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In-Vehicle Signing Functions of an In-Vehicle Information System*

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ABSTRACT

The definition of In-Vehicle Signing (IVS) functions was guided by the principles of traffic engineering as they apply to the design and placement of roadway signs. Because of the dynamic and active nature of computing, communications, and display technology, IVS can fulfill the signing principles of traffic engineering in ways that have been impossible with conventional signage. Current signing technology represents a series of compromises of these principles, especially the data and equations contributing to the calculation of required sight distance. A number of conditions relevant to sight distance are quite variable, e.g.: vehicle speed, visibility, weather, and driver reaction time. However, conventional signing requires that there are fixed values of each variable for the determination of (e.g.) legibility distance. IVS, on the other hand, will be able to tailor the timing of sign presentation to the dynamically diverse variable values of all of these conditions. A clear, in-vehicle sign display, adaptive to ambient and driver conditions, will in fact obviate the entire issue of sign legibility. These capabilities, together with information filtering functions, will truly enhance the presentation of sign information to drivers. The development of IVS is a critical step in the development of an integrated In-Vehicle Information System (IVIS).

INTRODUCTION

An IVS system is one which will bring information from roadway signs into the vehicle and present it to the driver, in such a manner that IVS will be an enhancement of the signing technology which is currently on the roads. The functions described here represent an initial operating capability to be manifested in a prototype, which will be designed, built, and tested in a follow-on effort. The initial capability will form the basis for future functional and informational enhancements, when IVS is eventually integrated with other driver information systems to become an IVIS, which will manage and fuse all driving-related information from many sources. These sources will include all Advanced Traveler Information Systems (ATIS) and related information services developed within the Intelligent Transportation System (ITS) program. The unified system will incorporate the human factors guidelines being developed, under a separate program, by the Battelle Seattle Research Center and its associated team partners (see e.g., 1).

An IVS system will provide significant enhancements to the driving task. Some of the primary benefits of IVS include:

- minimization of the exposure of the driver to unnecessary information.
- dynamic message saliency to facilitate enhanced attention allocation by the driver to important signing information.
- minimization of the driver's reliance on memory regarding signing information.
- minimization of the effects of extrinsic factors on sign visibility.
- enhanced message content to facilitate message understanding.

- message display timing which is based on driver characteristics in order to be sensitive to elderly and sight-impaired licensed drivers.
- minimization of the need for drivers to search for data/information.
- as necessary, employment of multiple input and output channels to equalize sensory and motor workload.

The IVS system is, for a number of reasons, a logical focal an IVIS. First, the primary goals of the IVIS and the IVS system are the same; i.e., information management. This similarity will facilitate a relatively straightforward transition of the management of sign information within the IVS system, to the management and fusion of all driving related information from many sources, including all ATIS and related information services developed within the ITS program. Second, much of the information which will be addressed by ATIS and related information services, are currently presented to drivers through the use of roadway signs. That is, in today's driving environment, information related to route guidance, navigation, traffic management, warnings and motorist services are presented to drivers through signs. This common basis suggests that lessons learned from IVS system analyses should be extended to other ATISs. Lastly, since safety and regulatory messages are the two most important types of information to be presented to the driver, other data and information sources should be managed in a similar manner. The management of regulatory and warning information within the IVS system should therefore set the precedent for managing all other data/information presented to the driver.

This paper describes the overall IVIS program, beginning with the IVS system analysis activities. Following this is a description of the process by which IVS functions were derived. The functions are defined to the system level, since the detailed, subordinate functions are too numerous for the present paper. For a more complete accounting of IVS functions, the reader is referred to the "Draft In-Vehicle Signing Functional Requirements Specification" (2), from which substantial portions of this paper were excerpted. Finally, there is a discussion of the potential synergistic benefits which can be expected as additional information sources are integrated during the development of an IVIS.

