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Invehicle Safety Advisory and Warning System (IVSAWS),

Volume I: Executive Summary

U.S. Department of Transportation
Federal Highway Administration

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FOREWORD

This report presents the results of a comprehensive study to identify candidate advisory, safety, and hazard situations where motorists would benefit from an Invehicle Safety Advisory and Warning System (IVSAWS). Functional specifications are also provided in sufficient detail to describe how these functions could be gradually incorporated into existing and future automotive vehicles. The IVSAWS, designed for rural, urban, and secondary roads, uses a proposed communication architecture based on transmitters placed on roadside signs and at roadway hazards to communicate with approaching vehicles equipped with IVSAWS invehicle radio receivers. This study will be of interest to transportation planners and engineers involved in motorist advisory and emergency communication systems.

Sufficient copies of the study are being distributed by the FHWA Bulletin to provide a minimum of two copies to each FHWA regional and division office, and five copies to each State highway agency. Direct distribution is being made to division offices.

Lyle Saxton
Director, Office of Safety an&Traffic
Operations Research and Development

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16. Abstract
The Invehicle Safety Advisory and Warning System (IVSAWS) is a Federal Highway Administration effort to develop a nationwide vehicular information system that provides drivers with advance, supplemental notification of dangerous road conditions using electronic warning zones with precise areas of coverage. The research study investigated techniques to provide drivers with advance notice of safety advisories and hazard warnings so drivers can take appropriate actions. The technical portion of the study identified applicable hazard scenarios, investigated possible system benefits,derived functional requirements, defined a communication architecture, and made recommendations to implement the system.

This volume is the first in a series. The other volumes in the series are:

FHWA-RD-94-190 Volume II: Final Report
FHWA-RD-94-191 Volume III: Appendixes A Through H (Reference Materials)
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (Lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^{o}F ❑ y ^{o}C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(9/5) y + 32] ^{o}C ❑ x ^{o}F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

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

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

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INTRODUCTION

In 1991, the United States Congress passed the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). This legislation allocated $600 million from 1992 through 1997 to improve mobility; enhance safety, improve the efficiency of existing transportation facilities, conserve energy resources, and reduce adverse environmental effects. These various ISTEA projects are collectively known as the Intelligent Vehicle-Highway System (IVHS).[1,2]

IVHS projects are funded through three of the Department of Transportation's (DOT) modal administrations — the Federal Highway Administration (FHWA), Federal Transit Administration (FTA), and National Highway Traffic Safety Administration (NHTSA). The national IVHS program includes initiatives in research, system architecture development, operational tests, institutional issues, and deployment efforts. This national IVHS program has identified 18 milestones: (1) tools and knowledge bases, (2) system architecture, (3) radio frequencies, (4) traveler information, (5) transit fleet management, (6) route guidance and navigation, (7) fare collection, (8) transportation demand management, (9) transportation management data base, (10) traffic control, (11) commercial vehicle applications, (12) commercial vehicle networks, (13) collision avoidance, (14) automated highways, (15) benefits and costs, (16) institutional and legal issues, (17) metropolitan deployments, and (18) rural applications. [3] A key effort within the rural applications milestone is the Invehicle Safety Advisory and Warning System (IVSAWS) program illustrated in figure 1.

The Invehicle Safety Advisory and Warning System is a Federal Highway Administration program to develop a nationwide vehicular information system that provides drivers with advance, supplemental notification of dangerous road conditions using electronic warning zones with precise areas of coverage. The goal is to ameliorate the severity of scenarios that are particularly hazardous and have remained hazardous despite traditional crash-reduction techniques such as mechanical signing. This system provides additional safety by enhancing the real-time interaction between the general driving public and professional agencies. While appropriate for both urban and rural settings, the primary focus of IVSAWS is the rural

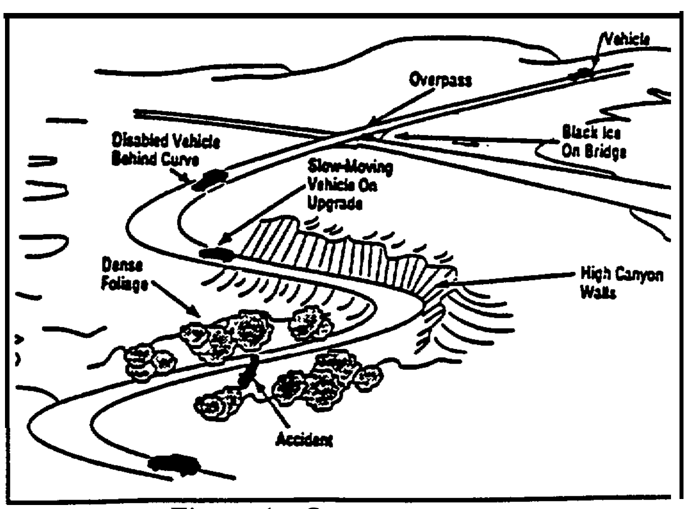

Figure 1. System concept.

transportation environment. The IVSAWS program investigated techniques to provide drivers with advance notice of safety advisories and hazard warnings so that drivers are able to take appropriate action to reduce the severity of such situations. The technical portion of this program identified applicable hazard scenarios, investigated the possible system benefits, derived the functional requirements for the system architecture, and gave recommendations for an optimal system implementation as part of a total invehicle motorist information package.

IVSAWS PROGRAM ROAD MAP

Figure 2 identifies the major tasks that comprised the IVSAWS program. Links between tasks are shown with arrows. Arrow labels identify major results from a given task that were required to support a subsequent task. The following paragraphs describe each task and identify supporting documentation contained within volumes III through V of the IVSAWS final report.

Program Plan

Documentation

- Chapter 1, Volume II, IVSAWS.
- Workplan for the Invehicle Safety Advisory and Warning System (IVSAWS), November 1990 (Appendix A, Volume III, IVSAWS).
- IVSAWS Engineering Change Proposal 3 (ECP-003) Overview, April 1992 (Appendix B, Volume III, IVSAWS).

Task Description

This effort established a framework for work to be performed under the IVSAWS contract on a task-by-task basis. Each task was defined and task outputs were identified. The original workplan was modified via Engineering Change Proposal 3 to reflect a change in program focus.

