| 1. Report No. FHWA/TX-92/1232-8 | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| 4. Title and Subtitle Advanced Technologies for Communicating with Motorists: A Synthesis of Human Factors and Traffic Management Issues | | 5. Report Date May 1992 |
| | | 6. Performing Organization Code |
| 7. Author(s) K.N. Balke and G.L. Ullman | | 8. Performing Organization Report No. Research Report 1232-8 |
| 9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, TX | | 10. Work Unit No. (TRAIS) |
| | | 11. Contract or Grant No. Study 2-18-91/94-1232 |
| 12. Sponsoring Agency and Address Texas Department of Transportation: Transportation Planning Division P.O. Box 5051, Austin, TX 78763 | | 13. Type of Report and Period Covered Interim Report (September 1990-May 1992) |
| | | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract

This report identifies and discusses a number of human factors, safety, and traffic management issues associated with available and emerging technologies for communicating with motorists in their vehicle. The advantages and limitations of each of these technologies are also discussed. The intent of this report is to provide the Department with insight into those issues that may influence the design, implementation, and operations of ADIS in Texas.

| 17. Key Words Motorist information displays, in-vehicle navigation displays, Advanced Driver Information Systems | 18. Distribution Statement No Restrictions. This document is available to the public through the National Technical Information Service Springfield, VA 22161 |
|---|---|

| 19. Security Classif. (of this report) Unclassified | 20. Security Classif. (of this page) Unclassified | 21. No. of Pages 62 | 22. Price |
|---|---|---|---|

Form DOT F 1700.7 (8-72)    Reproduction of form and completed page is authorized

# ADVANCED TECHNOLOGIES FOR COMMUNICATING WITH MOTORISTS:

# A SYNTHESIS OF

# HUMAN FACTORS AND TRAFFIC MANAGEMENT ISSUES

by

Kevin N. Balke

Gerald L. Ullman

Research Report 1232-8
Research Study 2-18-90/4-1232

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University System
College Station, TX 77843

May 1992

# METRIC (SI*) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|

### LENGTH

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| in | inches | 2.54 | centimetres | cm |
| ft | feet | 0.3048 | metres | m |
| yd | yards | 0.914 | metres | m |
| mi | miles | 1.61 | kilometres | km |

### AREA
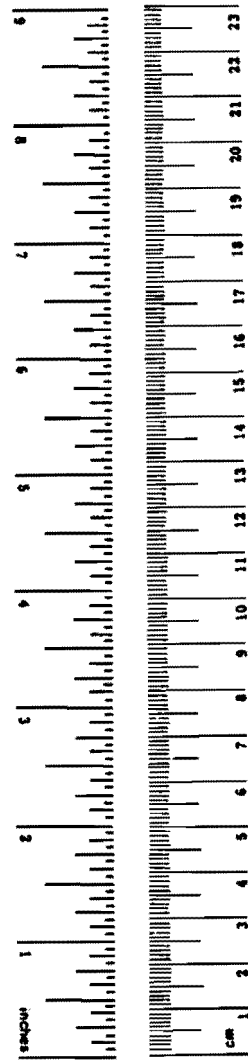
| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| in² | square inches | 645.2 | centimetres squared | cm² |
| ft² | square feet | 0.0929 | metres squared | m² |
| yd² | square yards | 0.836 | metres squared | m² |
| mi² | square miles | 2.59 | kilometres squared | km² |
| ac | acres | 0.395 | hectares | ha |

### MASS (weight)

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |

### VOLUME

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| fl oz | fluid ounces | 29.57 | millilitres | mL |
| gal | gallons | 3.785 | litres | L |
| ft³ | cubic feet | 0.0326 | metres cubed | m³ |
| yd³ | cubic yards | 0.0765 | metres cubed | m³ |

NOTE: Volumes greater than 1000 L shall be shown in m³.

### TEMPERATURE (exact)

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

* SI is the symbol for the International System of Measurements

## APPROXIMATE CONVERSIONS TO SI UNITS

### LENGTH

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| mm | millimetres | 0.039 | inches | in |
| m | metres | 3.28 | feet | ft |
| m | metres | 1.09 | yards | yd |
| km | kilometres | 0.621 | miles | mi |

### AREA

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| mm² | millimetres squared | 0.0016 | square inches | in² |
| m² | metres squared | 10.764 | square feet | ft² |
| km² | kilometres squared | 0.39 | square miles | mi² |
| ha | hectores (10 000 m²) | 2.53 | acres | ac |

### MASS (weight)

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| g | grams | 0.0353 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams (1 000 kg) | 1.103 | short tons | T |

### VOLUME

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| mL | millilitres | 0.034 | fluid ounces | fl oz |
| L | litres | 0.264 | gallons | gal |
| m³ | metres cubed | 35.315 | cubic feet | ft³ |
| m³ | metres cubed | 1.308 | cubic yards | yd³ |

### TEMPERATURE (exact)

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |

```
        °F                                          °F
        -40      32       98.6                      212
        -40    0   40    80    120   160    200
        |--|--|--|--|--|--|--|--|--|--|--|
        -40   -20   0    20    40    60    80    100
        °C                      37                  °C
```
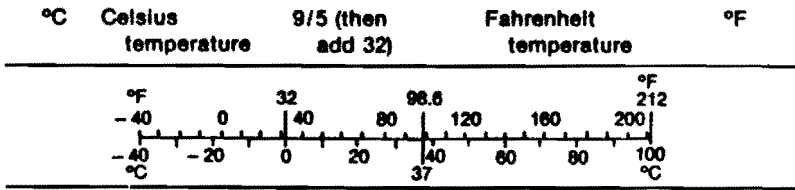
These factors conform to the requirement of FHWA Order 5190.1A.

# SUMMARY

This report identifies and discusses a number of human factors, safety, and traffic management issues associated with available and emerging technologies for communicating with motorists in their vehicle. The advantages and limitations of each of these technologies are also discussed. The intent of this report is to provide the Department with insight into issues that may influence the design, implementation, and operations of ADIS in Texas.

There are a number of available and emerging technologies for communicating with motorists in their vehicle. Currently available technology, such as changeable message signs, lane control signals, highway advisory radio, commercial radio traffic reports, and cellular telephones are being used by many metropolitan traffic management agencies nationwide as their primary means of communicating with motorists. While these devices have been shown to be effective in providing certain types of traffic information to motorists, information cannot be tailored to address the specific needs of individual drivers.

With recent advances in microcomputer and communications technology, several new technologies are emerging that offer the potential to communicate directly with motorists in their vehicle. These technologies include in-vehicle video display terminals, synthesized voice displays, and head-up displays. All of these technologies permit information to be tailored to specific individuals. However, the effectiveness and appropriateness of these technologies in the driving environment remains to be proved.

From a human factors and safety standpoint, the use of in-vehicle devices for communicating with motorists has raised a number of issues. The design and application of in-vehicle devices for communicating with motorists must be sensitive to the differences in the way that individuals acquire and use navigation information. While most systems use auditory displays to supplement visual displays, human factors theory and laboratory studies suggest that auditory displays, such as synthesized voice, should used as the primary mode to present navigation and route guidance information. Although drivers prefer complex map type displays, these types of display require longer glance times by drivers and require the driver to extract the needed information. Human factors research and experimentation indicates that verbal messages, either presented visually or orally, may have less of an impact on driver safety and performance.

In addition to the human factors and safety issues, there are a number of traffic management issues that directly impact highway and transportation agencies. Because of the effect that these systems are expected to have on the operations of the transportation system, transportation officials will be required to monitor and address new, non-traditional issues, such as market penetration, private funding and control, etc. Since the informational needs of motorists will be greatly expanded with ADIS, new levels of cooperation and coordination between jurisdictions and the private sector will be required to ensure a "blending" of technologies.

# IMPLEMENTATION STATEMENT

This report is intended to provide insight into the human factors and transportation management issues associated with both available and emerging technologies for communicating with motorists. The information in this report is intended to assist the Department in planning and implementing Advance Driver Information Systems. The report discusses administrative and policy level decisions which may affect the long-term implementation of ADIS in specific areas.

# DISCLAIMER

# ACKNOWLEDGEMENTS

**TABLE OF CONTENTS**

# LIST OF TABLES

# LIST OF FIGURES

# 1. INTRODUCTION

One way to better manage existing transportation systems is to provide more accurate and timely information to motorists. A number of devices ranging from standard signs, signals, and markings to computerized video terminals mounted on the dashboard of a vehicle can be used to provide motorists with information. This report focuses on the application of advanced technologies for communicating with motorists. Advanced technologies, both internal and external to the vehicle, are discussed. The report also examines the human factors, safety, and traffic management issues associated with the use of these technologies.

**Background**

With the completion of the Interstate Highway System, the nation's focus has changed from constructing new transportation facilities to operating existing facilities more effectively and efficiently. Intelligent Vehicle/Highway Systems (IVHS) are proposed for achieving better utilization of existing transportation facilities and systems. IVHS applies advanced computer, communication, and automotive technologies to "improve mobility and transportation productivity, enhance safety, maximize existing transportation facilities and energy resources, and protect the environment" (1).

There are five elements of IVHS:

- Advanced Transportation Management Systems (ATMS),
- Advanced Public Transportation Systems (APTS),
- Automatic Vehicle Control Systems (AVCS),
- Commercial Vehicle Operations (CVO), and
- Advanced Traveler Information Systems (ATIS).

Advanced Traveler Information Systems are designed to assist all modes of travelers (not just highway travelers) with both pre-trip and real-time decision-making necessary for safe, convenient, and efficient travel. ATIS provides travelers with information that can assist them in selecting the most efficient route, mode, or departure time for their specific trip purpose. Examples of the type of information that might be provided by an ATIS include information on bus or train scheduling and departure times,

1

reports on travel and congestion conditions, weather reports, information on transit stops and transfer locations, etc. (2)

Advanced Driver Information Systems (ADIS) is one component of ATIS. ADIS focuses on providing information to the driver while in his or her vehicle (3). In the ultimate implementation of ADIS, a direct communication link will be provided between a traffic management center and the driver. ADIS is expected to use sophisticated external and in-vehicle communication and graphical displays to relay real-time information on the status of the street and highway system, incident conditions, and parking availability to motorists. On-board navigational and route guidance systems will assist the driver in locating the vehicle's current position and provide the driver with routing information to a specific destination. Using real-time information from a traffic management center, ADIS will permit drivers to dynamically alter their routes in response to reports of congestion or incidents. Comprehensive data bases stored internally in the vehicle will permit motorists to identify and receive information about the specific location and features of services, hospitals, tourist attractions, etc. (1, 2). Some of the features that might be included in a fully operational Advanced Driver Information System include the following (4):

- On-board replication of maps and signs,
- Pre-trip electronic route planning,
- Traffic information broadcasts,
- Safety warning broadcasts,
- On-board vehicle locating and navigation planning, and
- Dynamic electronic route guidance.

Although the full benefits of ADIS will not be realized until more sophisticated route guidance and communication technologies are developed, the rudimentary systems that are currently planned or being implemented will provide direct and immediate benefits to the driver. Current ADIS technologies permit drivers to select routes that are expected to minimize their travel time and/or travel distance to their destination, avoid incidents and areas of congestion, and reduce the number of unnecessary trips. These actions result in a direct travel time and fuel savings benefits to the motorists. As more vehicles become equipped with ADIS, society as a whole benefits from reduced levels of congestion; more efficient movement of people and goods; and reduced fuel consumption, vehicle emissions, and motor vehicle accidents. (2)

The transfer of information between the driver and the traffic management center is paramount for obtaining the full benefits of ADIS. The information must be clear, concise, and easy for the driver to obtain and understand in the complex driving environment. Care must be taken to ensure that the information itself and the manner in which it is presented does not detract from the driving task.

Several emerging technologies (in-vehicle video display terminals, synthesized voice displays, and head-up displays) have the potential for being used to communicate with motorists in an ADIS. Ultimately, one or more of these emerging ADIS technologies may be blended into the transportation system consisting of several traditional communication devices (such as changeable message signs (CMSs), lane control signals (LCSs), highway advisory radio (HAR), commercial radio traffic reports, and cellular telephones) as well. CMS, LCS, and HAR are motorist information components of ATMS (and under direct transportation agency control), whereas the role that commercial radio and cellular telephone systems will play in IVHS are unknown. Each of these available and emerging devices have advantages and limitations in terms of their mode of presentation, driver acceptance, and performance. There are also numerous human factors, safety, and traffic management issues that have yet to be resolved, especially with respect to the use of the emerging technologies in the driving environment.