IVIS PROGRAM OVERVIEW

The IVS project is being conducted by the Oak Ridge National Laboratory (ORNL) for the Federal Highway Administration (FHWA). Initial efforts which began in late-FY-1994 involved: definition of an IVS system vision, and the conduct of quantitative and qualitative cost-benefit analyses on various ATIS-based IVS data sources (3); the conduct of an in-depth literature review that addressed the types of data/information drivers need, methods for data/information display, human factors studies regarding various information processing parameters (e.g., attention allocation, stress, cognitive workload, etc.), and existing and emerging technologies for in-vehicle displays and for vehicle/infrastructure communication (4); generation of IVS system functional requirements (2), generation of two IVS system concept candidates with associated high-level technical requirements (5), and an associated verification and validation (V&V) plan (6). All activities will have been completed by the end of October, 1995.

Follow-on research will have been initiated in early FY-1996 and will be conducted through FY-1998. The major research tasks will involve: broadening of the IVS functional requirements and system concepts, and V&V planning for an IVIS;

initiation of validation testing; development of an IVIS architecture; development of an IVIS preliminary and system design; development of the IVIS prototype; the conduct of verification testing; and the conduct of IVIS prototype evaluation testing. Throughout the conduct of the IVS/IVIS activities, ORNL has promulgated strong ties with industry, universities, and other applicable federal organizations. Two workshops have been conducted with participation from such organizations to elicit comments about existing research and advice about future directions. In early FY-1996, efforts will have been initiated to form a partnership between interested industry participants, FHWA, and ORNL for the purpose of joint development of an IVIS. Partnership formation is expected to be complete by mid-FY-1996.

IVS FUNCTIONAL REQUIREMENTS

Flowdown Process

The process of defining the functional requirements of an IVS system began with the stated goal of improving the presentation of roadway sign information to drivers. From this initially stated goal, two high level functional goals were derived: tailor the presentation of sign information to the driver; and tailor the presentation to the operating environment (e.g., the vehicle, the roadway, sign type, weather). Each of the functional goals imply certain classes of information which will be required to fulfill the goals. These classes of information are the supersets of all of the information requirements associated with the lower level functions. Similarly, all of the lower level functional requirements are derived from the functional goals in a hierarchical flowdown process (see Figure 1). This requirements flowdown process provides the audit trail through which all subordinate functions can be traced back to the functional goals and, ultimately, to the top level goal. It also provides the structure for configuration management during the subsequent design phase and supports traceability of all design decisions made in that phase.

The functional goals imply three system objectives to determine: what to display; how to display it; and when to display it. Each objective has information requirements associated with it. These information requirements are varied combinations of the classes of information associated with the two functional goals. In addition, each system objective implies two system level, or primary, functions. The resulting six primary functions comprise varying numbers and levels of subordinate functions. The lower level, subordinate, functions have information requirements which are defined at a much greater level of detail than those associated with the system level functions. The information required by the subordinate functions will be supplied either by other functions, by historical data, or by the driver.

Because of the manner in which functions were derived within the flowdown process, there is necessarily some redundancy in the following narrative descriptions of the different levels of the hierarchy.

IVS Goal

The goal of an IVS system is to enhance roadway sign information and its assimilation by drivers, through the display of sign messages in the vehicle. Two kinds of improvement are sought: signing effectiveness, i.e., the quality of sign information and the ease with which drivers can assimilate it; and safety, i.e., the degree to which signing contributes to, and does not distract from, the driving task. In addition, since such a signing system is likely to be electronic and active, there is

the potential legal threat of product and system liability posed by the possibility of system failures. There is, therefore, the associated goal of eliminating or minimizing the legal exposure of private manufacturers of IVS equipment and municipal providers of the IVS infrastructure.

Functional Goals

Two functional goals of the IVS system have been derived from the initially stated goal of improving the presentation of roadway sign information to drivers. These two functional goals state that the type of information presented and the manner in which it is presented, shall be tailored to: the driver; and the operating environment. Tailoring IVS operation to the driver implies information requirements in three classes: the driver's capabilities (e.g., sensory and psychomotor); the driver's goals (e.g., long distance travel along a particular route); and the driver's preferences (e.g., for display modality and sign filtering). Tailoring IVS operation to the operating environment implies requirements for three general classes of information: the sign (e.g., type, message, and location); the driving situation (e.g., vehicle weight and speed, roadway curvature and surface conditions); and the ambient conditions (e.g., light level, glare).