A major emphasis of the original workplan was to develop and demonstrate a proof-of-concept IVSAWS that would warn drivers using transmitters placed near roadway hazards. Engineering Change Proposal 3 expanded the “front-end” system design work to consider several other system design concepts. Prototype development was eliminated.

Hazardous Situation Identification and Prioritization

Documentation

- Chapter 2, Volume II, IVSAWS.
- Chapter 3, Volume II, IVSAWS.
- IVSAWS Task B Final Report, March 1991 (Appendix C, Volume III, IVSAWS).
- Driver Alert Distance Analysis Scenario Selection, February 1991 (Appendix D, Volume III, IVSAWS).
- Driver Alert Distance Analysis, March 1991 (Appendix E, Volume III, IVSAWS).

Task Descriution

This task developed a prioritized list of IVSAWS applications based upon an analysis of State and Federal highway accident data bases and highway safety engineering panel discussions. The application scenarios were used to derive the distance in front of a hazard at which drivers should be alerted (driver alert distance) via IVSAWS. The scenarios were also used to develop a set of candidate signaling formats that could be used to quickly inform drivers about the nature of an impending hazard (e.g., emergency vehicle, roadway accident).

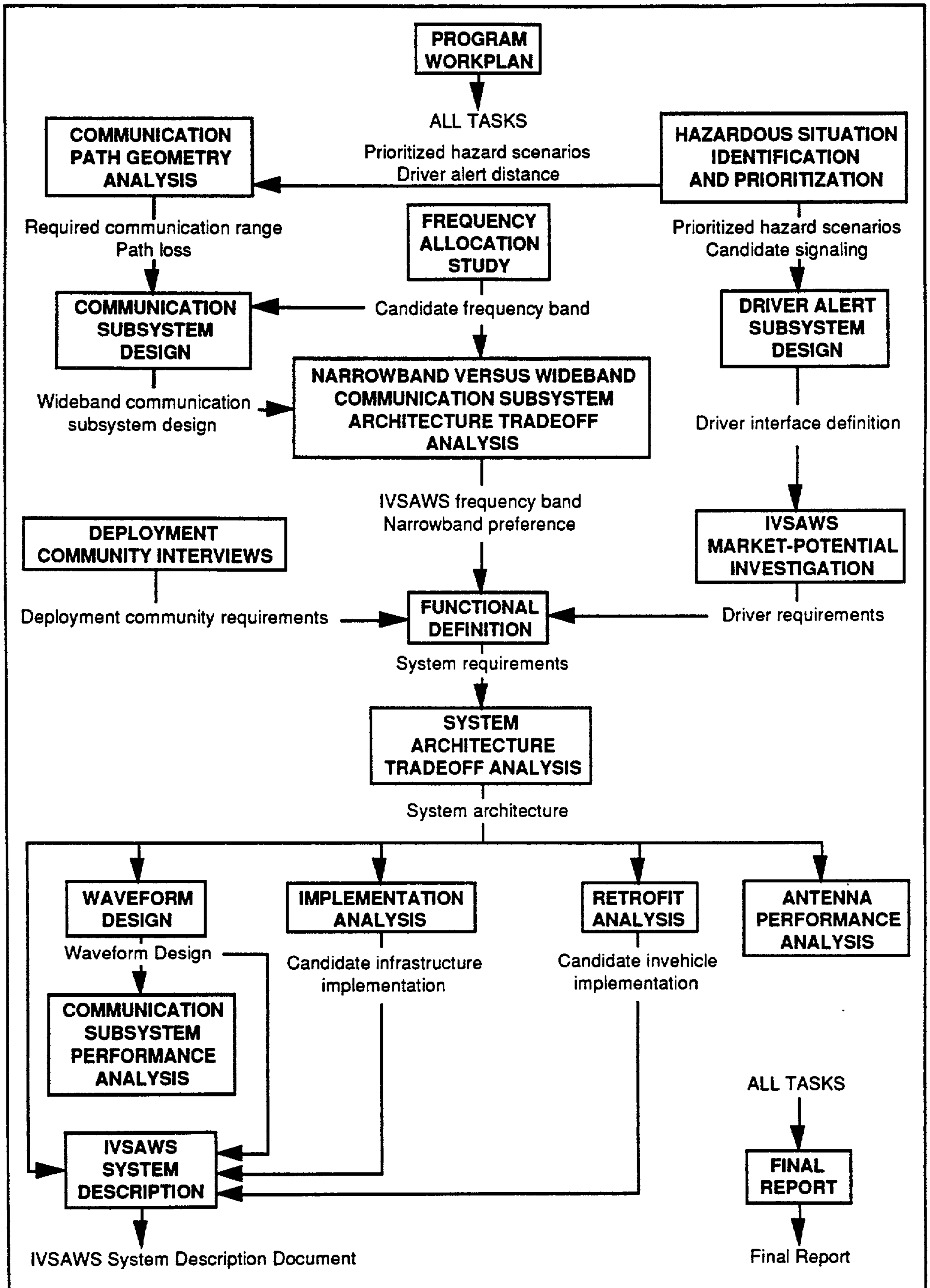

Figure 2. IVSAWS program road map.

Communication Path Geometry Analysis

Documentation

- Chapter 4, Volume II, IVSAWS.
- Chapter 5, Volume II, IVSAWS.
- Communication Path Geometry Analysis, February 1991 (Appendix F, Volume III, IVSAWS).

Task Description

The driver alert distance derived during the analysis identified above was used to define a maximum IVSAWS communication range, assuming IVSAWS transmitters would be placed near roadway hazards. Four sample roadway terrains were then used to determine the expected communication path losses as a function of radio frequency. The roadway terrains selected were as follows: (1) straight and flat high-speed highway, (2) curved highway through trees, (3) highway through rolling hills, and (4) curved road with interleaving mountains.

Driver Alert Warning Subsystem Design

Documentation

- Chapter 3, Volume II, IVSAWS.
- Invehicle Safety Advisory and Warning System (IVSAWS) Task E Report, Results of the Driver Alert Warning System Design, Mockup Testing, and Evaluation, November 1991 (Appendix G, Volume III, IVSAWS).