This report addresses the human factors, safety, and traffic management issues associated with both available and emerging devices for communicating with motorists. It focuses on the role that each device might have when ADIS becomes operational, and the advantages and limitations of each technology. The report also identifies some of the issues that should concern the Department in the development and implementation of ADIS in Texas.

**Objectives**

The three primary objectives of this report are as follows:

1. Assess the application, advantages, and limitations of available and emerging technologies for communicating with motorists in an Advanced Driver Information System;

2. Summarize the existing human factors and safety issues associated with the application of the advanced technologies for communicating with motorists; and

3. Summarize the traffic management issues associated with the use of the emerging technologies towards implementation of ADIS.

## Scope

The intent of this report is to provide insight into the human factors, safety, and traffic management issues associated with the available and emerging devices for communicating with motorists. It is intended to assist the Texas Department of Transportation (TxDOT) in the conceptual design and development of Advanced Traveler and Advanced Driver Information Systems. It is based on a compilation of published conference papers, newsletters, and research reports. No laboratory or field experimentation were performed as part of the development of this report.

## Organization of the Report

The report is organized into five chapters. Chapter 2 provides descriptions of the potential devices for communicating with motorists. Both in-vehicle and external devices are discussed. Chapter 3 summarizes the human factors and safety issues associated with the use of the advanced technologies for communicating with motorists. Issues relating to traffic management aspects of these devices are contained in Chapter 4. Chapter 5 provides a summary of the issues and provides administrative and policy-level recommendations for addressing the identified issues.

## 2. DESCRIPTION OF IN-VEHICLE COMMUNICATION TECHNOLOGIES

A number of technologies are already available and being used to communicate with motorists. Some of these technologies have been around for a number of years, whereas others have only recently been introduced in the driving environment. Meanwhile, as ADIS implementation progresses, a number of emerging technologies currently undergoing research and development may further enhance the ability of public agencies (as well as the private sector) to provide useful and accurate traffic and navigation information to drivers.

There has been some research and experience through the years on CMS, LCS, HAR, and commercial radio which has suggested the types of benefits (as well as limitations) to be expected from each. On the other hand, emerging technologies offer the opportunity to improve information dissemination and navigational assistance to motorists through advances in computer technology, video imaging, and understanding of human cognitive navigational processing. However, as yet, these emerging technologies are untested on a large scale. Furthermore, the success of these emerging technologies will be predicated on the ability of the private sector to successfully market the hardware to motorists, and the ability of the public and/or private sector to maintain the accuracy and credibility of the information.

This chapter provides an overview of the various available and emerging technologies for communicating with motorists. Basic usage and applications, along with the advantages and limitations of their use in the driving environment, are described for each technology. The available technologies for communicating to motorists while driving include:

- Changeable message signs (CMSs),
- Lane control signals (LCSs)
- Highway advisory radio (HAR),
- Commercial radio traffic reports, and
- Cellular telephones.

Changeable message signs (CMSs), lane control signals (LCSs), highway advisory radio (HAR), and commercial radio traffic reports have been in existence for a number of years (5). More recently, though, their implementation and use in urban areas has

expanded greatly as agencies look for ways to combat continually rising congestion levels. Research performed during the past 20 years has shown these technologies to be effective in providing certain types of traffic information which result in changes in motorist travel patterns. Cellular telephones are a more recent development. Deployment of cellular telephones within the driving population has grown tremendously during the latter 1980s. Already, several cities are taking advantage of this technology for incident detection by establishing toll-free numbers for motorists to report traffic problems they encounter while driving (6). In addition to their use for incident detection, however, cellular telephones allow motorists to access call-in traffic information systems enroute, rather than just prior to the start of a trip as was possible before.

Complementing those devices which are already available to motorists are those emerging technologies which are part of the ADIS component of IVHS. These technologies include the following:

- Video display terminals,
- Auditory display terminals, and
- Heads-up display terminals.

With respect to the emerging technologies, all three types of devices offer the opportunity for information to be tailored specifically to each individual motorist while in his or her vehicle. In the early phases of implementation, these devices will assist motorists with navigational decisions independent of traffic and other conditions, through static route planners, address databases, etc. However, they are envisioned to eventually communicate with real-time traffic information centers so as to assist motorists through dynamic route guidance and navigation. Questions remain, though, as to whether any, or all, of these emerging technologies can and will be effectively utilized by motorists.

**Description of Available Communication Technologies**

Available communication technologies, as referred to in this report, are those devices which are currently being used to communicate traffic and related information to motorists while in their vehicles. Such technologies may have been in existence for years, or may have only just been introduced into the driver information market. Regardless, all

6

of these technologies are now operational and are actually being applied in metropolitan traffic management.

## Changeable Message Signs

Changeable message signs (also called variable message signs) have been utilized to communicate with motorists for 30 years (7). They are used for real-time traffic warning, regulation, routing, and management purposes. In urban areas, CMSs are the primary device used by transportation agencies to communicate directly with motorists. A recent inventory (6) identified 57 different freeway operations systems in North America with CMSs anticipated or in use.

Early CMSs were quite limited in terms of the amount of information they could display, and the ease with which this information could be changed. However, advancements in computer technologies in the 1970s and 1980s resulted in the ability to quickly and easily display nearly any type of message that could physically fit onto a CMS. Partly in response to the increased flexibility of CMSs, human factors guidelines were developed to assist in the design and implementation of real-time motorist information messages (5).

A synthesis of available CMS hardware has just recently been completed (7). At the present time, CMSs can be light-emitting, light-reflecting, or a hybrid of both. New light-emitting hardware such as fiber-optics and super-bright light-emitting diodes (LEDs) are also being applied to CMS designs. Research also continues into more futuristic technologies such as holographic signs, dynamic graphic display boards, etc. Given the significant interest and investment in CMS technology nationally, they are destined to remain an important part of urban traffic management systems in the foreseeable future.

CMSs provide several advantages for communicating with motorists in real-time. First of all, the technology is proven and is being utilized extensively nationwide. Also, CMS operations are generally incorporated into the overall traffic management system of the freeway, corridor, or roadway network. In this way, transportation agencies have direct control over the amount and accuracy of information presented to motorists.

However, CMSs also suffer from several limitations. First of all, the location of the devices is fixed, which limits where and when motorists are able to access information.

Furthermore, motorists can see any given sign for only a small amount of time, which constricts the amount of information that can be presented to the motorist. Also, the visibility of CMSs can be affected by external conditions such as weather or a high percentage of large trucks. Finally, the information that is presented cannot be easily tailored to the needs of individual motorists. As a result, much of the information that is presented may not be relevant to the needs of a given motorist.

Table 1 summarizes the advantages and limitations of CMS technology in communicating with motorists.

---

**TABLE 1. ADVANTAGES AND LIMITATIONS OF CMS TECHNOLOGY.**

Advantages

- Proven technology
- Transportation agencies have direct control of information

Limitations

- Fixed locations
- Driver viewing time of messages is limited
- Visibility affected by external conditions
- Difficult to tailor information to individual motorists

---

Lane Control Signals

According to the Manual on Uniform Traffic Control Devices (MUTCD) (8),

"Lane-use control signals (LCS) are special overhead signals having indications used to permit or prohibit the use of special lanes of a street or highway or to indicate the impending prohibition of use."

8

The most common uses of LCS are to regulate reversible lane situations, such as at toll plazas, on urban arterials, or on reversible HOV transitways. However, they may also be used on freeway facilities to indicate the current condition of each travel lane.

The MUTCD allows the use of four LCS displays:

- A downward green arrow -- to indicate that the lane is open and that a driver is permitted to drive in the lane over which the arrow is located,
- A steady yellow X -- to indicate to a driver that he or she should prepare to vacate the lane because a signal change is being made to a red X,
- A flashing yellow X -- to indicate that a driver is permitted to use the lane over which the signal is located for a left turn (applicable to arterial streets only), and
- A red X -- to indicate that the lane over which it is displayed is closed to that direction of traffic, and that a driver shall not drive in that lane.

In addition, some transportation agencies are using other symbols (such as yellow downward arrows) to expand the types of information that a LCS system can present to motorists. However, these symbols have yet to be shown effective in communicating the desired information to motorists.

Table 2 presents a summary of the major advantages and disadvantages of using LCS to communicate with motorists. LCS have a finite number of displays which makes them simpler to operate manually, and possibly easier to automate using loop detector or video imaging data from an electronic surveillance system. LCS communicate only through colors and symbols (X's and arrows), so they can be understood by non-english-speaking drivers as well. Finally, they are under the control of the transportation agency, who in turn has control over when and what information is presented to motorists through this technology.

LCS systems have their disadvantages as well, however. Because they rely on a fixed number of symbols, they can relay only a limited amount of information to motorists about lane conditions. They cannot be used to make recommendations to motorists, or to warn them of the reasons for the lane conditions. Also, although symbols can be used to communicate with non-english-speaking drivers, human factors research suggests that symbols generally achieve lower levels of comprehension than similar word messages when describing lane blockages or closures (5).

9

---

**TABLE 2.  ADVANTAGES AND DISADVANTAGES OF LCS TECHNOLOGY.**


Advantages
- Simple to operate and automate
- Symbolic messages can be understood by non-english-speaking drivers
- Transportation agencies have control of information

Disadvantages
- Only fixed amount of information can be displayed
- Symbols tend to have lower comprehension levels

---

Highway Advisory Radio

Highway advisory radio (HAR) is another available technology that allows information to be communicated directly to the motorist.  HAR is broadcast on a special AM frequency (either 530 or 1610 Khz) which motorists can tune to on their car radios. An FM frequency HAR is also being considered at the present time (9).  HAR is not as widely used as CMSs in the United States for presenting traffic information.  At the present time, 23 freeway surveillance and control projects nationwide have or are implementing HAR systems (6).

Human factors considerations indicate that many types of information motorists may need or desire are well-suited to audio presentation.  Since the motorist receives most of their information through visual means, the visual sense may become overloaded in complex driving environments.  Presenting certain information by audio means is one way to reduce sensory overload and facilitate motorist comprehension of information (10, 11).  Furthermore, information can be presented continuously to the motorist long as he or she is within transmission range of the system.  As with CMSs, extensive research performed during the 1970s and 1980s has led to the development and design of implementation guidelines for HAR systems (5, 12, 13).

Unlike CMSs, however, HAR does require motorists to take action (by tuning to the appropriate frequency on their radios) in order to obtain information. In addition, visual signing is required to notify motorists to tune to the appropriate radio frequency. If motorists do not see the notification, they will not tune in to the information. However, efforts are underway to develop automated HAR systems (AHAR) which interrupt normal broadcasting channels to automatically present information to motorists (9). Also, HAR systems generally operate on fairly low power over a limited range. As such, information access is still somewhat limited to a specific location, although this limitation is not as severe as it is for CMSs. Finally, information presented by HAR is transient. If the motorist misses some part of the message the first time, her or she must listen to the entire message over again to get the specific part that was missed. The advantages and limitations of HAR are summarized in Table 3.

## Commercial Radio Traffic Reports

The final existing method of in-vehicle communication to the motorist is through the commercial media, in the form of periodic peak-period traffic updates by various stations in most large urban areas. Commercial radio stations may obtain their own traffic information through "eye-in-the-sky" reporting crews, obtain information from private traffic reporting services, or obtain information directly from the highway agency (as is done in the Chicago area (14)).

Table 4 presents the major advantages and limitations of commercial radio traffic reports. Commercial radio has the potential to reach a significant number of motorists, since most vehicles have operational radio units. Currently, most stations broadcast traffic information as part of their public service efforts and to attract and maintain a share of the market. Furthermore, recent studies indicate that these traffic reports are both desired and used by the motorists (15).

