comes down, as all the architecture issues do at heart, to the question of information. Our concern in previous work has been with information overload (see also Hancock & Caird, 1993; Hancock & Parasuraman, 1993). What we consider here initially is the problem of system level safety and viability in terms of physical safety and infuriation use (see also Parker, 1993). To accomplish this, we rely heavily on the work of Perrow (1984).

In response to the Three-Mile Island incident, the Nuclear Regulatory Commission undertook an investigation of the events which had occurred. In this process, they elicited comments and observations from many prominent individuals, among them Charles Perrow. His analysis of the incident grew into a more general exposition on the problems of safety in complex systems of which Perrow studied a number. His most interesting conception was a descriptive theoretical structure in which he sought to position complex systems within a Cartesian space whose axes were coupling and interactions. His original conception is given in Figure 9 which is reproduced from his work.

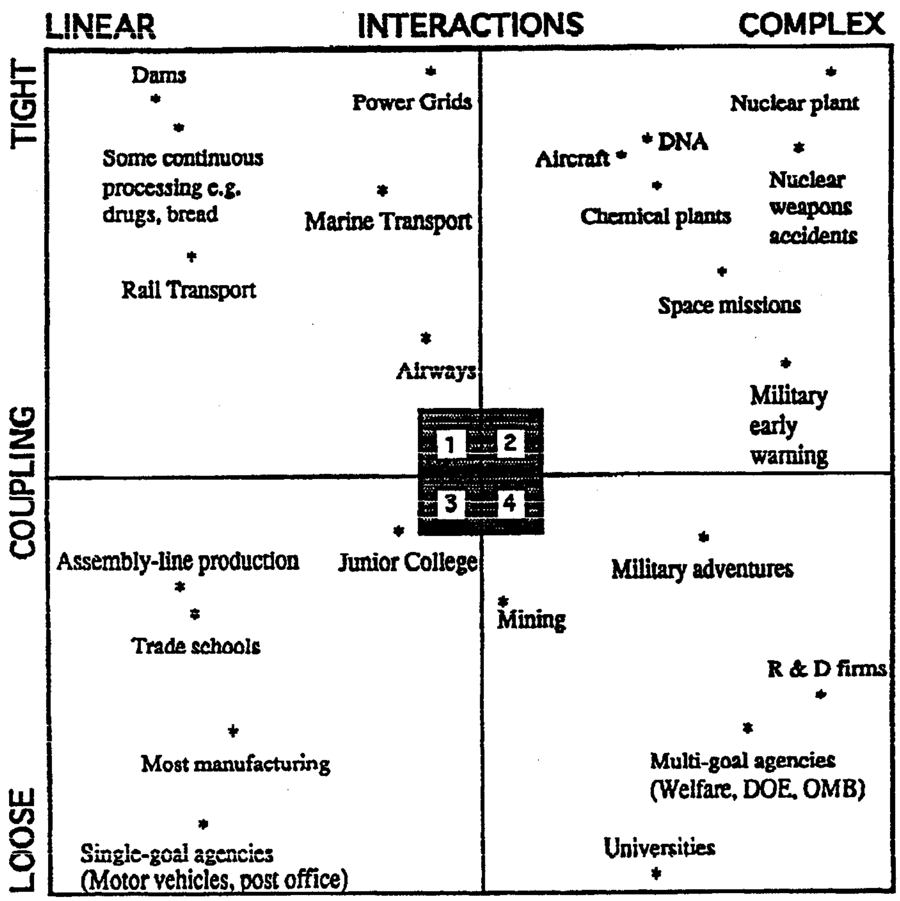


Figure 9. *Location of complex systems against their assessed degree of coupling and level of interaction (from Perrow, 1984).*

We do not attempt here to fully expand upon Perrow's notion but would recommend perusal of the original text. In a simplistic way, the cortical axis can be seen as a temporal metric. That is, how fast do elements of a system communicate between themselves. The tighter the coupling the more immediate the linkage in terms of temporal cause-effect relationships. Thus unitary physical entities such as dams are tightly coupled since the interaction is essentially all within one structure. Conversely, Universities are very loosely coupled since it takes a very long time for information or interaction to pass between component elements. Note that Perrow (1984) takes a microscopic view of transportation here and views each vehicle as essentially autonomous. We discuss this characterization below. The interaction axis refers to the nature of that coupling between elements. If there is a simple cause-effect relationship, as when billiard balls hit each other, the system can be characterized as linear. When the effect of a change in one element is widespread and non-linear the coupling is characterized as complex. Perrow places Trade Schools close to the linear end of the axis in which single causes are linked to single effects. He places space missions at the complex end of the scale where a single event, e.g., a ruptured oxygen tank, has wide scale effects, e.g., aborted mission. It should be immediately apparent that the placement of any system within this frame is a subjective process in which much depends upon the perceptions and knowledge of the individual doing the placing. Typically, we consider other people's systems to be loose and linear, and our own to be tight and complex. However, despite such arguments, these characterizations are of use.