Task Description.

The hazardous situation identification and prioritization task (described above) provided recommendations for driver signaling and the context for driver visual and auditory messages. The signaling recommendations and the hazard situations identified provided the basis for development of eight test symbols. A foam-core mockup environment was created in order to empirically test the symbols, or telltales, for driver recognizability, comprehensibility, and effectiveness. The symbols were tested individually as well as paired with audio tone, voice, and text messages. In general, the test results showed a preference for a driver alert presentation consisting of a short voice message, text message, and telltale pictogram.

Frequency Allocation Study

Documentation

- Chapter 4, Volume II, IVSAWS.
- Proposal for the Invehicle Safety Advisory and Warning System (IVSAWS), February 1990 (Appendix H, Volume III, IVSAWS).
- Invehicle Safety Advisory and Warning System (IVSAWS) Communication Technology Selection, Task C Report, June 1991 (Appendix I, Volume IV, IVSAWS).

Task Descriotion

This task searched the radio frequency (RF) spectrum for frequency bands compatible with the following initial IVSAWS bandwidth and transmission power requirements:l-MHz bandwidth and 5-W transmission power. The requirements were based upon the proposed IVSAWS Communication Subsystem design concept that used low-cost, portable spread-spectrum transceivers located near roadway hazards to disseminate hazard information to compatible invehicle transceivers. It was estimated that 1 MHz was the minimum bandwidth that could support reliable, low-cost spread-spectrum communication. Portability and cost restrictions limited transmission power.

A total of 11 candidate frequency bands were identified. However, communication path loss estimates derived during the communication path geometry analysis indicated that IVSAWS would need to operate at a frequency below 500 MHz in order to support communication with a 5-W transmitter. Thus, only three of the candidate frequency bands were suitable for IVSAWS operation, 42 MHz to 47 MHz, 420 MHz to 450 MHz, and 450 MHz to 470 MHz. Operation in any of the three bands would require co-channel operation with existing systems or relocation of existing systems to other frequency bands.

Communication Subsystem Design

Documentation

- Invehicle Safety Advisory and Warning System (IVSAWS) Communications Technology Selection, Task C Report, June 1991 (Appendix I, Volume IV, IVSAWS).

Task Description

An IVSAWS radio was designed for both the reception and transmission of digital messages between a roadway-deployed warning transceiver and an invehicle receiver. The radio employs spread-spectrum communication technology and operates in the 420-MHz to 450-MHz frequency band. The radio is comprised of three major subassemblies — frequency conversion module, digital correlator/processor, and microcontroller. The frequency conversion module translates the radio signal between its assigned location in the frequency spectrum and baseband (where the information is placed on or extracted from the waveform). The digital correlator/processor performs different types of processing during transmission and reception. During reception, the digital cot-relator/processor extracts the digital information from the radio waveform and presents it to the microcontroller. During transmission, the digital correlator/processor encodes the information from the microcontroller onto the radio waveform. The microcontroller controls the IVSAWS radio by storing messages and organizing the protocols used for message transfers. This module will also operate a driver display and execute software algorithms for the optimum display of hazard information.

Narrowband Versus Wideband Communication Subsystem Architecture Tradeoff Analysis

Documentation

- Chapter 4, Volume II, IVSAWS.
- Engineering Change Proposal 2 (ECP-002) Report, IVSAWS Communication Subsystem Architecture Tradeoffs, November 1991 (Appendix J, Volume IV, IVSAWS).

Task Description

In order to address concerns with obtaining a frequency allocation for IVSAWS operation in the 420-MHz to 450-MHz frequency band, alternatives to the baseline spread-spectrum architecture were examined. One architecture (called GPS-NB in the ECP-002 report) uses the Global Positioning System (GPS) to provide vehicle-to-hazard ranging, rather than using the integral round-tip-timing approach specified in the baseline task C report. This allows the communication link to be narrowband (5-kHz to l0-kHz bandwidth for a 2400-bps to 4800-bps data rate) and improves the potential for a Federal Communications Commission (FCC) allocation. Tradeoffs were performed between the two architectures. As a result, a narrowband IVSAWS communication subsystem architecture preference emerged. Thus, a communication subsystem redesign was required. More importantly, the scope of the IVSAWS program was expanded to consider operational concepts not using transmitters deployed near the hazard location. The examination of operational concept alternatives initiated an extensive study of IVSAWS system requirements based upon user (drivers and system deployment personnel) demands and needs.

Deployment Community Interviews

Documentation

- Chapter 6, Volume II, IVSAWS.
- Chapter 7, Volume II, IVSAWS.
- Assessment of IVSAWS Deployment Practicality, February 1993 (Appendix K, Volume IV, IVSAWS).
- Railroad Industry Interview Results, December 1993 (Appendix L, Volume V, IVSAWS).

Task Description

Currently, various agencies are responsible for detecting hazardous conditions and taking steps to increase motorist safety. These "safety" agencies include law enforcement organizations, fire departments, paramedics, construction crews, maintenance crews, and railroad operators. IVSAWS should be an extension of their normal duties and will provide them with another method for communicating with the general public. Consequently, personnel from these various agencies will be responsible for establishing the warning zones that alert the drivers. Just as functionality and cost are critical to consumer acceptance of IVSAWS, minimal operational impact is critical to deployment professionals' acceptance of IVSAWS. Therefore, personnel from various agencies were interviewed to determine if they liked the IVSAWS concept and to determine their perspective on preferred IVSAWS operations.

IVSAWS Market-Potential Investigation

Documentation

- Chapter 6, Volume II, IVSAWS.
- Market-Potential Assessment of IVSAWS, Research Among the General Public and Deployment Professionals, August 1992 (Appendix M, Volume V, IVSAWS).

Task Descriution

As the engineering studies progressed, many questions arose concerning which functions the driver could perform and which functions the system should perform. Could drivers be expected to determine whether or not an alert applied to them? Would drivers become very irritated with a low-capability system? Should drivers be able to summon help to the accident site? Should the vehicle electronics assume an accident has occurred when the air bag is released and automatically summon help or alert other drivers? All these capabilities are technically possible but could result in a cost that is unacceptable to consumers.