Objectives

Three objectives have been derived from the two functional goals of tailoring the presentation of sign information to the driver and to the operating environment. The first objective, **Detect and Filter**, is to determine which sign messages will be displayed to the driver, and to gather all data which will be required by subsequent functions. The series of information filters, used to determine sign message selection, will involve sign prioritization and sign applicability. The selection criteria applied by the two filters will reflect: driver goals, driver preferences, sign priority, and varying aspects of the driving situation. The second objective, **Display**, is to optimize and adjust the presentation of sign messages to the driver both before and after the activation of a sign display. Display optimization and adjustment shall be in accordance with: ambient conditions, driver capabilities, driver preferences, the number of simultaneous sign messages, and varying aspects of the driving situation contributing to the level of urgency of the sign message. The third objective, **Timing**, is to determine when a sign message display is activated and when it is deactivated. The timing of display activation will provide enough time and distance for the driver and the vehicle to execute an appropriate response. Activation timing will reflect calculations of sight distance requirements, and will take into account: driver capabilities, responses required by each sign, and the driving situation. The timing of display deactivation will mirror the sign applicability information filter. Once a sign message is no longer applicable, it will be deactivated.

System Level Functions

Six system level, or primary functions have been derived from the objectives. These functions represent the initial operating capability of IVS. Each primary function comprises varying numbers and levels of subordinate functions, which are not listed or shown here. The six primary functions are:

Sense and Encode Data

The first function which an IVS system will perform is to get information about a roadway sign and the driving situation into the system. This function will be executed first in the sequence of six primary functions performed for each sign detected. This function will perform: detection of the sign's presence, encoding of its type and message, and the determination of the location of the sign and its associated decision point, relative to the vehicle. Sensing and encoding of sign data will be performed continuously for each sign detected. This function will also continuously sense and encode data relevant to the driving situation, which will be required by subsequent functions: spatial conditions, temporal conditions, and operational conditions.

Select Sign Message

The system will select for presentation only sign messages which satisfy both of two information filters. The two information filters will be executed in series. The first filter will apply three sign prioritization criteria: sign type (i.e., regulatory and warning); support of the driver's goals (e.g., route and destination); or meeting the driver's preferences (e.g., for display of other sign categories). A sign message which satisfies any one of the three criteria will pass the first information filter. The second filter will determine whether a sign message is applicable to the relevant conditions: spatial; temporal; and operational. If a sign message does not satisfy all of the appropriate conditions of the second information filter, the system will not select the sign message for presentation to the driver.

Two examples will illustrate how the filtering function will operate. In the first example, a lane restriction sign is detected and passes the first filter because it is a high priority, regulatory sign. If the vehicle is not in the restricted lane, the message will not pass the second filter. If the vehicle is in the restricted lane, but the restriction applies only at a particular time of day which is different from the current time, the sign message will not be displayed. Finally, if the spatial and temporal conditions are met, but the restriction only applies to a certain class of vehicles (e.g., commercial trucks) different from the vehicle being driven, the sign will be filtered out. In a second example, a driver has entered into the system the intention to follow a specific numbered route to a specific destination. Even though of relatively low priority, in comparison to regulatory signs, messages related to the route and destination (e.g., mileage distance signs) will be displayed to the driver as long as they meet the conditions of applicability (e.g., vehicle direction of travel). All other guidance and information sign messages will, however, be filtered out. When IVS is eventually integrated with other ITS services and systems, the route selection could be input automatically from (e.g.) a routing and navigation system, an Advanced Traffic Management System (ATMS), or an integration of both.