One of the major limitations of commercial radio, however, is the lack of timeliness and accuracy of the information presented to the motorists. The presentation of traffic information is but one small part of the radio station's objectives, and so, the information must be scheduled within the overall programming structure. Consequently, time lags occur between the time information is obtained on traffic conditions or incidents and the time it is disseminated (16, 17). For example, motorists often state that accidents and other incidents that are reported by radio stations are no longer present when they reach

**TABLE 3.  ADVANTAGES AND LIMITATIONS OF HAR.**

Advantages

- Well-suited to presenting certain types of information
- Helps alleviate information load received visually
- Longer and more complex messages can be presented to motorist
- Transportation agencies have direct control over information dissemination

Limitations

- Requires motorist action to receive information (i.e., tuning radio)
- Low power transmission limits effective broadcast range
- Information is transient

the incident location.  Another limitation of commercial radio for disseminating traffic information is that the information presented is of a regional nature.  Motorists must listen to the entire report for any information on their planned roadways.  Also, the fact that the entire region must be addressed typically limits radio reports to only major traffic problems on freeways or major arterials.

Cellular Telephones

An in-vehicle communication technology that has seen dramatic growth in the past few years is cellular telephones.  These systems allow motorists and transit users to call an information data base to determine travel conditions, transit routes, and scheduling information to assist in pre-trip decisions.  In addition, information can be accessed enroute and decisions made whether to alter travel routes.  The creation of call-in systems has been a popular traffic impact mitigation strategy for many major urban freeway reconstruction projects in recent years (18).

This type of in-vehicle communication has the advantage over both CMS and HAR in that the motorist can be given some control over the type and amount of information they want to obtain (through a series of touch-tone menus, for example).  In addition, it

**TABLE 4. ADVANTAGES AND LIMITATIONS OF COMMERCIAL RADIO TRAFFIC REPORTS.**

Advantages

- Large audience can receive information
- Most radio stations now broadcast traffic information
- Surveys indicate many motorists desire information through this format

Limitations

- Information often not accurate nor timely
- Information is of a regional, not local, nature
- Transportation agencies cannot control information

is also possible to generate two-way communication between the motorist and the information source. Many urban areas have established "hotlines" for motorists to call in and report incident information to the highway agency.

However, as with HAR systems, this technology also requires action by the motorist to access information. Furthermore, the information is currently accessible to only a small portion of the driving population (currently about 3 percent of the population in Chicago have cellular phones, for example (19)). There are also significant operating costs associated with this technology, as any calls made using cellular telephones must be paid for by either the motorist, a public agency, or absorbed by the corporation providing cellular telephone communication capabilities in the region. Finally, there is some concern that cellular telephone usage while driving may degrade motorist attention and operating capabilities (20). However, manufacturers have developed "hands-free" telephones which allow motorists to listen and talk without holding the telephone receiver to help reduce safety problems. The advantages and limitations of cellular telephones are summarized in Table 5.

```
┌─────────────────────────────────────────────────────────────────────┐
│                                                                       │
│    TABLE 5.  ADVANTAGES AND LIMITATIONS OF CELLULAR TELEPHONES.       │
│                                                                       │
│                                                                       │
│   Advantages                                                          │
│                                                                       │
│        •   Type and amount of information received can be controlled  │
│            by motorist                                                │
│        •   Two-way communications possible                            │
│                                                                       │
│                                                                       │
│   Limitations                                                         │
│                                                                       │
│        •   Action required for motorist to obtain information         │
│        •   Market share is limited at the present time                │
│        •   Significant operating costs                                │
│        •   Safety concerns with telephone use while driving           │
│                                                                       │
│                                                                       │
└─────────────────────────────────────────────────────────────────────┘
```

**Emerging Technologies**

A variety of new technologies are emerging that will permit transportation agencies to communicate with individual drivers directly in their vehicle. These technologies include video display terminals or monitors mounted in the dashboard of the vehicle, synthesized voice displays, and in-vehicle head-up displays. While most of these technologies have been used extensively in the aviation industry for some time, they are just beginning to be applied in the automobile industry. Research efforts are currently underway to explore the applicability and appropriateness of these technologies in the driving environment.

In-Vehicle Video Display Terminals

One potential method of providing drivers with complex navigation and route guidance information is a video display terminal (VDT) mounted in the dashboard of a vehicle (11). A few systems are under various stages of development or in prototype form. Most of these systems will be used to provide motorists with route guidance and navigational information. Navigational and route guidance information can be presented on VDTs in two different formats (2). One approach is to present the driver navigation and route guidance information in the form of maps or equivalent displays. With these

systems, a global picture of the traffic network can be provided. Recommended routes can be highlighted on the video map display. In this format, all drivers, regardless of their destination, receive the same traffic and congestion information. The AMTIC system being developed in Japan and the Pathfinder System being developed in California are examples of this first type of system (21, 22).

In the other approach, simple symbolic signals (i.e. arrows), text instructions, or a combination of both guide the driver along a recommended route (11). The Autoguide (Great Britain) and the ALI-SCOUT (Germany) systems use simplified schematics of intersections with directional arrows indicating the next action to be taken by the driver (23) (See Figure 1). Some systems, such as the TravTek system being developed in Orlando, Florida, use a variety of displays depending upon whether or not the vehicle is in motion, the functions selected, and level of information desired by the driver (24). Figure 2 illustrates some of the various informational and navigational displays available with the TravTek system. A limited amount of navigational and traffic information functions (Figures 2d through 2f) are available while the vehicle is in motion. Conversely, those functions which involve a driver's actions to manipulate, such as the destination finding, electronic "yellow-pages" and trip planning functions, are available only when the vehicle is parked.

In-vehicle VDTs offer a number of advantages over available technologies in providing information to motorists while driving. The first obvious advantage is that information will be more readily accessible to the driver. By presenting this type of display in the vehicle, the driver will have constant and continuous access to current position, routing, and navigational information. Another major advantage of in-vehicle VDTs is that computer-generated navigational maps and displays are logical extensions of traditional forms of providing drivers with route guidance and navigation information. A final advantage to in-vehicle VDTs is that the format for providing information is flexible. Information can be displayed in text, graphics, or a combination of both. This will permit information to be better organized so as to reduce processing time and effort by the driver. Color can also be added to these displays to assist motorists in processing information more quickly and accurately.

As with the available communication devices, however, there are also limitations to in-vehicle VDTs. Perhaps the greatest limitation and concern with this technology is that drivers will have to take their eyes off the roadway in order to receive the information. Concerns also exist that in-vehicle VDTs present the driver with complex maps and

**'As the crow flies'** direction to the destination

**Follow main road**

**Change of direction** prepare execute

**Roundabout** take 3rd exit

**Lane** recommendation

**Switchover to** 'as the crow flies' direction in the destination area

**You left** recommended route

Distance information: always as the crow flies!

Figure 1.  Route Guidance Symbols used in German ALI-SCOUT System. Source: (23)

diagrams.  This creates a potential to overload the driver with too much information as well as add visual clutter inside the vehicle.  A more detailed discussion of these types of limitations is provided in Chapter 3.

Table 6  summarizes the advantages and limitations of using in-vehicle VDTs to communicate directly with drivers.

## Auditory Displays

While some auditory displays, such as warning and alert buzzers and beepers, have been used in automobiles for some time, recent advances in electronics have greatly expanded the range of auditory messages that can be presented to drivers. Technological advances in speech synthesis are primarily responsible for expanding the range and flexibility of auditory display systems.  Potential applications of speech technology include the following (11):
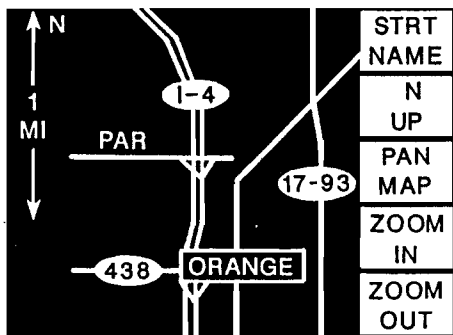
- fuel and vehicle status information;
- advisories of traffic, terrain, and weather information;

Services/Attractions Menu



Saved Destination Screen



Map of Local Area
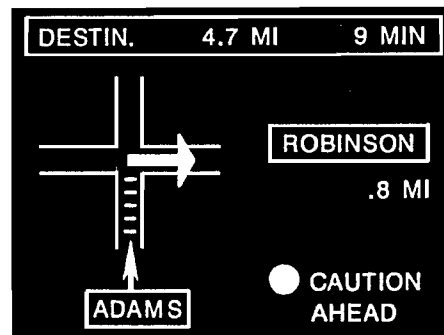


Guidance Map with
Traffic Warning Superimposed
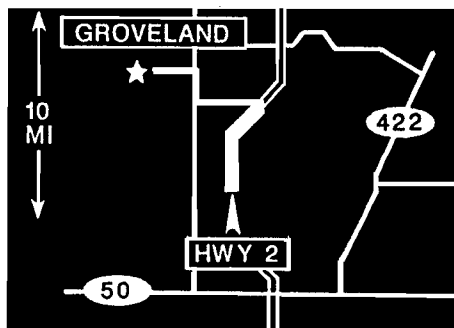


Route Map Display



Traffic Information Overlaid
on a Map Display

Figure 2. Examples of TravTek Information Displays.
Source: (24).

concentration at critical moments during the driving task. Since there is a wide range of noises and sounds in the automobile, auditory displays may have to compete with other auditory sources (e.g., the radio, passengers, general road and vehicle noise, etc.) for the driver's attention. Also, the overuse of auditory displays may lead to auditory clutter within the vehicle. Another major limitation to auditory displays is that they may interfere with the driver's ability to hear external emergency warnings and alerts such as at railroad grade crossings, and when emergency vehicles are on the road (26).

The complexity of the information that can be provided by auditory displays is another limitation. Warnings or alerts are easily communicated via auditory displays. However, more complex information, such as navigation and route guidance instructions, will have to be presented through speech. Drivers typically do not comprehend the meaning of a spoken message until the transmission is essentially complete. Often, long messages have to be repeated several times before the total meaning can be comprehended and remembered by the driver (12). For this reason, longer messages may be comprehended more rapidly by the driver through a visual message than through an auditory display (5,11). The advantages and limitations of auditory displays are summarized in Table 7.

---

### TABLE 7.  ADVANTAGES AND LIMITATIONS OF AUDITORY DISPLAYS

Advantages

- Reduces visual demands on driver
- Reduces visual clutter
- Good for transmitting alerts and warnings
- Does not require driver to take eyes off road