To answer these questions, motorists were surveyed using both qualitative "focus group" discussions and interactive computer surveys. Both techniques were used because high-involvement purchases, such as traffic hazard warning systems, are based on several factors considered "jointly" rather than a single factor alone. Qualitative questioning forces consumers to reveal their priorities when making these complex decisions. Computer-interactive interviewing eliminates respondent "editing" and any interviewer bias. The results are distilled into utility weights that are indications of the relative worth customers place on the components of a purchase decision.

The focus group discussions had three objectives: (1) to determine the overall driver reaction to the IVSAWS concept; (2) to determine which features, issues, and price points were most likely to stimulate purchase of IVSAWS; and (3) to determine those situations for which the driver felt IVSAWS would be most helpful. In this focus group survey, a market survey specialist had a prepared discussion guide to ensure consistent questioning of each group of about 10 drivers. The discussions started with general questions of their driving habits and finished with very specific questions about preferred features in an automobile safety system.

Functional Definition

Documentation

- Chapter 8, Volume II, IVSAWS.
- IVSAWS Task B, Subtask 4 Report (Engineering Change Proposal 3, Option AA) Functional Definition, February 1993 (Appendix N, Volume V, IVSAWS).

Task Description

This task defined the functions to be embedded within a first-generation Invehicle Safety Advisory and Warning System. Broadly, it specified the functional support that is required to establish an electronic warning zone around a roadway hazard or advisory site. It also defined the functions needed to present the warning or advisory data to a driver once a vehicle has penetrated an electronic warning zone.

The functional definition provided an integrated system requirements model that represents IVSAWS according to its information processing and control-state behavior. The process model breaks a system into its component functions, shows the data flow into and out of the function\. and describes how the functions operate on data flow inputs in order to generate data flow outputs. The control model indicates those circumstances under which the component function\ identified by the process model are activated.

System Architecture Tradeoff Analysis

Documentation

- Chapter 9, Volume II, IVSAWS.
- IVSAWS System Architecture Analysis, February 1993 (Appendix 0, Volume V, IVSAWS).

Task Description

The system architecture analysis task examined existing communication and geolocation systems to evaluate which of these available systems could satisfy IVSAWS functional requirements. Deployment-community interviews determined that the operational concept should be centralized-alert broadcasts from a regional operations center for the majority of the alert scenarios. Trains and mobile emergency vehicles traversing traffic should still function as independently operated warning nodes within this base station architecture. Market assessments determined that providing only relevant alerts is fundamental to motorist acceptance of IVSAWS. By applying quantitative system engineering methodologies, a geolocation capability was identified as the primary mechanism to provide the precise zone for each alert and hence, the primary means to prevent irrelevant alerts. Thus, the IVSAWS system architecture must provide for centralized communications, occasionally distributed mobile broadcasts, and precise position location.

Waveform Design

Documentation

- Chapter 10, Volume II, IVSAWS.
- IVSAWS Waveform Design #l (Narrowband Communication with GPS AOC Control), July 1993 (Appendix P, Volume V, IVSAWS).
- IVSAWS Waveform Design #2 (RBDS Communication with Coverage Control), July 1993 (Appendix Q, Volume V, IVSAWS).

Task Description

This task defined the modulation, forward error correction code, and message structure for the IVSAWS communication waveform.

Communication Subsystem Performance Analysis

Documentation

- Chapter 11, Volume II, IVSAWS.
- IVSAWS Communication System Performance Analysis, August 1993 (Appendix R, Volume V, IVSAWS).

Task Description

This task compared several candidate IVSAWS modulation schemes and analyzed several system performance parameters using the selected modulation scheme for the rural, suburban, and urban driving environments.

Implementation Analysis

Documentation

- Chapter 12, Volume II, IVSAWS.
- IVSAWS Implementation Analysis, April 1993 (Appendix S, Volume V, IVSAWS).

Task Description

This task identified commercial off-the-shelf (COTS) hardware and software available to implement IVSAWS Operations Center (IOC) functions. When implemented, the IOC functions may initially exist as a stand-alone system, however, the long-term goal will be to add the IOC system to a larger IVHS system in the form of a software applique. The IOC functions include collection of hazard and advisory event information, and IVSAWS message generation, storage, look-up, verification, and dissemination.

Retrofit Analysis

Documentation

- Chapter 13, Volume II, IVSAWS.
- IVSAWS Retrofit Analysis, April 1993 (Appendix T, Volume V, IVSAWS).

Task Description

This task identified the requirements for an invehicle IVSAWS. This analysis included derivation of new vehicle and retrofit vehicle IVSAWS configurations, cost data for the individual components, and identification of invehicle subsystem issues that must be decided at a future date.

Antenna Performance Analysis

Documentation

- Chapter 14, Volume II, IVSAWS.
- IVSAWS Antenna Performance Analysis, April 1993 (Appendix U, Volume V, IVSAWS).

Task Description

The proposed IVSAWS architecture will add two electromagnetic links to a modern vehicle containing several simultaneous, wireless systems. It will be necessary then to minimize the size of any added antenna or to share these new links with the existing vehicle antennas. This task analyzed the performance of several candidate IVSAWS antenna configurations.

IVSAWS System Description

Documentation

- Design Concept for an Invehicle Safety Advisory and Warning System (IVSAWS), May 1994 (Appendix V, Volume V, IVSAWS).

Task Description

This description provides a top-level functional system specification of a communications system between hazard transmitter and hazard receiver in sufficient detail to completely characterize an Invehicle Safety Advisory and Warning System. This documentation includes a description of the system architecture/waveform design, and identifies candidate IVSAWS invehicle and infrastructure implementations.