In his work, Perrow submitted that systems that are both complex and tightly coupled will have failures as a result of their design, not because of the normally attributed human failures. Indeed, such was his pessimism concerning the most dangerous identified technology, nuclear power, that Perrow advocated abandoning that technology in favor of possible alternatives. Our purpose here is to re-evaluate Perrow's assumption concerning motor vehicles, especially in light of IVHS developments which were barely conceived when Perrow did his work. Clearly, Perrow treats motor vehicles as each independent entities which have considerable freedom with respect to each other. From the individual drivers perspective this might be a reasonable assumption given that one does not live in a crowded conurbation. However, for large urban areas this is clearly not true. In his comic novel *Gridlock* , Ben Elton (1991, p. 47-48) observed:

> *"Traffic jams are strange things, they resonate. As when a stone is dropped in a pond, the matter does not end with the initial plop. Six feet away some frog on a lily gets a series of rhythmic ripples up the back flap and hops off going ribbit and looking for something semi-aquatic ... It is the same with traffic. It's quite possible for a person to miss a train at Waterloo because half an hour previously a one-driver bus on the Strand was confronted with someone who didn't speak English, only had a twenty pound note and wanted to be taken somewhere that provided traditional English scenes, haddock and tea-time. Traffic jams never actually end, they merely expand and contract, merging into one another, endlessly connected by frustration and grinding synchromesh. There is a little bit of the very first traffic jam in every one that has happened since."*

Residents of Los Angeles for example are very aware that their travel is directly affected by the actions of other drivers. At one time there were distinct rush-hours in Los Angeles and individuals and organizations could adjust their schedule accordingly to obviate rush-hour effects. With the increase in traffic density such demarcations have begun to blur such that no distinct peak times occur and as all users know, freeways are busy all the time. In these conditions, there is a much tighter coupling between road users than was ever envisaged some decade ago. At the macro-level, traffic managers have always viewed vehicles as coupled since they dealt with flow at that grain of observation. Thus in crowded or congested conditions, coupling is no longer loose but tight and getting tighter. At a micro-level, the individual driver sees more vehicles around them and has less room for maneuver.

If motor vehicles now no longer represent a simple loose coupling in all conditions, they also now no longer have simple linear effects. An accident on one freeway can result in backups on an alternate freeway and event result in further accidents at remote locations. We do not yet understand enough about the non-linearity of accidents to essay any predictions about concatenated events. However, the one-hundred car pile up on the California freeway system during a dust-storm begins to show what can happen in terms of domino effects. Therefore, we would submit, motor vehicles in crowded areas move directly from the non-threatening linear/loose combination toward the most dangerous tight/complex combination. The question we have to pose here is twofold. What is the potential impact of IVHS on this trend toward complexity for vehicles, and what design facets can be used to mitigate the potential for inherent systems failures in IVHS? To answer this, we cannot simply advocate a return to previous circumstances since it is acknowledged by all that traffic will increase at least for the foreseeable future.

Does this mean that IVHS systems will inevitably possess inherent system failures regardless of the architecture chosen simply because of the consequences that coupling and interaction impose? Perhaps this is the case. It is true that we are skilled at pointing to failures after they have occurred but are somewhat less facile in identifying what Reason (1990) labels "latent pathogens" prior to the event. The coupling function proposed by Perrow suggest that we should not couple as tightly as the present AVCS strategies suggest. Following the coupling argument, AVCS systems should, it appears, focus upon the development of more autonomous vehicles giving priority to intelligent cruise over approaches such as platooning. It is highly doubtful whether those who advocate any particular strategy would abandon it anyway on these grounds. For signing, perhaps we should look at simplifying information making it context specific and not widely broadcast as presently envisaged. One thing is clear from all the technologies Perrow surveyed. However automated any particular system appeared some human input was necessary. It is frequently this point of entry that non-linearity exploits on its way to disastrous failure.

RESIDUAL SIGNING

After all is said and done with IVHS implementations, there will still be many road users who for historical, personal, or economic reasons will not have access to the plethora of information that will be flowing about the system. Yet they, as much as any other road users have a right to expect a safe and efficient transport environment. How are we to serve these users? In this section, we discuss this service in terms of the evolving IVHS highway and the completed IVHS system. Although not specifically discussed, there is the question of pedestrian users and rural users, both of which are far more liable to rely on residual signing that the driver of the future. It is important for these drivers that information remain clear and consistent, as distractions will always remain problematic. In discussing these situations, who the population of users are may be a critical concern in indicating how residual signage will function.