Optimize Display

The selection of display modality (i.e., audio or visual) and type of display (e.g., head-up display), as well as design of display formats, are decisions which will be made during the design of an IVS system. Display design decisions will determine most of the factors influencing the ease with which sign information is assimilated by the driver, and the degree to which distraction from the driving task is minimized. Once in operation, IVS will optimize and adjust the display of sign information to meet a number of conditions. Drivers will be able to adjust the display to meet their preferences. For example, they will be able to adjust intensity or deselect unwanted display modes (e.g., a voice supplement). Ambient light and noise

conditions will be used by the system to adjust, automatically, the intensity and spectral content of visual and auditory displays. When multiple sign messages are selected for display by the filter function, these messages would be either separated over space (i.e., locations) or time (i.e., sequenced) or both, in order to avoid cluttering and driver overload.

Turn Sign Display On

The system will turn on the display of a sign message at a time and distance which will support the execution of an appropriate response by the driver and the vehicle. Estimation of display activation timing will be based on calculation of the time and distance required for the driver and vehicle to execute the required response given current conditions regarding the driver (e.g., reaction time) and the driving situation (e.g., vehicle speed, vehicle weight, roadway coefficient of friction). These calculations will be based on accepted human factors and traffic engineering data and models (7,8).

The rationale for this approach to message timing is as follows. In traffic engineering, the determination of a road sign's size, location, height, etc. is made according to the calculation of the required sight distance. Sight distance requirements (e.g., stopping sight distance) are generally divided into two distances or times: a human component and a physical component (9). The human component comprises the time required by the driver to: detect the sign, recognize its meaning, decide what to do, and respond. The physical component is determined by all of the factors which contribute to how long, in time or distance, it will take for the vehicle to perform the necessary maneuver (e.g., coming to a stop), once the driver has made the proper response (e.g., applying the brakes). The variability of either of these components is quite large. For example, variability in human reaction time is determined by a combination of sensory, perceptual, cognitive, and psychomotor capabilities. Each of these psychological factors varies greatly between individuals, and even within a single individual over time. The physics of a vehicle performing a maneuver are also dependent on a number of factors, e.g.: vehicle weight, vehicle speed, road surface/tire coefficient of friction. The design and placement of current roadway signs generally reflects the selection of one value for each of the many variables which contribute to the determination of required sight distance. For example, 85th percentile vehicle speed on a particular road is used to specify the minimum visibility distance requirements for traffic signals (10). IVS will adjust the time at which a sign display is activated to take into account the variability among: drivers, vehicles, and operating conditions. In this way the driver of a heavy vehicle traveling at a high speed will be alerted of an upcoming requirement to stop well before the driver of a lighter vehicle which is traveling at a lower speed.

Adjust Display

During the presentation of a sign display, the system will adjust the salience of the display in accordance with varying levels of message urgency. The determination of increasing or decreasing urgency will take into account the response required by a sign message and the difference between time and distance required, and time and distance available for the driver and vehicle to execute the required response. Increasing or decreasing display salience will serve two purposes: adjust the conspicuity of a sign message; and convey information to the driver about the changing level of urgency. For example, if a "stop" sign is displayed, and IVS determines that the driver and vehicle are not responding, the

visual or auditory salience of the display will increase (e.g., beeping, blinking, addition of a voice supplement, increased intensity).

Turn Sign Display Off

The time at which a sign display is turned off will be determined by a function which mirrors the second selection filter in the filtering function. When a sign message is no longer applicable, it will be deactivated. Offset time will be determined by the same sort of integration of spatial, temporal, and operational conditions described above. This function will accomplish two things. First, a sign message will be displayed for only the amount of time that it is applicable; thus minimizing display clutter and distraction from the driving task. Second, a sign message will be displayed for the entire duration of its applicability (e.g., speed limits, deer crossings); thus eliminating the need for a driver to remember the sign message.