RELEVANCE OF IVSAWS

The FHWA reported that motorists drove 3.4 billion km in 1990.[4] The National Highway Traffic Safety Administration (NHTSA) reports that accidents cause 41 thousand deaths, 3.5 million injuries, and $100 billion in losses annually.[5] In urban areas, congestion is a key contributor to accidents and their consequential losses. In rural areas, remoteness, weather effects, or infrastructure faults are often the major contributing factors. Accident statistics show that the combination of seat belts and airbags save 46 percent of lives that would have otherwise ended in fatalities due to the accident's severity. Thus, accident avoidance has the potential to prevent over 50 percent of all fatalities and other consequential losses. Studies in Japan's Guidelight program have revealed that as little as 1.5-s advance notice is often sufficient warning to prevent 90 percent of accidents at intersections and curves with low visibility.[6] The focus of IVSAWS is to provide immediate, near-term supplemental warnings during scenarios in which increased driver response time will reduce impending hazard severity.

RURAL TRANSPORTATION ENVIRONMENT

The 1990 census revealed that 75.2 percent of Americans live in urban areas.[7] However, this statistic masks the tremendous diversity that still exists. For example, California is the least rural, with only 7 percent of its population living apart from urban centers, whereas Vermont is the most rural, with 68 percent of its population living apart from urban centers. Furthermore, this increase in urbanization does not imply that all urban centers are large. Rather, as shown in figure 3, only 194 out of 19,289 metropolitan areas in the United States have populations over 100,000. Note that the largest city in Wyoming has 76,000 people. The transportation environment for these urban areas is predominantly rural, both in the nature of the roadways and in the tremendous distances between these urban centers.[8] Of the 6.3 million km of roadways in the United States, 5.1 million km are categorized as rural. These characteristics greatly impact the safety issues associated with driving in rural environments. Remoteness, weather conditions, and infrastructure problems (bridge access, railroad crossings) are often contributing factors to accidents in rural settings.

Accidents often involve only one vehicle or many vehicles, but seldom just two vehicles. These accidents are often many kilometers from the nearest phone, leaving people stranded. The inability to summon emergency services to an accident scene promptly is a real problem. In Western States, accident victims often become fatalities due to exposure during the winter because they are stranded or cannot summon help, rather than dying from injuries sustained in the accident. Response times to summon emergency services are typically measured in hours rather than minutes. Also, transport times for serious injuries can also be significant because many rural counties do not have hospitals. For example, Montana has over 15 539 km^2 in its territory and only 13 of the 56 counties have doctors or ambulances. Thus, the ability to summon services promptly via a mayday call would substantially mitigate these circumstances.

Another predominantly rural accident scenario is multiple car pileups due to weather-related poor visibility. Accidents involving ice and snow are common, but seasonal, in the Northern and Western Mountain States (Wyoming, Utah, Colorado, Montana). Accidents involving fog are common, but seasonal, in the Eastern States (Virginia, Tennessee, Massachusetts). Accidents involving dust are common, but seasonal, in the desert areas (California, Arizona, Nevada). A hazard-alert network could preempt some of these accidents by properly warning motorists to avoid driving under these conditions. Also, while a mayday transmitter feature in motorists' vehicles would not prevent such accidents, an accident-triggered mayday feature could prevent the catastrophic buildup effects of such accidents.

Table 1. Metropolitan areas by population.[7]

Ponulation	Number of Cities	Population (in millions)	Percent of Total
	19,289	152.9	100.0
1,000,000 or more	8	20.0	13.0
500,000 to 999,999	15	10.1	6.6
250,000 to 499,999	40	14.2	9.3
100,000 to 249,999	131	19.1	12.5
50,000 to 99,999	309	21.2	13.9
25,000 to 49,999	567	20.2	13.0
10,000 to 24,999	1,290	20.3	13.3
Under 10,000	16,929	28.2	18.4

Accidents at railroad grade crossings are relatively infrequent, but are almost always fatal. Only one-fourth of all railroad crossings are fully instrumented with lights and gates.[9] Most crossings are not instrumented due to the high infrastructure costs relative to the probability of an accident. One-third of the accidents are the vehicle striking the locomotive, one-third of the accidents are the locomotive striking the vehicle, and one-third of the accidents are the vehicle striking the freight cars, often near the center of the train. The motorists are interested in the presence of a train at a railroad crossing rather than just the existence of a railroad crossing. Placing an IVSAWS transmitter on each train and having the alert range proportional to train speed should help prevent such accidents. In order to alert only those motorists in the immediate vicinity, the electronic alert zone should have a rectangular shape rather than the circular shape from a simple broadcast approach. Hence, the sophistication of a geolocation system may be required.

HAZARD IDENTIFICATION

The IVSAWS situation identification and prioritization study was performed by the University of Michigan Transportation Research Institute during March 1991. This task identified candidate advisory, safety, and hazard situations using accident data and input from transportation engineering specialists. Sources for this accident data were the Federal General Estimates System and the States of Michigan and Washington. The transportation specialists included representatives from most rural States. These results are summarized in table 2.[10] These situations, requiring increased driver awareness, may be temporary, fixed, or mobile in nature.

Postulated temporary scenarios involve road maintenance, roadway construction, or accident scenes. The fixed scenarios contain elements that lead to repeated or fatal accidents. Examples are unmarked railroad crossings, one-lane bridges, or traffic corridors that repeatedly or seasonally experience low-visibility weather conditions.

Postulated mobile scenarios involve emergency, slow-moving, or wide-load vehicles. Emergency vehicles, such as fire, police, ambulance, and rescue, have the right of way through traffic. However, both congestion and improved automobile sound proofing make it increasingly difficult for emergency vehicles to traverse traffic safely. Motorists approaching slow-moving school buses or farm equipment on sharp turns have reduced response times. Wide loads require increased driver alertness to pass safely.

Table 2. Combined ranking of scenarios.