The evolving highway is always with us. That is, there are continuous changes on the highway in terms of road construction and the introduction of new elements, especially signage. We cannot here confine signage to the official traffic control devices and road signs that are constructed by State and Federal agencies. Rather, signage includes a wide variety of advertising and other displays specifically designed to draw the attention of the traveler. What is as yet uncertain is the degree to which such distractions influence driving efficiency. There is a long history in this area, with Ivan Brown's research being among the earliest and most thorough (Brown, 1962, 1964, 1965, 1967a, 1967b; Brown & Poulton, 1961; Brown, Tickner, & Simmonds, 1966, 1970). He, like we (Hancock, Wulf, Thom, & Fassnacht, 1990), used a variety of secondary task procedures to demonstrate the attentional demands of driving. These are important since they are one of the few human capacities that have been linked to driving safety. It is the case that current signage, broadly considered, does serve to distract attention from the driving task. However, the vital question is whether distraction reduces the margin of safety. Initially, the answer might appear quite obvious that it does. However, set against such a conclusion is the everyday observation that people frequently engage in additional tasks (e.g., shaving, putting on make up, even reading the paper) without having an immediate accident. This is the case since accidents are context specific.

In the past, we may have suspected that accidents make up a small proportion of a continuum of parametrically or non-parametrically distributed events. The prototypical example might be in rear-end collisions where an actual event is one part of the distribution where the average following distance is approximately two seconds behind the vehicle in front. This is a facile and most probably incorrect assumption since accidents are no simple extensions of linear events but are complex, non-linear events that require a much more sophisticated level of understanding (see Kauffman, 1993). Nor is it appropriate to consider all traffic accident types in one group since different dynamics apply to different circumstances. How do these observations affect signing? The answer lies in the nature of the distribution of driver attention and the nature of the failure of that attention during accident sequences. The critical question being, how can signage detract or facilitate that process of attention direction. Answers to this question are vital as the evolution of the signage panoply occurs.

CONCLUSIONS

Let us try to summarize some of the major points that have been made in the present report. We suggest that signage is the material element that is used to pass information to the traveler. This can be in the form of information about remote destinations, it can be in the form of immediate controls, or it can be in forms unrelated to travel which may inform or distract the driver. In certain circumstances, the presence of signage is benign and may even help the driver with problems like fatigue. During long-distance travel on straight freeways, all forms of signage can add to the variety of the display and mitigate the problems that boredom and fatigue bring. However, in busy conurbations, in dense traffic over uncertain routes with many converging and diverging roadways, signage may have a critical role in reducing driver uncertainty and therefore promoting safe passage. The critical factor is the CONTEXT in which the signage is placed. That is, we want to provide drivers with appropriate information when they need it. Further, we want to suppress irrelevant information, especially when they don't need it and it may prove distracting.

Past and contemporary signage is unable to achieve this aim since it cannot be directed so to serve each individual at each critical time. We have had to provide a general framework that is omnipresent so that signage is there, whether drivers are there or not. In human factors terms, the individual has had to adapt to the system not vice versa. As a result of this, there has to be training on both vehicle control (driving school) and obedience to traffic control devices (drivers license). Interestingly, drivers are given no training on navigation. This has been a traditional approach to the linkage between humans and the systems that they operate but it is not considered an optimal one (Kantowitz & Sorkin, 1983; Hancock, 1987; Hancock & Chignell, 1987). There is a propensity within such a design strategy to adopt the "blame and train" response when the system fails. The alternative is to customize the situation for the individual (see also Chapanis, 1951). That is the system adapts to the individual traveler. This is of course the point of entry for IVHS systems.

The barriers to a full implementation are the process of information integration at a systems level and the provision of appropriate interfaces at an individual level. The latter appears to be directly related to IVNS systems but as noted in that section, they provide distal navigation information and at present are not conceived as proving proximal vehicle control information. The latter function falls to two related IVHS technologies that are two companion facets of AVCS. These are active vehicle control and in-vehicle collision avoidance warning systems (Hancock, 1993). While the combination of these systems, fully instantiated, promises to divest vehicle control from the driver to automation, the lessons from other technical areas inform us of the fallacy of complete "sterile" automation. Signage has a critical role in this sequence of development since, policy toward signage largely reflects what overall strategy any one group wishes to adopt. Dismissal of signage is the engineering automation view, integrated adaptive signage is the human factors approach. These differing views make it essential to consider alternatives as IVHS architecture are proposed and evaluated.