IVIS INTEGRATION

The IVS functions have been purposely bounded to include only information provided by roadway signs. Circumscribing the system in such a manner is necessary and proper, at this time, to prove the technology which will be required for bringing sign information into the vehicle, and to assess the benefits of doing so. This approach, to be performed in the follow-on IVIS prototype effort, resembles the Demonstration/Validation phase in the development of a new military weapon system. It serves to mitigate technological risk and to validate the system concept before the "real thing" is deployed. However, such a partitioning of IVS from all of the other ITS information services, especially those within ATIS, must be recognized as artificial. The overlap among systems is made clear when one considers some of the classes of information provided by signs: routing and guidance (In-Vehicle Routing And Navigation: IRANS), motorist services (In-Vehicle Motorist Services Information System: IMSIS), and warnings of hazards (In-Vehicle Safety Advisory Warning System: IVSAWS), as well as regulatory information. The partitions which have been raised among these and other information systems have been based largely on the **sources** of the information, not the information itself. The users of the information, drivers, need information and should not be concerned with its source, just with its validity and timeliness. The following discussion will address the current partitioning of information systems and a few of the synergistic benefits that can be expected from an integrated IVIS, which manages information based primarily on **informational needs**, not on the source.

Considering first the four in-vehicle ATIS (IVS, IRANS, IMSIS, and IVSAWS), the following distinctions and commonalities emerge. IVS is concerned with rather local geometry, measured in meters, of a vehicle's location on a section of road and the relative location of a sign or decision point (e.g., an intersection). IRANS deals with a much larger geographical area, measured in kilometers, based on information coming from, e.g.: global positioning system (GPS), on-board inertial navigation systems (INS), cartographic data bases, and dynamic routing algorithms. Both systems provide information on guidance and routing, but obtain such information from very different sources and on very different scales. When linked, IRANS could tune IVS to present guidance and routing sign messages which support the selected route. Similarly, the local precision of IVS can be used to confirm and sharpen the accuracy of (e.g.) a GPS derived location, without the expense of a differential GPS (DGPS) service. The value and the accuracy of both information systems are

increased by their integration. IMSIS provides information on the locations and types of motorist services based on (e.g.) an on-board data base. Linked to IRANS and IVS, guidance can be provided to the needed service with the same sort of synergy as that described above. IVSAWS information on an upcoming intersection hazard could make the presentation of intersection-related signing by IVS much more intelligent. If a hazard is such that re-routing is required, which in turn will cause additional motorist services to be needed, the advantages of linking all four systems becomes obvious. The above examples of the synergistic benefits of information fusion are, of course, far from exhaustive. From the driver's point of view, an intelligent IVIS will provide higher quality information, more meaningfully filtered, via a unified display interface which will actually entail less user input and more display effectiveness than any of the constituent subsystems.

The combined capability of an integrated IVIS will also provide an intelligent partner for other ITS information services. The communication from an Advanced Traffic Management System (ATMS) to IVIS can be extremely efficient, with ATMS transmitting traffic management goals, and IVIS performing the more local information management tasks required to meet those goals. As additional services (e.g., vehicle proximity sensing systems) become available, IVIS will be able to incorporate them in ways that will enhance the performance of its existing subsystems. For example, if IVS senses a lane restriction, but the vehicle proximity system senses other vehicles preventing a lane change maneuver, the two systems working together can more sensibly communicate the situation to the driver, than either could alone. The integration of systems dealing with the spatially dynamic information of the roadway and other vehicles will permit IVIS to play a larger and larger role in directly supporting the control aspect of driving, not only the guidance and navigation aspects that it will start with.

In the longer-term, further development of the IVIS can be envisioned to extend toward dynamic and real-time vehicle control. That is, technologies which support the display of real-time data and information to the driver for eventual translation into a control activity can be envisioned to be utilized by an advanced vehicle control system. For example, a vehicle heading toward a four-way stop will have displayed a stop sign within the vehicle. If for some reason the driver does not respond, an auditory message emphasizing the urgency to stop is provided to the driver. If in the extreme, the vehicle senses no efforts on the part of the driver to stop the vehicle, the automated control system would initiate an automated stopping task sequence.

In general, the described development of an IVS system, its integration into an IVIS, and the eventual development of an automated control system is a reflection of the logical integration of system functions that is expected as advanced systems evolve. In the long-term, many of the technologies being developed under the 29 user services of the ITS program will share information sources and architectures. Such integration is desirable to minimize cost and unneeded redundancy. The envisioned development of the IVIS is characteristic of such integration.