Limitations

- May disrupt driver concentration
- May lead to auditory clutter (noise)
- Difficult to present long and/or complex information
- Slow communication medium
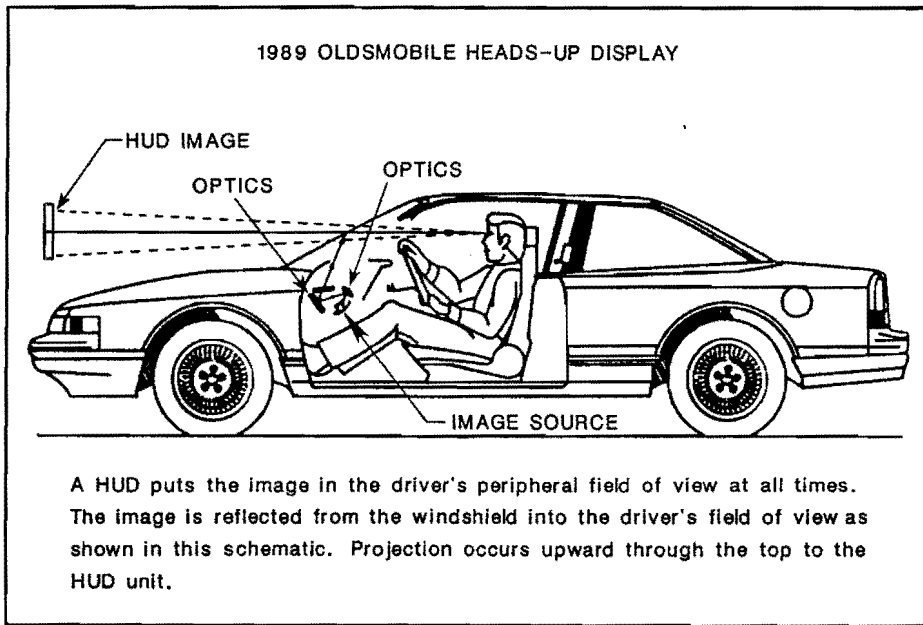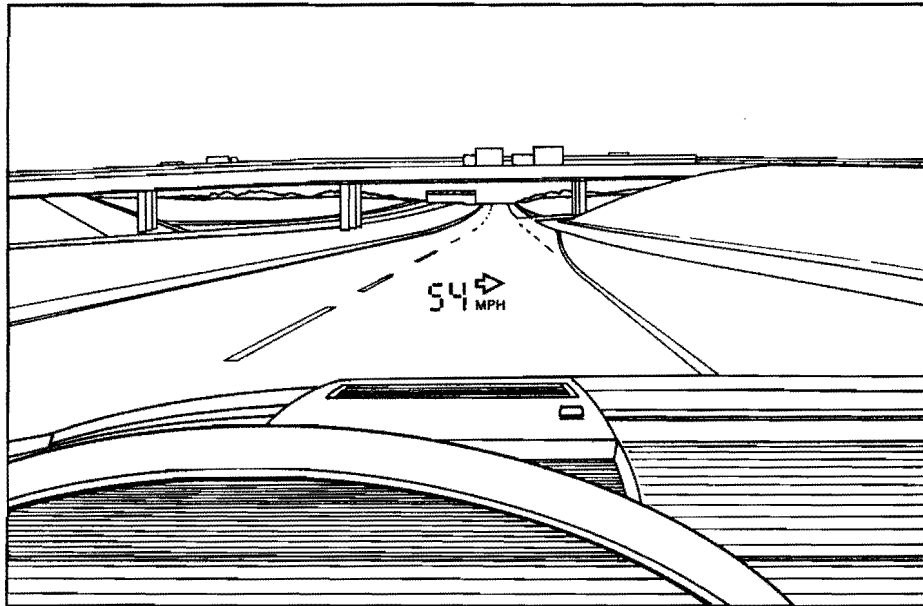- May mask external emergency warnings

---

## Head-Up Displays

As technology continues to improve, the Head-Up Display (HUD) is an obvious alternative to in-vehicle VDTs for presenting visual navigational and route guidance information to motorists (2). Although originally developed for the aviation industry, several automobile manufacturers are beginning to develop HUDs for presenting vehicle status and navigational information to drivers. Figure 3 illustrates the use of a HUD being developed by one automobile manufacturer.

A wide variety of options for displaying information may be available using HUDs. Through the use of icons and alpha-numeric text, navigation and route guidance information may be projected directly into the driver's field of view (11). This permits information that is normally provided via instruments embedded in the dashboard to be available without requiring the driver to take his or her eyes off the roadway ahead. HUDs are believed to provide drivers with the following two benefits over traditional internal navigational and vehicle status displays (11, 26):

1. Because navigational and vehicle status information is projected into the driver's field of view, the need for visual scanning between two information sources (the inside instrument panel and the outside environment) is reduced;

2. Through optical techniques, information may be presented at the same apparent distance as the outside world. This may reduce the accommodation time as the driver scans the visual horizon.

However, there are numerous concerns regarding the safety and applicability of using HUDs in the driving environment (11). Currently, most HUDs under development and implementation provide drivers with only relatively simple information such as speed indications. However, research is currently being performed on the use of HUDs to provide motorists with complicated navigational and route guidance information (27). Unlike in an aircraft, the visual background in the driving environment is constantly changing and is rich with color contrast which may obscure the visibility of the information display. The projection of additional information into the driver's view may also create clutter in complex driving environments (11). Significantly more research into the interaction between HUD format, optical and attention variables, and task performance is required in order to determine whether or not HUDs are superior to in-vehicle video or

20

1989 OLDSMOBILE HEADS-UP DISPLAY

HUD IMAGE

OPTICS  OPTICS

IMAGE SOURCE

A HUD puts the image in the driver's peripheral field of view at all times. The image is reflected from the windshield into the driver's field of view as shown in this schematic. Projection occurs upward through the top to the HUD unit.

Reprinted with permission from SAE R-102
© 1990 Society of Automotive Engineers, Inc.

Figure 3.  Illustration of a Head-Up Display of a 1989 Oldsmobile (11).

auditory displays in the driving environment (27).

Table 8 summarizes the advantages and disadvantages of using head-up displays for communicating with motorists.

---

**TABLE 8.  ADVANTAGES AND LIMITATIONS OF HEAD-UP DISPLAYS.**

Advantages

- Reduces need for visual scanning
- Permits transfer of information with out driver moving eyes off roadway
- Reduces accommodation time
- Reduces visual clutter inside vehicle

Limitations

- Restricted to simple instructions
- Potential for driver information overload
- Problems with contrast changes
- Creates visual clutter in complex driving environment

---

## Closing Remarks

As this chapter has illustrated, no one technology (now available or yet emerging) is the total remedy for motorists who want information for making navigational decisions or route guidance assistance to reach their intended destinations.  With available technologies, the amount of information that can be disseminated in a timely fashion to motorists is constrained to a large extent by the hardware.  Furthermore, external conditions can degrade the information dissemination process, and the inability to customize information to specific individuals further limits the types of information that could be provided.  The development of the emerging technologies is expected to remove these types of limitations, allowing motorists access to more information than ever before.

However, these technologies present extensive visual and auditory stimuli that must compete for the motorist's attention during the driving task.

It is unlikely that the emerging technologies will eliminate the need for those technologies now available. Too much has been invested in the development and implementation of these devices for them to simply be forgotten in the technology race that is occurring in the area of ADIS. Perhaps more importantly, it should be noted that there is a hierarchy of information needs within the navigational tasks motorists perform. Some information can be effectively disseminated via available technologies, whereas other information can only be distributed via technologies now emerging. The key to future effective information management will be the degree to which all forms of technology can be integrated to provide a cohesive information "package" for the motorist.

## 3. HUMAN FACTORS AND SAFETY ISSUES OF ADIS DISPLAYS

The primary objective of ADIS is to provide drivers with information that assists them in reaching their destinations in a quick, efficient, and economical manner. How well ADIS achieves this objective depends, in part, on how well the information is communicated to the driver. To be of benefit to the driver, information must be timely, clear, concise, and easily understood. The drivers may be unable to process the information in an efficient manner and may become overloaded if too much is presented at one time, or in a poor manner.

There are many unanswered questions related to the use of emerging in-vehicle displays for communicating with motorists. The questions are the subject of ongoing human factors and safety research. Some of the more critical and pertinent questions that remain to be resolved include the following:

- What information do drivers need to navigate?
- How should route guidance and navigation information be presented to the driver? (map displays, turn-by-turn instructions, etc.)
- Is it better to use visual displays or auditory displays to provide motorists with route guidance and navigation information?
- How well will in-vehicle communication displays be accepted by drivers?
- What are the safety implications of providing route guidance and navigational information directly to drivers in their vehicle while they are driving?

In many ways the first three questions have been relevant to the development of the more familiar forms of motorist information displays (i.e. CMS, LCS, HAR). The purpose of this chapter is to discuss the pertinent research that has been directed at answering these questions relative to in-vehicle displays. The discussion of these questions can be grouped into the following topic areas:

- Acquisition of Navigational Information
- Mode of Presentation
- Coding of Information
- Impact on Driver Safety and Performance

## Acquisition of Navigational Information

The differences in the way that individuals acquire and use navigational and route guidance information may impact the long-term benefits of ADIS. Human factors research (28, 29,) suggests that there are three levels of knowledge that drivers use in navigating: (1) landmark knowledge, (2) route knowledge, and (3) survey knowledge. Landmark knowledge is considered to be the lowest level of knowledge of an area. At this level, an individual's knowledge of the area is characterized by highly visible and salient landmarks including buildings, mountains, etc. Drivers use these landmarks to find paths or routes to their destinations. They typically have limited knowledge of the street network and navigate to their destination by "feel."

As a driver becomes more familiar with an area, he or she acquires a greater sense of route knowledge. At this level, drivers navigate from one location to another using landmarks or other visual features to trigger pre-determined navigation decisions (such as turn left, turn right, or continue straight at a given intersection). They prefer and use step-by-step instructions of the maneuvers to be performed on a route from an origin to a destination. They use landmarks to identify locations where an action should be performed (e.g., "turn left at the church"). Although route knowledge can be gained from written driving directions or from route planning using maps, the most direct method of acquiring route knowledge is by traveling the actual route.

The highest level of knowledge of an area can be classified as survey or "map-like" knowledge. At this level, knowledge of an area is retained in the form of a "birds-eye view" map (a internal cognitive map), which is analogous to the true physical map of the area. Using survey knowledge, drivers have the ability to describe the relative location of two landmarks within an area without actually having ever traveled a route that connects them. This type of knowledge is obtained and extracted most directly from maps.

Because different drivers have different information needs and desires, in-vehicle communication devices must be flexible to accommodate these different information needs. Individuals who possess only landmark knowledge of a particular area (e.g., a business person visiting a location for the first time) would likely benefit from an in-vehicle static route guidance and navigational display. As driver familiarity with an area increases, however, their information needs change. Drivers who navigate using "route knowledge" information would probably desire a system that provides simple turn-by-turn instructions

(such as in the ALI-SCOUT and Autoguide systems). Finally, individuals who possess a high level of survey knowledge of an area would probably perceive a system that provides a virtual map display and illustrates the "shortest" path determination as being most beneficial to them (29, 30).

Furthermore, driver information needs change with time, depending upon each driver's particular driving situation. Through experience, some drivers progress through all three levels of knowledge, while others never progress beyond landmark or route level knowledge. This is implied by research which shows some individuals have good knowledge of the traffic network and routinely search for better routes (in terms of travel time savings), whereas other drivers refuse to deviate from their established routes regardless of the level of delay and congestion encountered (31). Potentially, in-vehicle displays would benefit both types of drivers; however, the type and level of information desired by each is likely to be different. The key is to have an information system that is flexible to accommodate individual motorist needs and desires.

## Mode of Presentation

Another of the major human factor issues yet to be resolved is whether information should be presented using visual or auditory displays. Most of the in-vehicle display systems currently under development use a visual format (a map display or graphical representation (arrows) of turning instructions) to present drivers with route guidance and navigation information. In most cases, the driver will have the option to use auditory displays (i.e.,synthesized voice) only as a supplement to the visual displays. However, research has shown that map displays supplemented with auditory guidance instructions allow for more efficient navigation and are preferred by more motorists than map displays alone (32). Moreover, there is strong theoretical and empirical evidence that implies that auditory displays should be used as the primary mode for presenting in-vehicle route guidance and navigational information. This evidence suggests that auditory displays are currently not being designed and implemented to their maximum potential in most in-vehicle communication systems being developed.

Multiple resource theory suggests that humans utilize several mental formats to obtain and process information (29). Figure 4 illustrates the concept of the multiple resource theory. The theory states that two tasks (e.g., driving a vehicle and reading a map) requiring the use of the same resource (e.g., visual information) tend to interfere
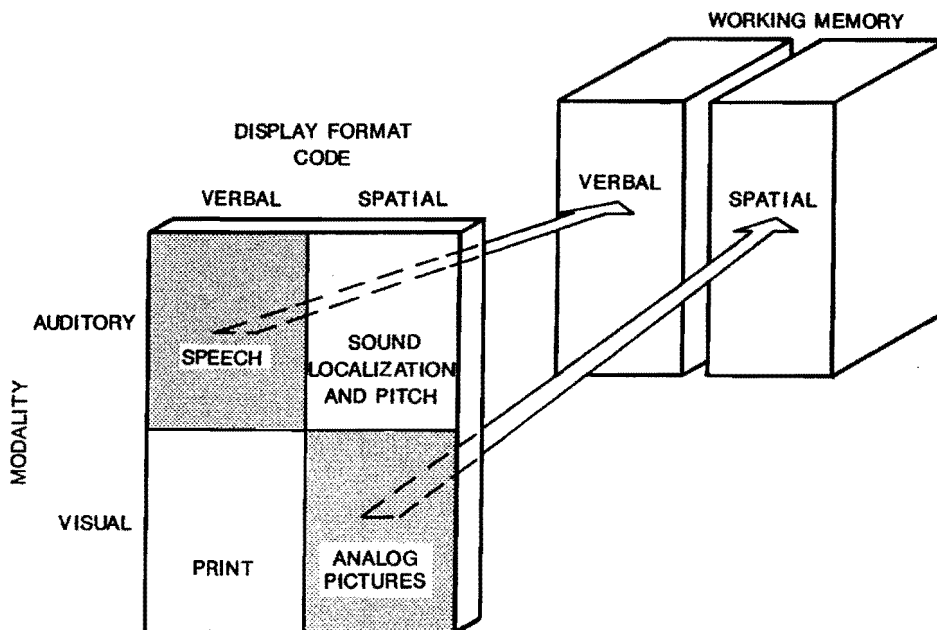
Engineering Psychology and Human Performance. Christopher D. Wickens. Copyright
● 1992 by HarperCollins Publishers Inc. Reprinted by Permission of HarperCollins
Publishers.