RELEVANCE TO THE MINNESOTA DEPARTMENT OF TRANSPORTATION

- Traditional signage provides warning and advisories. This function subserves momentary control and distal navigation of the vehicle.
- Current signage is a subset of all information in the traffic environment.
- Different IVHS programs will re-distribute this information and its communication.
- Different IVHS programs will enhance the availability of information, especially about real-time traffic conditions.
- The first impact of advanced signage will be felt for Mn/DOT at the Traffic Management Center (TMC).
- This will occur through the use of tools that extend the sensory and effector capability of the traffic manager.
- In effect the traffic manager will have more information coming in and will therefore have more to broadcast.
- Like many individuals in process control, the traffic manager can be easily swamped by this information overload.
- Information can be managed by asking <u>who</u> needs <u>what</u> information, <u>when</u> and <u>where</u>.
- These questions should dominate when an overall Mn/DOT IVHS architecture is considered.
- Effective systems design cuts out overlap but still provides full coverage. Information redundancy is a key question for local architecture design in IVHS.
- The goal is to provide a safe and efficient roadway transportation systems for all Minnesotans and to provide National and International leadership in these issues.
- We need to question the assumption that more information means better decisions about travel. Although this is a strong belief we need to continually evaluate it.
- When does signage and information become distracting and how can we design an integrated IVHS system to avoid this?
- The present review argues against sterile AVCS "platoon" approaches and favor the development of autonomous vehicle control.

- How can we integrate IVNS systems if they have no point of liaison with Mn/DOT architecture designs. Consequently the TRILOGY program is key in this area.

- At present there is little information about advanced signage in rural areas. The focus here should be on widespread broadcast and needs further research.

At recent discussions with Department of Transportation Personnel, we have been asked to identify the impact of this information on three practical aspects of their mission. These are: i) accident reduction, ii) congestion reduction, and iii) user acceptance.

1) Accident Reduction

This is a difficult assessment, since our previous work on accidents have identified them as non-linear events which makes prediction an arduous task. However, the present work would indicate that information overload, especially if distracting the drivers' attention from the main task of momentary vehicle control, may be a pre-cursor to accident events. It is also unfortunate that accidents are impoverished indicators since we do not have a baseline of the number of "near-misses." However, if IVHS is to achieve its stated aim of accident reduction it is clear that both in-vehicle and outside-vehicle information sources must present context-specific information in the most simple manner possible. We suggest that information overload is therefore not advised, especially in Metropolitan driving where driving demands are great to begin with.

2) Congestion Reduction

People who know where they are going, and know what the traffic environment is like are liable to make more informed decisions that will reduce the overall traffic congestion. This is the principal upon which contemporary IVHS technologies are based. However, that information must be presented in a timely and trustworthy manner. The lost-traveler picking up a fallen direction sign, not knowing which way it originally pointed is a cliché in the movies. However, the same principal applies to all travelers. Unreliable or outdated information could seriously damage implementation of technologies such as variable message signs since they, in and of themselves, can sometimes add to congestion. Traditional signage is static but if it avoids ambiguity is reliable. Unfortunately, for the traveler who follows the same route each day, as frequently happens in urban driving, the static sign rapidly looses all informational value. Even traffic control devices lose their novelty as experienced drivers "know" where each stop-light and stop sign is placed.

Dynamic signage, as envisaged and being implemented in IVHS, promises much more flexibility. However, widespread broadcast of information on a whole network of roads does not have the purpose-specific effect that is desired. To effectively reduce congestion, we have to target our users individually. While this is technically complex, it is not beyond the capability of contemporary position-location and computational systems.

3) <u>Driver Acceptance</u>

The final issue is driver acceptance. It is a critical one since if the traveling public rejects IVHS technologies, a vast amount of resources will be wasted. In general, the only guarantee about human behavior is that individuals differ. Therefore, some individuals will embrace the complexity of advanced technologies and some will be completely put off by such changes. Therefore, a recommendation that we would make is that considerable effort be put into users surveys of potential designs. In this respect, it is important to consider older drivers who are liable to be those who will stay with traditional signing methods as far as possible. The last thing we advocate is that driver acceptance of early innovations is a key issue for further consideration.

REFERENCES

Andre, A., Hancock, P.A., & Smith, K. (1993). Getting there from here with TRAVTEK. *Ergonomics in Design,* **2**, 16-17.

Allen, T.A. (1967). Luminance requirements for illuminated signs. *Highway Research Record,* **179**, 16-37.

AUTOCAD Manual. (Graphics Design Package for CAD and 3D Object Creation).

Avant, L.L., Nelson, J.N., Short, N., Connerley, M., Bowes, M., & Thieman, A.A. (1988). Prerecognition sensory and cognitive processing of traffic signs. In: Gale, A.G., Freeman, M.H., Haslegrave, C.M., Smith, P., & Taylor, S.P. (Eds.). *Vision in vehicles II.* (pp. 77-86) North-Holland: Amsterdam.

Avant, L.L., Thieman, A.A., Brewer, K.A., & Woodman, W.F. (1986). On the earliest perceptual operations of detecting and recognizing traffic signs. In: Gale, A.G., Freeman, M.H., Haslegrave, C.M., Smith, P., & Taylor, S.P. (Eds.). *Vision in vehicles.* North-Holland: Amsterdam.