Application	Value
Train at/approaching crossing	13
Accident site (motorist mayday)	12
Environment-related hazard	11
Moving emergency vehicle	10
Roadway construction zone	10
Accident site (remote activation)	10
School bus or special vehicle	7
Infrastructure hazard	7
Detour advisory	6
Disabled vehicle at roadside	5
Traffic backup (queue detection)	4

DRIVER INTERFACE

The driver alert warning system (DAWS) represents the vehicular subsystem used to convey information concerning advisory, safety, and hazard situations to the driver in a vehicle. The DAWS study, completed in November 1991, used anthropometric analysis and mockups to evaluate the IVSAWS human-machine interface with respect to ease of message perception and correct driver response to messages. Subjects were exposed to hazard pictograms and then were asked to verbalize their understanding and preferences regarding the signaling characteristics. Varying signaling characteristics included (a) monochrome, (b) color, (c) blink, (d) tone, (e) text message, and (f) voice message. As shown in figure 3, the signaling presentation preferred by the group was the combination of color, audio tone, text, and a short voice message. Previous studies have shown that most subjects could not identify the majority of the automotive icons or pictograms in the SAE standard J1048.[11] Thus, a multimodal format was perceived as the most effective presentation method for a safety warning system. All subjects further agreed that IVSAWS would be a substantial aid to the driver.[12]

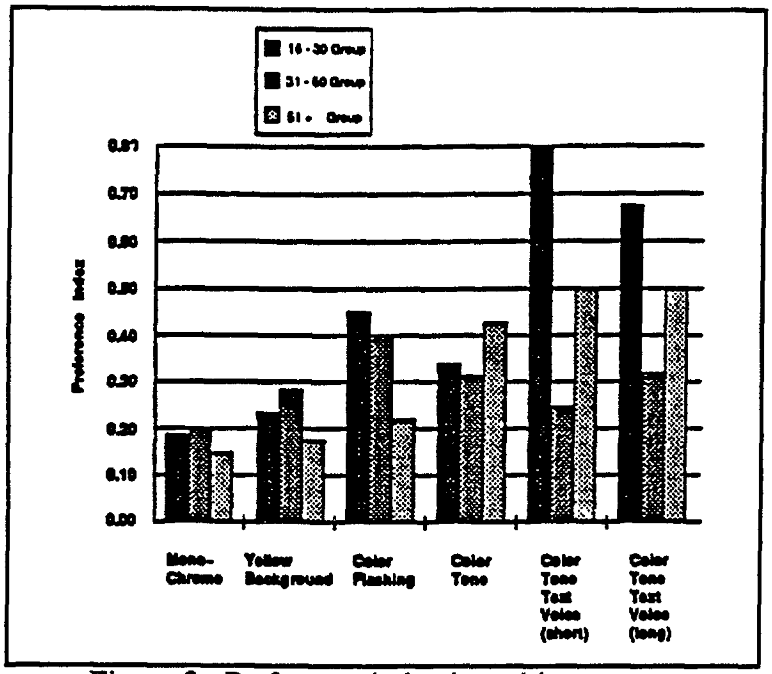

Figure 3. Preference index by subject group.

RANGE CONTROL

The first IVSAWS communication subsystem architecture study was performed during November 1991. The operational concept baseline established at that time was that the warning units would be located at and transmit from each hazard site. The system architecture for this operational concept is independently operated transmission nodes performing local area broadcasts. This study determined that a simple broadcast communications approach, while costing the least, would notify too many inappropriate drivers due to variations in driver alert distances and signal propagation distances.

The proper warning interval for each motorist depends critically on vehicle speed and the intended driver response. These requirements translate into distances from the hazard at which the driver should be notified for maximum effectiveness, as shown in table 3.[10]

The United States has diverse geographical features, such as flat open desert, rolling hills, forested areas, and mountains. An IVSAWS warning unit transmitting from an emergency vehicle with a fixed power level would have radically different propagation distances in these diverse terrains. As shown in figures 4 and 5, representative losses were estimated using the Longley Rice Propagation model from the Environmental Science Service Administration in the Department of Commerce. Worst-case scenarios must be considered for this safety system, yet, link margin then exists whenever terrain geometry or alert distances are not worst case. Any excess link margin translates into more link range, which in a broadcast architecture alone, equates to excess time prior to the hazard that a driver is alerted. If a driver is notified just once, then the driver is likely to forget or, in confusion, perform maneuvers detrimental to other drivers' safety. If a driver is notified repeatedly, then the driver will be irritated and lose confidence in the system.

The variability in driver alert distances and propagation distances necessitates that some form of relative range determination between the warning unit and motorist is required. If relative range information is available, then a processor in the vehicle DAWS can store any received alert and determine the appropriate time to present that alert.

Relative ranges can be obtained using one of three basic methods: (1) range can be derived from round-trip propagation time of spread-spectrum transmissions; (2) range can be derived from differences in position estimates, either in the Global Positioning System (GPS) or in the Position Information Navigation System (PINS); or (3) range can be derived from position messages supplied to vehicles from the infrastructure. In the latter case, IVSAWS must operate from anywhere in the country and this infrastructure does not yet exist. PINS is based on pilot tones from FM broadcast stations and, hence, supports a centralized architecture. Thus, spread-spectrum and GPS were the only viable alternatives.

The benefit of a GPS approach is that only a narrowband, one-way transmission would be required. Also, this approach would permit alerts to be associated with irregularly shaped, variable-sized alert zones. Such zones would permit alerts to pertain selectively to one of two parallel roads. However, this was recognized as more of an urban problem rather than a rural one. At the time, the GPS cost of $1000 per unit was considered too high to justify solely for IVSAWS use. The target price for the invehicle unit is equal to a low-end car stereo system so that drivers will consider this an affordable safety option. Note that since that time, the cost of a GPS unit has more than halved. Also, this cost would be especially reasonable when shared by an integrated IVHS platform. Most vehicle navigation system developers now presume that GPS will be integral to navigation and driver information systems so that cumulative bias errors can be periodically removed from the location and map-matching algorithms.[13]

The benefits of a spread-spectrum approach are its low cost due to mature technology, its superior performance in the presence of co-channel interference, and its inherent support of the vehicle mayday function. The ranging computation algorithm and the waveform to support the ranging process are proven technology from the Position Location Reporting System (PLRS) developed by Hughes Aircraft for the U.S. Marine Corps.[14] Spread-spectrum radios are also commercially available from Proxim, Paramax, and others for under $500.[15,16] This approach's liability is obtaining a Federal Communications Commission (FCC) frequency allocation in the 50-MHz to 500-MHz (possibly to l-GHz) portion of the RF spectrum, which is most useful for mobile communication, yet is extremely congested. As an early IVHS program, IVSAWS efforts pointed out the critical need for the Federal Highway Administration to pursue

Table 3. Driver alert distances.