Figure 4. Format of Information Display Using Separate Resources.

with one another while two tasks using two different resources (visual and auditory) tend
not to interfere with one another. In other words, two different mental processes (such
as controlling the lateral placement of a vehicle and navigating a vehicle) may occur
simultaneously when the information needed to execute these tasks is presented in
different formats (i.e., visual versus auditory senses). Since driving is primarily a control
task which requires visual/spatial information, multiple resource theory suggests that
navigation and route guidance information would be better presented using auditory
displays, eliminating the conflict between the control and the navigation task.

Empirical studies have shown that in-vehicle auditory displays can be used to
provide drivers with navigational and route guidance information. Research performed
in the 1970s illustrated that motorists were capable of following voice instructions for
navigational purposes (33, 34). More recently, direct comparisons of visual and audio
navigation displays have been carried out. For example, one study which examined
alternative modes for presenting drivers with directional instructions found that drivers

made fewer navigational errors, drove fewer miles, and reached their destination in the least amount of time when an auditory display was used to provide the information (35). In another study that compared auditory displays to visual displays at three different levels of information complexity, it was found that drivers made less severe speed reductions and fewer navigational errors when route guidance and navigation information was presented using auditory devices (36). However, other research has shown that as long as route guidance and navigation instructions are relatively simple, the mode of presentation (auditory versus visual) is not significant and, in fact, the manner in which the information is presented (verbal messages versus spatial/graphical messages) is of greater importance in the design of in-vehicle information displays (37).

## Coding of Information

One of the primary concerns of in-vehicle displays is the amount of time required for drivers to obtain and process information. The amount and complexity of information that drivers can safely receive and process is also an issue yet to be resolved. In general, more complex information requires greater attention and processing time, regardless of the mode used to convey the information (29). Therefore, complex motorist information displays may adversely impact driver workload and performance.

As discussed in Chapter 2, the various systems currently in operation or under development have different philosophies for displaying route guidance and navigation information to drivers. For example, the ALI-SCOUT system in Germany uses simple diagrammatical symbols supplemented with a voice output to provide real-time navigational and route guidance information. Conversely, the Pathfinder system displays vehicle location and congestion information to the driver on a computer-generated moving-map display (22). Route guidance information is then displayed to drivers by highlighting specific routes. Another display philosophy being considered is to let the driver decide the type of display he or she wants (i.eg., a moving-map display with highlighted routes and congestion information, or a simple diagrammatical display that provides turn-by-turn instructions). This latter philosophy is the approach being used to display travel information to the drivers in the TravTek system (24).

Limited laboratory and controlled field study results imply that verbal route guidance and navigational displays (turn-by-turn instructions) are more easily understood and processed by drivers than spatial map displays (36, 38). A recent FHWA study also

found that driver performance was significantly impacted by the use of complex map displays to provide drivers with route guidance and navigational information (21). The FHWA study concluded that messages of medium complexity (e.g., "TAKE 1$^{ST}$ RIGHT -->"), presented either visually or orally would result in safer overall driving.

However, a few studies of driver preferences indicate that drivers prefer map displays over text or turning arrow displays. With map displays, drivers can obtain a global perspective of all the available routes. Map displays also provide supplemental information, such as distances between intersections and surrounding landmarks, that are not available on other types of displays. On the other hand, drivers indicated that they found it difficult to sustain the high level of concentrated attention needed to extract all the necessary information from map displays and still maintain an adequate level of control over their vehicles (29, 38).

When subjects were asked to compare graphical symbol displays (such as turn arrows used in the ALI-SCOUT system) and computer generated map displays (such as used in Pathfinder system), drivers preferred the simpler graphical displays. The graphical displays were judged to place less of a cognitive demand on drivers, since drivers are given explicit instructions on how to reach their destinations. With computer-generated map displays, drivers have to extract the information they need (38).

The above discussion illustrates that the question of how information should be presented to motorists has yet to be resolved. A strong basis of understanding was developed through research performed regarding information processing time and workload on the design and implementation of CMS and HAR systems (5). However, the focus of those research efforts was to determine what format should be used for each type of system so as to maximize the amount of information transferred within the constraints of limited exposure time to the drivers. With in-vehicle communication devices now under development, the question becomes more complex. The flexibility offered by these emerging technologies allows information to be made continuously available to the driver. Thus, the exposure time constraints have been relaxed. However, motorists are still limited in how much information they can process while driving. Likewise, certain presentation formats enhance information processing whereas others seriously inhibit it. New research efforts must continue to build upon those early human factors studies so as to most effectively develop and implement in-vehicle displays.

## Impact on Driver Safety and Performance

Perhaps the most important human factors issue yet to be resolved is the impact that video, auditory and HUD displays have on driver safety and performance. It is feared by many within the human factors and transportation engineering communities that the introduction of in-vehicle communication devices, particularly VDTs mounted on the dashboard of the vehicle, will be an unnecessary distraction and divert the driver's attention away from the roadway (26). If the driver is required to view a complex display while operating a vehicle, it is feared that he or she may not be able to fixate upon the roadway ahead and may be unable to maintain proper speed, direction, and/or lateral positioning in the travel lane. Long glances inside the vehicle also limits drivers from attending to critical external information (i.e., changing traffic conditions, roadway obstructions,) that may be potentially hazardous to them (39). Table 9 shows the ranges of glance times observed for conventional vehicle dashboard displays and for an electronic map display (40). This table shows that substantial longer glance times are required to obtain navigational information from complex map displays than for most common gauges and equipment now located within vehicles.

Drivers must maintain almost continuous eye fixations on the roadway ahead in order to maintain proper lateral positioning within a travel lane (41). For this reason, it is recommended that displays be designed so that critical information can be obtained through short glances, or kept available to the driver until it can be safely and conveniently reviewed (26). However, even short glances inside the vehicle (less than six seconds) increase the probability that the driver will deviate from the travel lane (39).

The TravTek system in Orlando has taken another approach towards addressing the issue of driver distraction due to in-vehicle navigation devices (24). This system limits the amount of information that can be accessed by the driver when the vehicle is in motion. Only information that directly supports the driving task (i.e., turning instructions, position information, congestion reports,) is available to the driver when the vehicle transmission is in DRIVE. Route planning, destination finding, and services and attractions listings are available only when the vehicle transmission is in PARK. By limiting the amount of information that is available to the driver while the vehicle is in motion, the designers of the TravTek system have attempted to reduce the level of distraction and eyes-off-road time and keep drivers focused on the driving task. The success of this approach is currently being researched in the field.

**TABLE 9. COMPARISON OF GLANCE TIMES BETWEEN CONVENTIONAL AND ELECTRONIC MAP DISPLAYS.**

| Total Display Glance Time Mean, $T_D$ (Seconds) | Conventional Displays | Electronic Map Display |
|---|---|---|
| $0 \leq T_D < 1.0$ | Following Traffic Speed | |
| $1.0 \leq T_D < 2.5$ | Remaining Fuel Info Lights Tone Controls Balance Controls Sentinel Fan Vent Time | Destination Distance Destination Direction |
| $2.5 \leq T_D < 4$ | Fuel Range Fuel Economy Defrost Temperature Cassette Tape | Heading Zoom Level Appropriate Direction |
| $4 \leq T_D < 8$ | Power Mirror Tune Radio Cruise Control | Roadway Name (Av.) Roadway Distance (Av.) Cross Street (Av.) |
| $T_D \geq 8$ | | Roadway Name (N. Av.) Roadway Distance (N. Av.) Cross Street (N. Av.) |

*(Av.) indicates required information was immediately available;
(N. Av.) indicates that information was not immediately available.

Source: (40)

Another area of concern for many transportation and human factors professionals is how the performance of older drivers will be affected by in-vehicle route guidance and navigational displays. In general, the impacts of in-vehicle communication devices are likely to be more pronounced on older drivers than on younger drivers. Research shows that drivers over 50 years of age require a greater amount of time to complete certain driving tasks and to look at navigation displays and dashboard instruments. These drivers also make more navigation and control errors than younger drivers (30, 34). Since the proportion of older drivers in the traffic stream will continue to rise in the years ahead, the ability of this group to safely drive and navigate with in-vehicle devices should be a major concern for transportation officials.

## Closing Remarks

The success or failure of in-vehicle devices for communicating with motorists ultimately depends upon the degree to which they are accepted and used by drivers. In order to succeed, in-vehicle displays must be designed to be user-friendly, trustworthy, evolutionary, and beneficial to the customer. If in-vehicle devices become intimidating, irritating, or unreliable, they are destined to fail. The key to achieving driver acceptance is to provide only the information the driver wants, in a form that he or she can use in a timely manner (42).

To date, transportation agencies have had little involvement in the development and deployment of actual prototype in-vehicle devices for communicating with drivers. Most of the developmental work, at least in the United States, is being performed by private industry. Traditionally, transportation agencies have been responsible for installing, maintaining, and operating systems to collect traffic and congestion information. Certainly, this information will be a vital component of ADIS. However, the role of transportation agencies must expand to address a new set of issues. Questions such as how the information shall be distributed, who should be responsible for the quality and accuracy of the information, and who should be responsible for installing the necessary support infrastructure, face agencies as ADIS are integrated into existing traffic management and operations systems in the United States.

# 4. TRAFFIC MANAGEMENT ISSUES

Apart from the specific human factors issues concerning various types of emerging in-vehicle technologies, the entire genre of these devices present the opportunity to provide motorists with extensive amounts of roadway, traffic, and other information. In addition, these systems will be able to "assist" the motorist in his or her decision-making and provide guidance regarding which routes to take, how to get to those routes, and how long it will take to reach his or her destination. Although this technology offers significant potential for reducing congestion and improving travel in urban areas, a number of technical and practical issues remain regarding its eventual implementation.

This chapter is devoted to a discussion of the major traffic management issues that arise concerning the deployment and use of the emerging technologies for in-vehicle communications. These issues are separated into the following four topic areas:

- Driver response to in-vehicle driver information technology,
- Traffic information access and management,
- Infrastructure development, and
- Liability concerns.

## Driver Response to In-Vehicle Driver Information Technology

One of the major traffic management issues is the lack of understanding of the extent to which motorists will accept and respond to the information to be provided through emerging in-vehicle technologies. Limited case studies and field tests indicate that motorists do adjust their travel patterns in response to real-time information presented through the available technologies (i.e., CMS, HAR, cellular telephone) for communicating with motorists (32, 42, 46). Messages presented via these available technologies, however, are designed to be displayed to all motorists. In contrast, most likely scenarios of emerging in-vehicle technology will require motorists to purchase new vehicle hardware (and possibly subscribing to an information service to obtain data to operate that hardware). As a result, there will be fewer individuals receiving information. Because of the direct costs involved, however, those individuals may be more responsive to the information and recommendations presented to them.

The evolution of ADIS is envisioned to occur in three primary stages (2):

- Information stage (1990-1995) -- when emphasis will be on providing motorists with improved static navigation information to allow them to make more informed choices;
- Advisory stage (1995-2000) -- when dynamic traffic condition information will be made available to drivers in their vehicles, allowing them to react in real-time to changing traffic conditions; and
- Coordination stage (2000-2010) -- when information flow between vehicles and the public infrastructure will become two-way, and when information dissemination will be coordinated with corridor and network traffic control strategies (i.e., integrated freeway-arterial control systems, adaptive traffic signal operations, etc.)