Bawden, H.H. (1900). A study of lapses. *Psychological Review,* **3**, 1-122.

Billings, C.E. (1989). Toward a human-centered aircraft automation philosophy. *Proceedings of the International Symposium on Aviation Psychology,* **5**, 1-7.

Brown, I.D. (1962). Measuring the spare mental capacity of car drivers by a subsidiary auditory task. *Ergonomics,* **5**, 247-250.

Brown, I.D. (1964). The measurement of perceptual load and reserve capacity. *Transactions of the Association of Industrial Medical Officers,* **14**, 44-49.

Brown, I.D. (1965). A comparison of two subsidiary tasks used to measure fatigue in car drivers. *Ergonomics,* **8**, 467-473.

Brown, I.D. (1967a). Car driving and fatigue. *Triangle: Sandoz Journal of Medical Science,* **8**, 131-137.

Brown, I.D. (1967b). Decrement of skill observed after seven hours of car driving. *Psychonomic Science,* **7**, 131-132.

Brown, I.D., & Poulton, E.C. (1961). Measuring the spare "mental capacity" of car drivers by a subsidiary task. *Ergonomics,* **4**, 35-40.

Brown, I.D., Simmonds, D.C.V., & Tickner, A.H. (1967). Measurement of control skills, vigilance and performance of a subsidiary task during 12 hours of car driving. *Ergonomics,* **10**, 665-673.

Brown, I.D., Tickner, A.H. & Simmonds, D.C.V. (1966). Effects of prolonged driving upon driving skill and performance of a subsidiary task. *Industrial Medicine and Surgery,* 35, 760-765.

Brown, I.D., Tickner, A.H., & Simmons, D.C.V. (1970). Effect of prolonged driving on overtaking criteria. *Ergonomics,* **13**, 239-242.

Brown, K. (1993). IVHS and the future of State Departments of Transportation. *Intelligent Vehicle-Highway Systems Review,* July, 51-62.

Burwell, D.G. (1993). Is anybody listening to the customer? *Intelligent Vehicle Highway Systems Review,* Summer, 17-26.

Chapanis, A. (1951). Theory and method for analyzing errors in man-machine systems. *Annals of the New York Academy of Sciences,* **51**, 1179-1203.

Colomb, M., & Hubert, R. (1991). Legibility of variable message signs. In: Gale, A.G., Brown, I.D., Haslegrave, C.M., Moorhead, I., & Taylor, S. (Eds.). *Vision in vehicles III.* (pp. 309-316), North-Holland, Amsterdam.

Designer's Workbench Manual. Corypheus Software Inc. San Francisco, CA.

Deutsch, J., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review,* **70**, 80-90.

deVries-de Mol, E.C., & Walraven, P.L. (1988). (Eds.). *Roadsigns.* CIE Publications No. 74. Vienna.

Dewar, R.E. (1988). Criteria for the design and evaluation of traffic sign symbols. *Transportation Research Record,* **1160**, 1-6.

Dewar, R.E. (1989). Traffic signs. *International Review of Ergonomics,* **2**, 65-86.

Dewar, R.E. (1993). Warning: Hazardous road signs ahead. *Ergonomics in Design,* July, 27-31.

Dewar, R.E. & Ells, J.G. (1974). A comparison of three methods for evaluating traffic signs. *Transportation Research Record,* **503**, 38-47.

Dewar, R.E., Ells, J.G., & Mundy, G. (1976). Reaction time as an index of traffic sign perception. *Human Factors,* **18**, 381-392.

Dingus, T.A., & Hulse, M.C. (1993).Human factors research recommendations for the development of design guidelines for advanced traveler information systems. *Proceedings of the Human Factors Society,* **37**,1067-1071.

Donald, D. (1994). *Reducing speed: The relative effectiveness of a variety of sign types.* Australian Road Research Board, Research Report ARR No. 246, Victoria, Australia.

Drory, A., & Shinar, D. (1982). The effects of roadway environment and fatigue on sign perception. *Journal of Safety Research,* **1**, 25-32.

Dudek, C. (1979). Real time displays. *Proceedings of the International Symposium on Traffic Control Systems,* Volume 1, Resources Papers (pp. 186-216), (Berkeley, CA).

Dudek, C.L. (1978). *Human factors requirement for real-time motorist information displays Volume 1: Design guide.* Texas Transportation Institute, Report No. FHWA-RD-78-5.

Dudek, C.L., Messer, C.J., & Jones, H.B. (1971). Study of design considerations for real-time freeway information systems. *Highway Research Record,* **682**, 37-45.

Dudek, C.L., Stockton, W.R., & Hatcher, D.R. (1982). Real-time freeway to freeway diversion: The San Antonio experience. *Highway Research Record,* **841**, 1-14.

Ells, J.G., & Dewar, R.E. (1979). Rapid comprehension of verbal and symbolic traffic signs. *Human Factors,* **21**, 161-168.