SUMMARY AND CONCLUSIONS

The functional requirements defined for IVS constitute an initial operating capability for IVIS that will determine what sign information to display to drivers, how it will be displayed, and when it will be displayed. A structured requirements flowdown process was created to support the definition of six system level functions and their associated subordinate functions and information requirements. The

flowdown process will permit traceability of all levels of requirements and subsequent design decisions back to the IVS goal. As such, the functions and process defined here will form the bases for the design, construction, and operational test of an IVS prototype in a follow on project. The process of requirements analysis and system design will be complemented by a parallel effort of verification and validation in each phase of the IVIS systems engineering program.

The initial IVIS signing capabilities described here have been purposely circumscribed to include only information provided by roadway signs. This has been done to partition the IVS-specific design and test issues, and is recognized as an artificial necessity. The IVS initial operating capability must be viewed as one step in a process of integration, with the other ITS information services, into a unified IVIS. This IVIS will manage all driving related information regardless of source. The combined capability of such an IVIS will result in synergistic benefits which go far beyond the cumulative abilities of the separate, constituent subsystems.

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ENDNOTES

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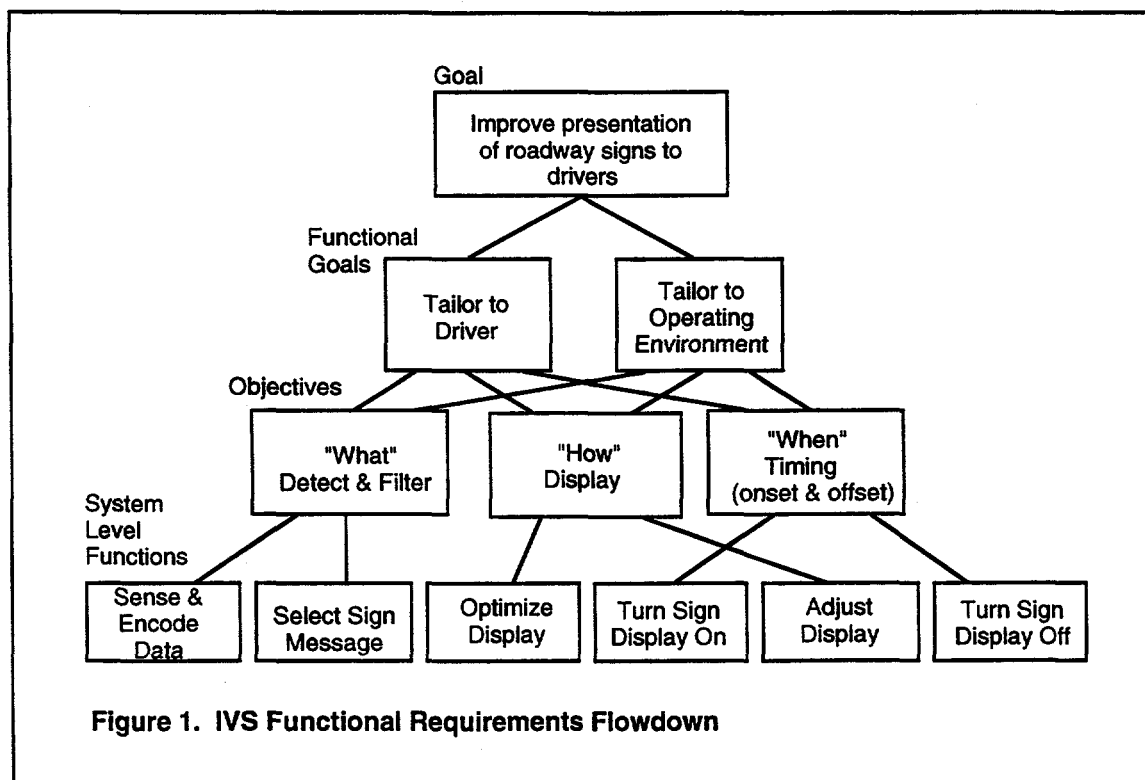


Figure 1. IVS Functional Requirements Flowdown