Table 10 summarizes the key features of ADIS that are expected to become operational during each of the three anticipated phases of implementation. In the information stage, transportation agencies will begin communicating with motorists indirectly through the provision and updating of network data to private vendors. Direct real-time communication of travel conditions is not anticipated until the Advisory stage, expected to occur in the mid- to late 1990s. In this stage, transportation agency concerns regarding market penetration of this technology and the expected motorist response to information will become paramount.

Traditionally, market penetration (the proportion of consumers obtaining a given product) and segmentation (which consumers are obtaining the product) have been of interest only in the private sector. In the past, public agencies, particularly transportation agencies, operated in an environment where all information and benefits generated by that agency were generally accessible by the entire driving population. However, as emerging technologies are implemented, not all motorists will be receiving all available information, and market penetration of emerging technologies will become a key concern of transportation agencies.

Furthermore, concerns of market penetration by the transportation agency will likely change with increasing sophistication of ADIS devices. For example, the costs of static electronic route planning or navigation systems that assist in locating addresses and determining shortest-path routes may be reduced to such a level in the future that large numbers of consumers purchase the devices. A high market penetration would be

**TABLE 10. STAGES OF ADIS DEVELOPMENT.**

Information Stage

- Dead-reckoning map-matching navigation system
- Digital traffic information receiver
- Static route-planning for minimum travel distance
- Color video display for maps, traffic information, and route guidance
- Map database including turn restrictions and freeway signing
- Business directory integrated into map database
- Electronic vehicle identification for toll debiting
- Digital cellular telephone

Advisory Stage

- Supplement dead-reckoning system with global positioning system receiver
- Dynamic route-planning based on minimum travel times
- Synthesized voice for traffic information and route guidance
- Semi-automatic MAYDAY using cellular telephone for emergency assistance

Coordination Stage

- Digital traffic transceiver for two-way information flow
- Enhance dynamic route-planning to incorporate expected travel conditions
- Automatic MAYDAY, vehicle locating, and coordinated dispatch of emergency vehicles (using transceiver information)

Source: (2)

desirable from the transportation agency perspective, reducing wasted travel due to navigational errors (estimated to be 45 billion dollars per year nationally (48)).

On the other hand, as real-time navigation and route guidance systems that take traffic conditions into consideration evolve, a smaller market share may be desired from a public/societal perspective. Recent traffic simulation experiments suggest that a traffic system with too many motorists with accurate current travel time and route guidance information in congested traffic networks may reduce, and possibly, negate any benefits due to this technology. One study, for example, suggests only 10 to 20 percent of the driving population should adjust their travel patterns under certain operating conditions in order to maximize the benefits of in-vehicle driver information technology (49). These results were based on simulation experiments, though, using fairly stringent assumptions and theoretical traffic conditions. However, experiments with an actual route guidance system in Europe (ALI-SCOUT) indicate that user benefits due to this technology level off or start to decrease when market penetration within the system exceeds about 15 percent (50). These examples serve as a warning of the complexity of ADIS interactions and potential impacts upon network congestion.

Market penetration of the emerging technologies will be affected by several factors, including motorist-perceived travel benefits from owning these devices, purchase and operating costs, and long-term device and information credibility that develops from extended use. Experts predict that the out-of-pocket costs to consumers will be the controlling factor that determines the level of market penetration achieved (51). Although it is doubtful that highway agencies will be able to influence the purchase prices of these devices and control market penetration, strategies for affecting the operating cost of the technology (such as assessing user fees for access to the real-time traffic information) may need to be implemented (9). Agencies should begin developing administrative policies and establishing legal precedents that will allow them to control or influence operating costs if they so desire.

The painstaking effort that Japan as well as many European countries have taken to provide motorists with accurate and timely information has generated a favorable attitude among drivers in those countries towards immediate acceptance of in-vehicle navigation technology. For example, Japan has steadily improved its ability to provide motorist information over the last twenty years. Japan now has more than 3000 CMSs installed upon 3000 miles of roadway network, and surveys indicate that motorists utilize and place considerable confidence in these signs (52). Unfortunately, such

predispositions have not been established in the United States. In order to nurture motorist confidence in real-time information, highway agencies (and/or the private sector) may have to proceed more slowly with the implementation of in-vehicle driver information technology, showing successes and benefits through small deliberate steps. Successful application of the emerging technology will depend on the degree to which individual motorists can achieve significant personal benefits, as consumers will not likely be motivated to invest in technology solely for the benefit of society.

## Traffic Information Access and Management

Accurate and detailed traffic information, collected by transportation agencies, will be essential to the successful implementation of ADIS. The demand that will exist for these data raises additional concerns as to its proper utilization and management by the transportation agency. Specific areas which will need to be addressed by transportation agencies in the future are:

- How interjurisdictional cooperation and integration of traffic data should be handled,

- What involvement transportation agencies should have in the dissemination and control of traffic information via the emerging technologies, and

- How information will be best distributed to motorists through the overall information system which utilizes both available and emerging communication technology.

Interjurisdictional coordination is a requirement in any effective corridor or regional traffic management system to prevent data collection redundancies and to establish cooperative traffic management strategies among all of the various roadway facilities (53, 54). Such coordination will become even more essential as technology advances towards dynamic traffic information and route guidance systems. Massive amounts of data will be collected from the roadway network in the near future. Coordination and cooperation between agencies (as well as between departments of the same agency) will have to be streamlined so as to allow for the automatic collection, integration, evaluation, and dissemination of information from all data sources. Furthermore, the high price tags associated with this technology necessitates cost-sharing strategies. Essentially all of the

existing IVHS-related demonstration projects in the United States (i.e., INFORM on Long Island, SMART corridor in Los Angeles, HITS in Houston, TravTek in Orlando, and ADVANCE in Chicago) involve cooperative financing and operating arrangements between the federal, state, and local transportation agencies as well as with the private sector (55-59).

Interjurisdictional cooperation and coordination of traffic within a region will be important for other reasons as well. Case studies of several major urban freeway reconstruction projects and with new freeway ramp metering systems suggest that local jurisdictions are extremely sensitive to the potential impact of increased traffic on their street system (60, 61). Promises by state agencies to monitor impacts and to adjust operating policies if impacts become too severe have helped quell local agency fears in some instances. A similar approach may be required to help facilitate implementation of emerging technologies. Whatever the approach taken, problems with "turf protection" and perceptions of independent facility operations that currently plague many areas will have to be overcome.

In addition to coordination between the various public agencies, coordination and cooperation between the public and private sector will become increasingly important as new technology is implemented. It is obvious that the private sector will be the major player the development of the actual in-vehicle units. However, such technology will have to be compatible with information sources that will eventually exist within the roadway infrastructure, an infrastructure for which transportation agencies have responsibility and control. The current direction of events appears to be towards demonstration projects of different technologies throughout the United States. On the positive side, this approach prevents technology from being constrained prematurely and fosters continued research and development. On the negative side, relying on the market to define standards allows many extraneous factors (i.e., politics, corporate profits) to adversely influence the direction of technology.

It is uncertain as to the degree to which transportation agencies should and will be involved in traffic information dissemination and management via emerging in-vehicle technologies. Public agencies exist to serve the general public in a fair and unbiased manner. The available methods of communication (CMS, HAR) generally provide fair and equal access of information to all drivers. However, in-vehicle technologies will create a scenario where only those motorists with units in their vehicle will have access to certain information. Furthermore, those motorists will (conceivably) be able to reap substantial

benefits, in terms of reduced travel times, stops, and fuel consumption from having access to that information. In theory, even those motorists without access to information will benefit from having other motorists alter their travel paths in response to traffic information (49); however, the amount of that benefit may be quite small in proportion to the benefits gained by motorists utilizing in-vehicle technology.

Recent literature suggests that public agency involvement in IVHS may be best-suited to the provision of traffic information to private sector dissemination companies in return for user fees from the companies (50). The private sector companies would then market the information and recover their fees directly from motorists. Such a scenario is predicated, of course, upon the ability of the private sector to generate a profit. The situation may develop where the manufacturers of in-vehicle ADIS hardware take on the information dissemination function. In this way, profits could be generated through the combined sale of the units and the ongoing sale of information. From the transportation agency's perspective, the recovery of at least part of the costs of collecting traffic information can help reduce the imbalance of benefits of the information to those motorists with, as compared to those without, the in-vehicle technology. In addition, this approach is also consistent with the national transportation policy of more privatization of transportation services, and of the recovery of more of the costs of the transportation system through user-based fees (62).

Finally, it must be recognized that ADIS will not totally replace existing driver communication technologies, at least not in the foreseeable future. Rather, the emerging technologies will have to "blend" into an overall motorist information dissemination package. The challenge to transportation agencies and the private sector alike will be to coordinate the type and amount of information presented through the different technologies. This coordination will be necessary to maximize the efficiency of the transportation system while at the same time avoiding information redundancy or overloading driver senses (particularly through the in-vehicle displays). Conversely, potential problems may occur if conflicting information and guidance is presented, such as where a CMS indicates the need to divert but the routing algorithm within the vehicle indicates that the best route is to remain on the roadway.

In addition, the potential responses of motorists to the existing technologies will need to be considered in the presentation of information via the ADIS displays. For example, CMSs will likely serve an important role in informing motorists of downstream incidents so that they may choose alternative routes. The location where motorists would

be expected to alter their travel paths in response to the CMS information and the routes used instead would be important to the route choice recommendations provided by an in-vehicle display. Without coordination of all information sources, the effectiveness of ADIS will certainly be diminished.


**Infrastructure Development to Support ADIS**

Perhaps the most pressing issue now facing transportation agencies in the implementation of ADIS is the infrastructure requirements necessary to provide the information support for this technology. Table 11 presents some of the infrastructure requirements envisioned for ADIS according to the different stages of implementation defined previously (2). Infrastructure needs will include various hardware components, systems integration components (such as provided by a traffic information center (TIC)), and administrative organizations to provide the necessary monitoring and support services by the transportation agency.

As dynamic traffic information and route guidance technology continues to develop, transportation agencies will have to decide between two different system architectures: vehicle-based or infrastructure-based architectures. Vehicle-based systems will rely on hardware components in the vehicle to perform the majority of the computations necessary to determine vehicle location, elapsed travel times, and route guidance information. An infrastructure-based systems will be structured around a centralized control center or remote roadside transceivers, from which vehicles are told their location, travel times, route guidance instructions, and possibly other information.

Both vehicle-based and infrastructure-based support systems have advantages and disadvantages, the most significant of which are summarized in Table 12. Vehicle-based support systems offer the advantage of requiring users to pay a greater portion of the initial and operating costs of the technology, through more expensive hardware and monthly contract fees to obtain information. In addition, having the majority of the system "intelligence" within the vehicle minimizes the chance that a vehicle will become lost within the roadway network, even if it loses contact with beacons or transmitters outside of the vehicle. As a final note, a vehicle-based system is expected to foster continued market competition and lead to ongoing technological advancement.

```
TABLE 11.  EXPECTED INFRASTRUCTURE REQUIREMENTS BY STAGE
              OF ADIS IMPLEMENTATION.


Information Stage
        •    Traffic Information Center (TIC) to collect, format, and transmit
             traffic information (normal travel times, incidents, etc.)
        •    Roadside traffic information transmitters
        •    Organizations to prepare and distribute map and business
             directory data bases
        •    Agencies to inspect and certify accuracy of route guidance
             data bases
        •    Stations to read vehicle identification


Advisory Stage
        •    Expansion of TIC to distribute current travel times
        •    Network of traffic information transmitters


Coordination Stage
        •    Traffic Management Center (TMC) (enhanced TIC) to coordinate
             control strategies with motorist responses
        •    Emergency service centers for coordinated management of
             emergency vehicles
        •    Conversion of traffic information transmitters to transceivers
             (two-way communication)

Source:  (2)
```

Infrastructure-based systems, on the other hand, have a more immediate implementation potential (the infrastructure-based LISB system in Germany has been operational since 1989 (63)).  In addition, this technology will result in a lower cost to motorists, which in turn will likely increase the proportion of motorists opting to purchase the technology (i.e., increased market penetration).  Perhaps the biggest advantage, however, is that traffic and route guidance information can be coordinated and controlled by the disseminating agency.