Elton, B. (1991). *Gridlock.* Sphere Books: London.

Emmerson, P., & Linfield, P. (1986). Perception of variable traffic signs. In: Gale, A.G., Freeman, M.H., Haslegrave, C.M., Smith, P., & Taylor, S.P. (Eds.). *Vision in vehicles.* (pp. 57-65), Elsevier Science Publishers: Amsterdam.

Evans, L. (1991). *Traffic safety and the driver.* Van Nostrand Reinhold, New York: New York.

Fisher, J. (1992) Testing the effect of road traffic signs' informational value on driver behavior. *Human Factors,* **34**, 231-237.

Gale, A.G., Freeman, M.H., Haslegrave, C.M., Smith, P., & Taylor, S.P. (1986). (Eds.). *Vision in vehicles.*, Elsevier Science Publishers: Amsterdam.

Gale, A.G., Freeman, M.H., Haslegrave, C.M., Smith, P. & Taylor, S.P. (Eds.). (1988). *Vision in vehicles II.* Amsterdam: Elsevier Science Publisher.

Gale, A.G., Brown, I.D., Haslegrave, C.M., Moorhead, I., & Taylor, S. (1991). (Eds.). *Vision in vehicles III.* North-Holland: Amsterdam.

Gisler, W., Rowan, N., & Ogden, M. (1992). Dynamic lane assignment using fiber optic signs. *Transportation Research Record,* **1368**, 10-17.

Gordon, D.A. (1981). The assessment of guide sign information load. *Human Factors,* **23,** 453-466.

Hall, R.D., McDonald, M., & Rutley, K.S. (1991). An experiment to assess the reading time of direction signs. In: Gale, A.G., Brown, I.D., Haslegrave, C.M., Moorhead, I., & Taylor, S. (Eds.). *Vision in vehicles III.* (pp. 333-350) North-Holland: Amsterdam.

Hancock, P.A. (1984). Environmental stressors. In: J.S. Warm (Ed.). *Sustained attention in human performance.* (pp. 103-142), New York: Wiley.

Hancock, P.A. (1987). (Ed.). *Human factors psychology.* Amsterdam: North-Holland.

Hancock, P.A. (1993). Evaluating in-vehicle collision avoidance warning systems for IVHS. In: E.J. Haug (Ed.). *Concurrent engineering: Tools and technologies for mechanical system design.* (pp. 947-958), Berlin: Springer-Verlag.

Hancock, P.A., & Caird, J.K. (1992). Intelligent vehicle highway systems: Problems and promises. *Human Factors Bulletin,* **35** (10), 31-4, (Part I), **35** *(11),* 5-7 (Part II).

Hancock, P.A., & Chignell, M.H. (1987). Adaptive control in human-machine systems. In: P.A. Hancock (Ed.). *Human factors psychology.* (pp. 305-345), Amsterdam: North-Holland.

Hancock, P.A., Dewing, W.L., & Parasuraman, R. (1993). A driver-centered system architecture for intelligent-vehicle highway systems. *Ergonomics in Design, 2,* 12-15, 35-39.

Hancock, P.A., & Parasuraman, R. (1992). Human factors and safety in the design of intelligent vehicle-highway systems. *Journal of Safety Research,* **23,** 181-198.

Hancock, P.A., Wulf, G., Thom. D., & Fassnacht, P. (1990). Driver workload during differing driving maneuvers. *Accident Analysis and Prevention,* **22,** 281-290.

Heatherington, K.W., Worrall, R.D., & Hoff, G.C. (1970). An analysis of driver preference for alternative visual information displays. *Highway Research Record,* **303,** 1-14.

Henderson, R.L (1987). (Ed.). *Driver performance data book.* Washington, D.C.: National Highway Traffic Safety Administration.

Hodge, A.R., & Rutley, K.S. (1978). *A comparison of changeable message signals for motorways.* TRRL Supplementary Report, 380. Crowthorne.

Hoffman, E.R., & MacDonald, W.A. (1980). Short-term retention of traffic turn restriction signs. *Human Factors,* **22,** 241-251.

Hulbert, S., & Beers, J. (1971). *Research development of the changeable message concept for freeway traffic control.* Highway Research Board Special Report No. 129, 24-25.

Jacobs, R.J., Johnston, A.W., & Cole, B.L. (1975). The visibility of alphabetic and symbolic traffic signs. *Australian Road Research,* **5,** 68-86.

Johansson, G., & Backlund, F. (1970). Drivers and road signs. *Ergonomics,* **6,** 749-759.

Johansson, G., & Rumar, R. (1966). Drivers and road signs: A preliminary investigation of the capacity of car drivers to get information from road signs. *Ergonomics,* **9,** 57-62.

Kantowitz, B.H., & Sorkin, R.D. (1983). *Human factors: Understanding people-system relationships.* John Wiley and Sons, Inc.