Vehicle speed (km/h)	Driver Alert Distance - meters			
	Increased Attention	Lane Change	Full Stop Car	Full Stop Heavy Truck
64.4	286.7	366.0	353.8	402.6
80.5	356.8	448.3	472.7	553.5
96.6	430.0	533.7	619.1	732.0
112.7	506.3	622.2	793.0	936.3
128.8	573.4	701.5	960.7	1150.0

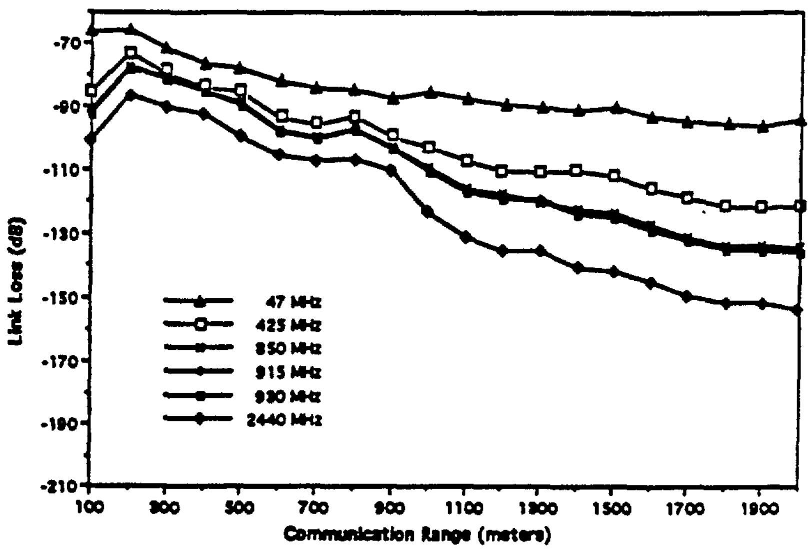

Figure 4. Link losses in flat terrain.

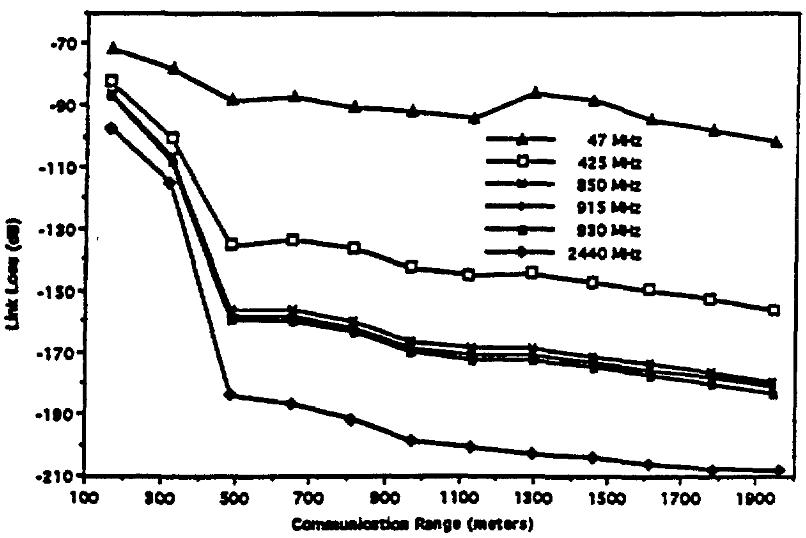

Figure 5. Link losses in heavy foliage.

the IVHS frequency allocation issue from an institutional viewpoint.[17] The 1992 IEEE Vehicular Technology Conference keynote address also asserted that the spectral logjam could halt IVHS development in its tracks. While this spectral issue has been investigated at a Federal level, the IVSAWS program conducted market research.

MARKET ASSESSMENT

Human factors issues are a significant consideration in the IVSAWS design and will significantly affect acceptance or rejection of IVSAWS by the general public and safety professionals. Relevant and timely alerts are ultimately a question of filtering levels within IVSAWS. In a simple system, the driver could be expected to ascertain an alert's pertinence, be responsible for remembering early alerts, or possibly tolerate a repeated alert. In a more complicated system, directionality and relative range are resolved so that alerts are stored and then presented to the driver at the appropriate time. In a very sophisticated system, alerts are associated with irregularly shaped, variably sized zones and motorists are only presented those alerts upon entering the corresponding zone. Similarly, as the system gets more sophisticated for the driver's benefit, the potential operational impact on safety and deployment professionals grows accordingly. IVSAWS provides additional safety by enhancing the real-time interaction between the general public and professional agencies. In order to solicit a broad-based evaluation of the preliminary IVSAWS concept, a market assessment was conducted with each user group.

The engineering studies identified several scenarios that were potential hazards, but required significantly more functional capabilities than other hazard scenarios in order to mitigate the hazard scenario. For example, should traffic queues be detectable? Should warnings discriminate between highways and parallel access roads or between directions on a divided highway? Should the system set up geographic warning zones with specified road information? Should drivers be able to summon help in the event of an accident? Should the vehicle electronics assume an accident has occurred when the airbag is released and automatically summon help or alert other drivers? Is retrofit capability important? These issues are summarized in figure 6. The survey results are summarized in figure 7.

IVSAWS Could Support Other Scenarios With Appropriate System Features For Enhanced Functionality:

- Directionality
- Filtering to Reject Irrelevant Alerts
- Variable Warning Distances
- Queue Detection
- Irregularly Shaped Coverage Areas
- Minimized Workload for Emergency Personnel
- Remote Activation of Warning Units
- Automatic and Manual Motorist's Mayday

Figure 6. Scenario issues.