In this way, information strategies could be established that provide more overall benefits to the public as a whole (i.e., a system-optimal goal) as opposed to only improving the individuals travel route (i.e., a user-optimal goal).

```
┌─────────────────────────────────────────────────────────────────┐
│                                                                   │
│    TABLE 12.  ADVANTAGES AND DISADVANTAGES OF VEHICLE-BASED        │
│    AND INFRASTRUCTURE-BASED INFORMATION SUPPORT SYSTEMS.           │
│                                                                   │
│                                                                   │
│                   Vehicle-Based Support Systems                    │
│                                                                   │
│  Advantages                                                       │
│        •      Users pay more of initial costs                     │
│        •      Users have less chance of getting "lost" (by losing │
│               contact with system)                                │
│                                                                   │
│  Disadvantages                                                    │
│        •      Considerably more R&D required before technology is  │
│               ready for implementation                            │
│        •      High initial costs to motorists may limit market    │
│               penetration                                         │
│        •      Technology compatibility of various vendors may be  │
│               difficult to achieve                                │
│                                                                   │
│                                                                   │
│                Infrastructure-Based Support Systems               │
│                                                                   │
│  Advantages                                                       │
│        •      Market competition will drive and define course of  │
│               technology                                          │
│        •      Sooner implementation potential                     │
│        •      May allow agency to pursue system-optimum diversion │
│               strategies                                          │
│        •      Lower cost to motorists                             │
│                                                                   │
│  Disadvantages                                                    │
│        •      Motorists may become lost if they lose contact with │
│               system                                              │
│        •      High capital costs to agency                        │
│        •      Philosophical concerns over nonuniform disbursement │
│               of benefits                                         │
│                                                                   │
└─────────────────────────────────────────────────────────────────┘
```

Vehicle-based systems also have disadvantages. Vehicle-based systems will require considerable research before they will become practically viable, in such areas as hardware and software development, communication technologies, and distributed control policies. The high purchase price of this technology, while requiring users to pay a bigger share of the system costs, may also limit market penetration of these systems. In addition, several types of vehicle-based systems, each developed by a competing private firm, may exist in a region, raising concerns about system compatibility and transferability.

There are also several disadvantages with infrastructure-based systems. Although both technologies will require some capital investment by the highway agency, an infrastructure-based support system will require a larger capital and operating investment by transportation agencies to provide the necessary hardware and software intelligence over the entire roadway network, and to obtain and retain the trained personnel to operate and maintain it. An infrastructure-based system also poses a problem with motorists who lose contact with the system, becoming lost with no way to be directed back. Finally, there are philosophical concerns regarding the relatively high costs borne by the public sector when the majority of the benefits of the technology are not uniformly distributed over the entire population.

Present trends world-wide tend to suggest that technology is moving towards vehicle-based systems (50). However, transportation agencies in the United States may still face considerable pressure from the private-sector to implement infrastructure-based systems to minimize investment risks and maximize profit potential for companies. Of course, such decisions by an agency must be based on all important factors, and not unduly influenced by forces which are biased or which do not have the best interest of the public as a whole in the forefront.

Transportation agencies will also be required to be constantly vigilant against efforts by the private sector to selectively implement technology so as to maintain competitive advantages or to maximize profits. A company may want to provide route guidance information only on the freeway system in an area, for example, because it carries the majority of motorists who would desire the company's product. Recommendations to divert from a freeway to an arterial street under incident conditions, however, would have be coordinated with local jurisdictions. Otherwise, these local agencies may seek compensation for perceived "damages" caused by diverted traffic on their arterial street system.

## Liability Concerns

The final issue discussed in this chapter is that of public and private sector liability in the ongoing implementation of emerging ADIS technologies. Liability concerns are a major issue for many aspects of IVHS, particularly for automatic warning systems and automated vehicle control systems. Failure of these systems could be catastrophic and exposes the public and private sector alike to damage claims. Because ADIS deals

primarily with the navigation tasks of drivers, rather than vehicle control and guidance, failures of these types of systems are likely to be less catastrophic in nature.

Nevertheless, liability issues do exist. The potential for local agencies to take legal action in response to perceived degradation of the surface street system because of diverted traffic has already been discussed. Also, individuals who become lost or are diverted into an area where they are robbed or otherwise attacked may choose to seek damages from the agency providing the information to them. To what extent agency responsibility exists in these situations has yet to be decided in the courts. However, legal defense costs alone are enough of an impetus to warrant agency efforts to protect itself before this technology is implemented.

## Closing Remarks

It must be recognized that the issues discussed in this chapter do not exist independently of one another. Rather, decisions made with respect to one issue both depend upon, and impact, decisions regarding other issues. The choice between infrastructure-based and vehicle-based support systems is one such issue having broad ramifications. For example, the choice between infrastructure-based and vehicle-based support systems may influence not only a transportation agency's initial capital and operating costs, but also its degree of liability and therefore its legal costs as well. As another example, the type of support system implemented will affect the amount and type of information that can be disseminated via the emerging technologies, which affects market penetration and expected motorist response. In addition, the potential for conflicting information to be presented via the available communication technologies versus in-vehicle displays will also likely vary depending on the type of support system utilized.

# 5. SUMMARY

The direct transfer of information between drivers and transportation agencies is essential for achieving the full benefits of ADIS. In order for information to be useful to the driver, it must be presented in a clear, concise, and timely manner. Information that is inaccurate, inconsistent, or subject to misinterpretation reduces the credibility of the information system and the transportation agency in eyes of the driver. Therefore, care must be taken to ensure that the manner, mode, and format in which information is presented to motorists does not distract from the driving task.

This report has discussed a number of human factors, safety, and traffic management issues associated with available and emerging technologies for communicating with motorists in their vehicle. The report discussed the role that each of these technologies may have in ADIS. The advantages and limitations of each of these technologies were also discussed. The report is intended to provide insight into the current human factors, safety, and traffic management issues that may influence the design, implementation, and operations of ADIS in Texas.

Several devices are currently used by transportation agencies to communicate with motorists. These include changeable message signs, lane control signals, highway advisory radio, commercial radio, and cellular telephones. While each of these devices have their own advantages and limitations, they do share some commonalities. For example, these devices generally have a large target audience and can be used to reach a large portion of the driving population in an area. Another attribute of these systems is that the transportation agency, for the most part, can control the type, format, and content of the information being disseminated. On the other hand, because the information is broadcast to everyone, these devices do not permit transportation agencies to tailor information to specific drivers.

Several different types of emerging technologies are being developed to communicate with motorists directly in their vehicle. These include in-vehicle video display terminals, auditory displays, and head-up displays. All of these devices provide a flexible format for providing information to drivers. Information is readily accessible and can be tailored to meet the individual needs of the driver with these devices. However, there are concerns that, because of the capabilities of these devices, drivers will be provided with

too much information. Also, the potential to increase noise, both visual and auditory, are also a concern with these technologies.

From a human factors and safety standpoint, the use of in-vehicle devices for communicating with motorists raises a number of issues. The design and application of in-vehicle devices for communicating with motorists must be sensitive to the differences in the way that individuals acquire and use navigation information. While most systems under development use auditory displays to supplement visual displays, human factors theory and laboratory studies suggest that auditory displays should used as the primary mode to present navigation and route guidance information to drivers. Although drivers prefer complex map displays, these types of display require longer glance times and require the driver to extract the needed information. Human factors research and experimentation indicates that verbal messages, either presented orally or through visual text displays, may have less of an impact on driver safety and performance.

In addition to the human factors and safety issues, a number of traffic management issues directly impact transportation agencies. The extent to which motorists will accept and respond to information that is provided through these emerging in-vehicle technologies is unknown. Furthermore, equity issues related to the level of access that different drivers have to information also arise. As the sophistication of in-vehicle route guidance and navigational systems change, the information needs and requirements of motorists are subject to change. Slow and deliberate steps should be taken in implementing ADIS so as to nurture motorist confidence in real-time information.

Additionally, transportation agencies must also be concerned with the level of market penetration. On one hand, a high level of market penetration is desirable so as to eliminate navigational waste due to static route planning errors. On the other hand, high market penetration could potentially reduce or negate any of the benefits of having in-vehicle communication to reroute traffic during incident conditions. Agencies should begin examining administrative policies and legal precedents that may permit them to control the level of market penetration.

Transportation agencies must also be concerned with the access and management of traffic information. Interjurisdictional coordination and cooperation, both within a region and between regions, will be necessary to collect, integrate, evaluate, and disseminate the information needed to support ADIS. New levels of cooperation and coordination between the public and the private sector will also be necessary for the successful

implementation of ADIS. Because of this, the traditional role of the transportation agencies as the information provider may have to be altered.

The role that currently available technologies will play in future ADIS also needs to be examined. A plan or framework should be developed so as to ensure a "blending" of technologies into a comprehensive information dissemination system. Transportation agencies are now or will soon be asked to make infrastructure decisions that may define the direction of ADIS for their communities. Policy and administrative decisions relating to the type of system (vehicle-based versus infrastructure-based) and amount of private participation that is desirable in the funding, design, implementation, maintenance, and operations of in-vehicle route guidance and navigation information must be considered carefully.

Transportation agencies must also be prepared to address the legal and liability issues that may arise when systems fail or expose drivers to hazardous situations. Whereas the extent of an agency's responsibility remains to be tested in court, transportation agencies are advised to explore the potential legal ramifications before implementing ADIS technology.

# 6. REFERENCES

1.  Mobility 2000 Presents Intelligent Vehicles and Highway Systems. Executive Summary. Texas Transportation Institute, College Station, TX. July 1990.

2.  Rillings, J. H. and R. J. Betsold. "Advanced Driver Information Systems." IEEE Transactions on Vehicle Technology. Volume 40, No. 1. February 1991.

3.  Personal Communication with C. L. Dudek, Member of Advanced Traveler Information Systems Committee of IVHS America. April 1992.

4.  Report to Congress on Intelligent Vehicle-Highway Systems. U. S. Department of Transportation. Office of the Secretary of Transportation. Report No. DOT-P-87-90-1. March 1990.

5.  Dudek, C.L. and R.D. Huchingson. "Manual on Real-Time Motorist Information Displays." Report No. FHWA-IP-86-16. Federal Highway Administration, Washington, DC. August 1986.

6.  Dunn, W. M. and R. A. Reiss. "Freeways Operations Projects: North American Inventory Update." Report prepared for the Transportation Research Board, and Federal Highway Administration. Dunn Engineering Associates, West Hampton, Beach, NY. March 1991.

7.  Dudek, C.L. "Guidelines on the Use of Changeable Message Signs." Report No. FHWA-TS-90-043. Federal Highway Administration, Washington, DC. May 1991.

8.  Manual on Uniform Traffic Control Devices. Federal Highway Administration. Washington DC. 1986.

9.  Davies, P., N. Ayland, C.H.11, Rutherford, M. Hallenbeck, and C. Ulberg. "Assessment of Advanced Technologies for Relieving Urban Traffic Congestion." NCHRP Report No. 340. Transportation Research Board, Washington, DC. December 1991.

10. Huchingson, R.D. New Horizons for Human Factors in Design. McGraw-Hill Book Company, New York, NY. 1981.

11. Stokes, A., C. Wickens, and K. Kite. Display Technology: Human Factors Concepts. Society of Automotive Engineers, Inc., Warrendale, PA. 1990.

12.    Huchingson, R.D., R.J. Koppa, and C.L. Dudek. "Human Factors Requirements for Real-Time Motorist Information Displays. Vol. 3, Human Factors Evaluation of Audio and Mixed Modal Variables." Report No. FHWA-RD-78-17. Federal Highway Administration, Washington, DC. August 1978.

13.    Dudek, C.L., R.D. Huchingson, and W.R. Stockton. "Human Factors Design of Dynamic Visual and Audio Displays for Metropolitan Traffic Management. Vol 3, Highway Advisory Radio," Report No. FHWA/RD-81/041. Federal Highway Administration, Washington, DC. January 1981.

14.    McDermott, J.M. "Freeway Operations Activities in the Chicago Area." Strategies to Alleviate Traffic Congestion. Institute of Transportation Engineers, Washington, DC. 1988. pp. 62-66.