Kauffman, S.A. (1993). *The origins of order.* Oxford University Press: Oxford.

Keele, S.W. (1973). *Attention and human performance.* Goodyear, CA.

Kerr, J.S., Snelgar, R.S., Jordan, T.R., Emerson, P.G., & Linfield, P.B. (1988). Optimal display factors for light emitting variable message road signs. In: Gale, A.G., Freeman, M.H., Haslegrave, C.M., Smith, P. & Taylor, S.P. (Eds.). *Vision in vehicles II.* (pp. 277-288), Amsterdam: Elsevier Science Publisher.

King, L.F. (1975). Recognition of symbol and word traffic signs. *Journal of Safety Research,* 7, 80-84.

Klein, L.A., Rantowich, N.A., Jacoby, C.C., & Mingrone, J. (1993). Intelligent Vehicle Highway Systems (IVHS) architecture development and evaluation process. *Intelligent Vehicle Highway Systems Journal,* **1,** 13-34.

Luoma, J. (1991). Perception of highway traffic signs: Interaction of eye fixations, recalls and reactions. In: Gale, A.G., Brown, I.D., Haslegrave, C.M., Moorhead, I., & Taylor, S. (Eds.). *Vision in vehicles III* (pp. 325-332), Amsterdam: North-Holland.

MacDonald, W.A., & Hoffman, E.R. (1991). Drivers' awareness of traffic sign information. *Ergonomics,* **34,** 585-612.

Mace, D.J. (1988) Sign legibility and conspicuity. *Transportation in an Aging Society.* in Transportation Research Board Special Report 218 (Vol. 2; pp. 270-293).

Mackie, R.R., & O'Hanlon, J.F. (1977). A study of the combined effect of extended driving and hear stress on driver arousal and performance. In: R.R. Mackie (Ed.). *Vigilance.* Plenum Press: New York.

Manual of Uniform Traffic Control Devices. (Rules and Guidelines for the Development of Road Traffic Signage). Department of Transportation. Washington, D.C.

Midwest Research Institute, (1982). *Public Highway User Fee System: An Assessment of Public Understanding and Priorities*. MRI project number 7193-D.

Milosevic, S. & Gajic, R. (1986). Presentation factors and driver characteristics affecting road-sign registration. *Ergonomics*, **6**, 807-815.

Mitchell, A., & Frobes, T.W. (1942). Design of sign letter sizes. *Proceedings of the American Society of Civil Engineers*, **68**, 95-105.

Norman, D.A. (1988). *The psychology of everyday things*. Basic Books, Inc., New York: New York.

Oborne, D.J., Branton, R., Leal, F., Shipley, P., & Stewart, T (1993). (Eds.). *Person-centered ergonomics: A Brantonian view of human factors*. London: Taylor & Francis.

Olson, P.L., & Bernstein, A. (1979). The nighttime legibility of highway signs as a function of their luminance characteristics. *Human Factors*, **21**, 145-160.

Paelke, G., & Green, P. (1992). Development of a traffic information system driver interface. *Proceedings of the Second IVHS Conference*, 793-802. IVHS America, Washington, D.C.

Pamos, P., van der Brink, T., Alferdinck, J., & Folles, E. (1988). Matrix signs for motorways: System design and optimum light intensity. In: Gale, A.G., Freeman, M.H., Haslegrave, C.M., Smith, P. & Taylor, S.P. (Eds.). *Vision in vehicles II*. (pp. 269-276), Amsterdam: Elsevier Science Publisher.

Parker, G. (1993). Putting IVHS to work to enhance safety. *Intelligent Vehicle-Highway Systems Review*, Spring, 45-50.

Perez, W.A., & Mast, T.W. (1992). Human factors and advanced traveler information systems (ATIS). *Proceedings of the Human Factors Society*, **36**, 1073-1077.

Perrow, C.A. (1984). *Normal accidents: Living with high risk technologies*. New York: Basic Books.

Preston, H. (1994). *AUTOCAD Type D sign & Type OH Sign Development*. BRW Inc., Minneapolis, MN.

Preston, H. (1994). *Stop, yield and no control at isolated low volume intersection*. Paper presented at the Fifth Annual Transportation Research Conference, St. Louis Park, MN, May.

Reason, J. (1990). *Human error*. Cambridge University Press: Cambridge.

Rutley, K.S., & Webb, P.J. (1979). Recognition distances and understanding of legends on an experimental motorway signal. *Transportation Road Research Laboratory Supplementary Report*, 500, Crowthorne.

Saxton, L. (1993). Mobility 2000 and the roots of IVHS. *Intelligent Vehicle-Highway Systems Review*, Spring, 11-26.

Schneider, W.A., & Shiffrin, R.M. (1977). Automatic and controlled information processing. *Psychological Review*, **84**, 1-62.

Shamskhou, H. (1993). Technology evaluation of variable message signs: A comparative analysis of LED vs. fiber optic technology. *Compendium of Technical Papers*, ITE Annual Meeting.

Shinar, D. (1978). *Psychology of the road: the human factors of traffic safety*. New York: Wiley.

Shinar, D., & Drory, A. (1983). Sign registration in daytime and nighttime driving. *Human Factors*, **25**, 117-122.

Shinar, D., & Schieber, F. (1991). Visual requirements for safety and mobility of older drivers. *Human Factors*, **33**, 507-519.

Smiley, A., & Dewar, R.E. (1987). *Changeable message signs: A driver preference survey.* Ontario Ministry of Transportation and Communications (Toronto, Canada).

Spijkers, W. (1991). The recognition of traffic signs under 'natural' conditions. In: Gale, A.G., Brown, I.D., Haslegrave, C.M., Moorhead, I., & Taylor, S. (Eds.). *Vision in vehicles III*. (pp. 317-324), Amsterdam: North-Holland.

Stockton, W.R., Dudek, C.L., Fambro, D.B., & Messer, C.J. (1975). *Evaluation of a changeable message sign system on the inbound gulf freeway*. Texas Transportation Institute Research Report, 200-1f, 100p.

Summala, H., & Hietamaeki, J. (1984). Driver's immediate responses to traffic signs. *Ergonomics*, **27**, 205-216.

Summala, H., & Naatanen, R. (1974). Perception of highway traffic signs and motivation. *Journal of Safety Research*, **6**, 150-154.

Testin, F.J., & Dewar, R.E. (1981). Divided attention in a reaction time index of traffic sign perception. *Ergonomics*, **24**, 111-124.

Transportation Research Board (1988). *Transportation in and aging society I: Improving mobility and safety of older persons*. National Research Council, Washington, D.C.

Transportation Research Board (1991). *Advanced vehicle and highway technologies.* Special Report No. 232, National Research Council.

Turner, J.M., Dudek, C.L., & Carvell, J.D. (1978). *Real-time diversion of freeway traffic during maintenance operations.* Transportation Research Record, No. 683, p. 8-10.

Upchurch, J., Armstrong, J., Baaj, M.H., & Thomas, G. (1992). *Evaluation of variable message signs: Target value, legibility, and viewing comfort.* TRB Presentation. Washington, D.C.

van Norren, D. (1981). *Informatiedragers langs de weg: Een overzicht vanzichtbaar-heidsproblemen.* Report C-25, Institute of Perception, TNO, Soesterberg (NL).

Wiener, E.L., & Curry, R.E. (1980). Flightdeck automation: Promises and problems. *Ergonomics,* **23**, 995-1011.

Wiener, E.L., & Nagel, D.C. (Eds.). (1989). *Human factors in aviation.* New York: Academic Press.

Wolfman, H. (1989). Sign luminance as a methodology for matching driver needs, roadway variables and signing materials. *Transportation Research Board,* Washington, D.C.

Wooley, B. (1993). *Virtual worlds.* Oxford: Blackwell.

Youngblood, W. (1976). *Night legibility study of various traffic sign materials.* 3M Company Technical Report Summary.

Technical Report Documentation Page

1. Report No. MN/RC - 94/33	2.	3. Recipient's Accession No.
4. Title and Subtitle Human Factors Issues In Traffic Signing		5. Report Date August, 1994 6.
7. Author(s) Peter Hancock		8. Performing Organization Report No.
9. Performing Organization Name and Address Human Factors Research Laboratory 164 Norris Hall University of Minnesota Minneapolis, Mn. 55455		10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) Mn/DOT 68429
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Office of Research Administration 200 Ford Building-Mail Stop 330 117 University Avenue St. Paul, Mn. 55155		13. Type of Report and Period Covered Final Report 1991-1992 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This work reports results of an experimental program on human factors issues in traffic signing. The first task examines the problems associated with the programming of signs for evaluation of driver response in simulation. It is concluded that growing technical tools permit traffic engineers to test proposed signage, and avenues of implementation are given. The second task examines driver response in simulation to multiple real-world signs. It is concluded that while much effort is given to distinguishing the utility of individual signs, multiple signs in combination produce more complex decrements. Recommendations are made as to maximum sign density. The final task provides an assessment of signage in future IVHS driving environments. It points to the role of signage as a component of communication. A list of issues for future signage implementation is given for consideration as the Department moves to provide safe and efficient transport for the people of Minnesota into the 21st century.

17. Document Analysis/Descriptors Signage XTAR IVHS IVNS		18. Availability Statement No restrictions. This document is available through the National Technical Information Services, Springfield, Va. 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 76	22. Price

Office of Research Administration
200 Ford Building, 117 University Avenue
Saint Paul, Minnesota 55155

(612) 282-2272