15.    Shirazi, E., S. Anderson, and J. Stesney. "Commuters' Attitudes Toward Traffic Information Systems and Route Diversion." Transportation Research Record 1168. Transportation Research Board, Washington, DC. 1988. pp. 9-15.

16.    Dudek, C.L. and D. Cummings. "Applications of Commercial Radio To Freeway Communications - A Study of Driver Attitudes." Report No. 139-3. Texas Transportation Institute, College Station, TX. July 1970.

17.    Dudek, C.L., J. D. Friebele, and R.C. Loutzenheiser. " A Study of Freeway Traffic Information Reported via Commercial Radio." Report No. 139-8. Texas Transportation Institute, College Station, TX. June 1971

18.    Ullman, G.L., R.A. Krammes, and C.L. Dudek. "Synthesis of Traffic Management Techniques for Major Freeway Construction." Report No. FHWA/TX-90-1188-1. Texas Transportation Institute, College Station, TX. May 1989.

19.    McLean, C.H. "Cellular Phones - A Key Traffic Management Component." Compendium of Technical Papers, Institute of Transportation Engineers. 1991. pp. 272-274.

20.    Brookhuis, K.A., G. Devries, and D. DeWaard. "The Effects of Mobile Telephoning on Driving Performance." Accident Analysis and Prevention. Vol. 23, No. 4, 1991. pp. 309-316.

21.    Tsuzawa, M. and H. Okamato. "Advanced Mobile Traffic Information and Communication System -- AMTICS." Paper No. CH2789-6/89/0000-0475. Conference Record of Papers presented at the First Vehicle Navigation and Information Systems Conference. IEEE Vehicular Technology Society. New York, NY. 1989. pp. 475-483.

22. Mammano, F.J. and R. Sumner. "Pathfinder Status and Implementation Experience." Paper No. 912784. <u>Vehicle Navigation and Information Systems Conference Proceedings</u>. Report No. SAE/P-91/253. Society of Automotive Engineers, Inc. Warrendale, PA. October, 1991. pp. 407-414.

23. von Tomkewitsch, R. "Dynamic Route Guidance and Interface Transport Management with ALI-SCOUT." <u>IEEE Transactions on Vehicle Technology</u>. Volume 40, No. 1. February 1991.

24. Dingus, T.A., J.T. Carpenter, et. al. "Human Factors Engineering the TravTek Driver Interface." Paper No. 912821. <u>Vehicle Navigation and Information Systems Conference Proceedings</u>. Report No. SAE/P-91/253. Society of Automotive Engineers, Inc., Warrendale, PA. October 1991. pp. 749-756.

25. Alexander, G.L. and H. Lunenfeld. <u>Driver Expectancy in Highway Design and Traffic Operations.</u> Report No. FHWA-TO-86-1. Federal Highway Administration, U. S. Department of Transportation. Washington, DC. April 1986.

26. Lunenfeld, H. "Human Factor Considerations of Motorist Navigation and Information Systems." Conference Record of Papers presented at the First Vehicle Navigation and Information System Conference. IEEE Vehicular Technology Society, New York, NY. 1989. pp. 35-42.

27. Shekar, S., M.S. Coyle, M. Shargal, et. al. "Design and Validation of Headup Displays for Navigation in IVHS." Paper No. 912795. <u>Vehicle Navigation and Information Systems Conference Proceedings</u>. Report No. SAE/P-91/253. Society of Automotive Engineers, Inc. Warrendale, PA October 1991. pp. 537-542.

28. Thorndyke, F.W. <u>"Performance Models for Spatial and Locational Cognition"</u>. Technical Report R-2676-ONR. Rand Corporation, Washington, DC. December 1980.

29. Wickens, C.D. <u>Engineering Psychology and Human Performance.</u> Second Edition. Harper Collins Publishers, Inc. New York, NY. 1992.

30. Gould, M.D. "Considering Individual Cognitive Ability in the Provision of Visible Navigation Assistance." Paper No. CH2789-6/89/0000-0443. <u>Conference Record of Papers presented at the First Vehicle Navigation and Information Systems Conference.</u> IEEE Vehicular Technology Society, New York, NY 1989. pp.

31. Mannering, F.L. "Poisson Analysis of Commuter Flexibility in Changing Routes and Departure Times." <u>Transportation Research</u>. Volume 23B, No. 1. Pergamon Press. Great Britain. 1989. pp. 443-447.

32. Lablale, G. "Influence of in Car Navigation Map Displays on Drivers Performance." Vehicle/Highway Automation: Technology and Policy Issues. Society of Automotive Engineers, Inc., Warrendale, PA. 1989.

33. Dabney, J.C. and C. L. Dudek. "Driver Response to a Highway Advisory Radio System in New Braunfels, Texas". Transportation Research Record 808. Transportation Research Board, Washington, DC. 1981. pp. 38-40.

34. Dudek, C.L., R.D. Huchingson, and R.Q. Brackett. "Studies of Highway Advisory Radio Messages for Route Diversion." Transportation Research Record 904. Transportation Research Board, Washington, DC. 1983. pp. 4-9.

35. Streeter, L., D. Vitello, and S.A. Wonsewicz. "How to Tell People Where to Go: Comparing Navigation Aids." International Journal for Man/Machine Studies. Volume 22. 1985.

36. Walker, J., E. Alicandri, C. Sedney, and K. Roberts. "In-vehicle Navigation Devices: Effects on the Safety of Driver Performance." Paper No. 912793. Vehicle Navigation and Information Systems Conference Proceedings. Report No. SAE/P-91/253. Society of Automotive Engineers, Inc., Warrendale, PA. October 1991. pp. 499-526.

37. Verwey, W.B. "Simple In-Car Route Guidance Information from Another Perspective: Modality versus Coding." Paper No. CH2789-6/89/0000-0056. Conference Record of Papers presented at the First Vehicle Navigation and Information Systems Conference. IEEE Vehicular Technology Society, New York, NY. 1989. pp. 56-60.

38. Parkes, A.M., M.C. Ashby, and S.H. Fairclough. "The Effects of Different In-Vehicle Route Information Displays on Driver Behavior." Paper No. 912734. Vehicle Navigation and Information Systems Conference Proceedings. Report No. SAE/P-91/253. Society of Automotive Engineers, Inc., Warrendale, PA. October 1991. pp. 61-70.

39. Zwahlen, H.T. and D.P. Debald. "Safety Aspects of Sophisticated In-Vehicle Information Displays and Controls." Proceedings of the Human Factors Society. 30th Annual Meeting. 1986.

40. Wierville, W.A., J.F. Autin, T.A. Dingus, and M.C. Hulse. "Visual Attentional Demand of an In-Car Navigation Display System." Vision in Vehicles - II. Proceedings of the Second International Conference on Vision in Vehicles. Elsevier Science Publishers B.V. Amsterdam, The Netherlands, 1988.

41. Zwahlen, H.T. "Driver Eye Scanning, the Information Acquisition Process and Sophisticated In-Vehicle Information Displays and Controls." Ergonomics International 85 Proceedings. Taylor and Francis. London, England. 1985.

42. Heinrich, B.F. "IVHS - An Automotive Perspective." Paper No. 912780. Vehicle Navigation and Information Systems Conference Proceedings. Report No. SAE/P-91/253. Society of Automotive Engineers, Inc., Warrendale, PA. October 1991. pp. 377-384.

43. JHK & Associates. "INFORM Evaluation." Draft report to the Federal Highway Administration. January 1991

44. Turner, J., Dudek C.L. and Carvell, J. "Real-Time Diversion of Freeway Traffic During Maintenance Operations." Transportation Research Record 722. Transportation Research Board, Washington, DC. 1979. pp. 36-40.

45. Dudek, C.L., Weaver, G. , Hatcher, D., and Richards, S. "Field Evaluation of Messages for Real-Time Diversion of Freeway Traffic for Special Events." Transportation Research Record 682. Transportation Research Board, Washington, DC. 1978. pp. 37-45.

46. Richards, S., Stockton, W., and Dudek C.L. "Analysis of Driver Responses to Point Diversion for Special Events." Transportation Research Record 682. Transportation Research Board, Washington, DC. 1978. pp. 46-52

47. Roper, D., Zimowski, R., and Iwamasa, A. "Diversion of Freeway Traffic in Los Angeles: It Worked." Transportation Research Record 957. Transportation Research Board, Washington, DC. 1984. pp. 1-4.

48. King. G.F. and T.M. Mast. "Excess Travel: Causes, Extent, and Consequences." Transportation Research Record 1111. Transportation Research Board, Washington, DC. 1987. pp. 126-137.

49. Mahmassani, H.S. and P. Shen-Te Chen. "Comparative Assessment of Origin-Based and En-Route Real-Time Information Under Alternative User Behavior Rules." Paper presented at the 70th Annual Meeting of the Transportation Research Board, Washington, DC. January 1991.

50. Chen, K. "Policy Implications of Driver Information Systems." Paper presented at the 71st Annual Meeting of the Transportation Research Board, Washington, DC. January 1992.

51.  Underwood, S.E.  "Social and Institutional Considerations in Intelligent Vehicle-Highway Systems." <u>Automated Highway/Intelligent Vehicle Systems: Technological and Socioeconomic Impacts</u>.  Society of Automotive Engineers, Warrendale, PA. 1990.  pp. 59-76.

52.  Ervin, R.D.  "An American Observation of IVHS in Japan."  University of Michigan.

53.  Dudek, C.L.  and  G.L.  Ullman.  "Freeway Corridor Management."  <u>NCHRP Synthesis of Highway Practice 177</u>.  Transportation Research Board, Washington DC.  March  1992.

54.  Neudorff, L.G.  "Guidelines for Successful Traffic Control Systems, Volume II: Final Report."  Report  No.  FHWA-RD-88-014.  Federal  Highway  Administration, Washington, DC.  August 1988.

55.  Baxter,  D.H.,  T.C.  Werner,  and  R.M.  Gardeski.  "The  Integrated  Motorist Information System:  The Ideal and the Real."  <u>Strategies to Alleviate Traffic Congestion</u>.  Institute of Transportation Engineers, Washington, DC.  1988.  pp. 86-101.

56.  Rowe, S.E.  "Los Angeles SMART Corridor Project."  <u>Proceedings</u>, Engineering Foundation Conference on Traffic Control Methods.  Santa Barbara, CA.  March 1989.  pp. 215-225.

57.  Balke,  K.N.,  W.R.  McCasland,  S.Z.  Levine,  and  C.L.  Dudek.  "Collection  and Dissemination of Real-Time Travel Time and Incident Information with In-Vehicle Communications Technologies."  <u>Vehicle Navigation and Information Systems Conference Proceedings</u>.  Report No.  SAE/P-91/253.  Society of Automotive Engineers, Warrendale, PA.  October 1991.  pp. 77-82.

58.  Rillings, J.H., and J.W. Lewis.  "TravTek."  <u>Vehicle Navigation and Information Systems Conference Proceedings</u>.  Report No.  SAE/P-91/253.  Society of Automotive Engineers, Warrendale, PA.  October 1991.  pp. 729-738.

59.  Boyce,  D.E.,  A.  Kirson,  and  J.L.  Schofer.  "Design  and  Implementation  of ADVANCE: The Illinois Dynamic Navigation and Route Guidance Demonstration Program."  <u>Vehicle Navigation and Information Systems Conference Proceedings</u>. Report No.  SAE/P-91/253.  Society of Automotive Engineers, Warrendale, PA. October 1991.  pp. 415-426.

60.  Ullman, G.L., R.A. Krammes, and C.L. Dudek. "Synthesis of Traffic Management Techniques for Major Urban Freeway Reconstruction."  Report No. FHWA/TX-90/1188-1.  Texas Transportation Institute, College Station, TX.  May 1989.

61.  Robinson, J. and M. Doctor.  "Ramp Metering Status in North America."  Report No. DOT-T-90-01.  Federal Highway Administration, Washington, DC.  September 1989.

62.  "Moving America: New Directions, New Opportunities."  A Statement of National Policy Strategies for Action.  U.S. Department of Transportation.  February 1990.

63.  Sparmann, J.M.  "Acceptance and Benefits of the Berlin Route Guidance and Information System. (LISB)."  Paper presented at the Conference of the Strategic Highway Research Program and Traffic Safety on Two Continents.  Gothenburg, Sweden.  September 1991.