Most drivers interviewed were interested in the general IVSAWS concept. Most of the interviewees drive alone about 48 km/day during the week. Half of the respondents listen to traffic reports on a regular basis. The survey results indicated that the motorists are ready for IVSAWS now and 75 percent want a system for their current vehicle rather than waiting to purchase one with their next new vehicle. Because this is a safety system, price is not the most important issue. Warning time, warning distance, and false alarms are of greater concern to the general public. A warning of 2 min at speed was the dominant preference. Drivers would not tolerate more than one irrelevant alert per month without losing confidence in the system. Participants generally agreed with the rankings of hazard scenarios about which they would expect to be alerted. Consistent with previous studies, the participants strongly preferred a dual visual and audio alert mode with location maps.[18]

Subjective and Objective Benefits of IVSAWS Relationship to Other IVHS Concepts:

- Long-Range Alerts (2 min at speed)
- Fast Alert Zone Deployment
- Few Irrelevant Alerts
- Compatibility with Current Procedures
- Mayday Capability
- Identify Distance to Hazard
- Compatibility with Current Systems
- Rugged Equipment
- Video Map Display
- Voice Alerts

Figure 7. Customer-requested features.

The personnel from various police, fire, ambulance, and transportation departments were also very interested in IVSAWS. Interestingly, the warning times and distances that the deployment professionals felt that IVSAWS should provide matched the warning times and distances preferred by the general public. These safety professionals were predominantly concerned with near-zero additional workload in emergency situations, such as at an accident scene. Setting up geographic warning zones, even using graphical tools, was “too time-consuming” at these critical moments. All the deployment agencies felt that minimizing operational impact on patrol personnel takes precedent. As such, these agencies preferred a centralized operational concept that is compatible with existing operational procedures. In this concept, warning units are still installed in patrol vehicles for mobile alerts, but detailed messages are now broadcast from a regional operations center. Personnel at the scene provide hazard information to their respective agency’s communication center using standard procedures. These various agency centers would then relay the hazard data to their regional IVSAWS operations center. This IVSAWS center would determine the appropriate warning zone for that hazard and then activate the alert transmissions. This approach also readily supports the need for traveler information services (weather, etc.) in the rural transportation environment. Also, the total mileage of roadways managed under rural agencies strongly favors centralized per capita approaches (e.g., wide-area broadcast) rather than distributed per mile approaches for system architectures.[18]

SYSTEM DESIGN METHODOLOGIES

Because IVHS implementation in the United States will ultimately be funded by consumer purchases, human factors issues are a significant consideration. The initial IVSAWS engineering studies determined that the variability in driver alert distances and signal propagation distances necessitates that some form of relative range determination between the warning unit and motorist is needed so that alerts are not excessively and prematurely given to drivers. A spread-spectrum approach was initially selected because it is compatible with a distributed architecture and a low-cost solution.[10] But, as the subsequent customer surveys showed, a relevant alert capability was far more important than this safety system's cost to motorists. This capability and the other customer-requested features were formalized using a hybrid of two system engineering processes in order to determine a more responsive and cost-effective system architecture.

Quality Function Deployment (QFD) and Structured Requirements Specification (SRS) are two methods to facilitate product planning and ensure that key functions are identified and implemented in a product's design. The process that identified the IVSAWS functional requirements is an adaptation and combination of QFD and SRS.[l9-21]

QFD is initiated with product planning and continues through the product life, including customer support once a product is available in the marketplace. QFD translates customer demands into appropriate technical requirements for each state of a product's development and production .

Under this contract, the key deliverable to FHWA are the functional requirements for a system design that is in sufficient detail to support prototype development. When properly implemented, these functional requirements enable IVSAWS to fulfill its primary objective — to increase the probability of a correct driver response to roadway hazards.

IVSAWS customer requirements were derived during the six functional definition studies. These market assessments are, in effect, the QFD Quality Matrix data analysis. The requirements definition portion of systems engineering are represented as customer demands (Whats) in a QFD Quality.Matrix. The means to satisfy these demands are called quality characteristics (Hows) in a QFD Quality Matrix. In the systems engineering process, this represents translating product requirements into functional specifications. The qualitative part of QFD is identifying customers, their preferences, and potential solutions. The quantitative part of QFD is correlating customer demands with quality characteristics so that resources are allocated to those functional areas that most affect customer needs.

The IVSAWS QFD Quality Matrix yields several major conclusions. From the deployment community's perspective, remote and automatic activation of IVSAWS alert zones should receive strong consideration in order to satisfy stringent law enforcement deployment time requirements. Also, position measurement accuracy for both the alert zone and emergency vehicle location is a critical system parameter. From a motorist's point of view, communication coverage, hazard location measurement accuracy, and vehicle location accuracy are three top system functional parameters.

The QFD charts for performing IVSAWS product definition compare IVSAWS function with respect to customer demands, quality characteristics, and subsystem mechanisms. SRS was used to identify these functional requirements in this QFD tradeoff process for IVSAWS.

The SRS method centerpiece is an integrated requirements model that represents the system according to its information processing and control-state behavior. The process model breaks a system into its component functions, shows the data flow into and out of the functions, and describes how the functions operate on data flow inputs in order to generate data flow outputs. The control model indicates those circumstances under which the component functions identified by the process model are activated.

The process model starts with a data context diagram (DCD) that shows the interaction of a system with its external environment. The DCD is decomposed into a hierarchical set of data flow diagrams (DFD). A DFD contains processes, data flows, and data stores. Data flows are information in any form, ranging in complexity from a single bit to a complete description. Data flows can split or merge, but information is always conserved. Data stores are merely data flows that remain constant until the input data source provides an update. In this hierarchical "parent-child" structure of DFD's, a "parent" process appearing in one DFD is defined by a more detailed DFD consisting of "child" processes, data flows, and data stores.

The SRS process identified eight major IVSAWS functions: (1) secure frequency allocation, (2) define area of coverage, (3) refine zone location, (4) tailor IVSAWS message, (5) generate alert, (6) alert driver, (7) process driver commands, and (8) maintain standards.

Of the eight identified functions, the define area of coverage (AOC) function has the most impact on product reliability. The define AOC function must have sufficient precision to limit alert dissemination to one of two parallel roads spaced 30 m apart or one of two roads intersecting at greater than 30" angles. The define AOC function has the highest correlation with customer demands and quality characteristics. Based on the results of the QFD Quality Matrix, this function deserves 35 percent of the funds associated with IVSAWS infrastructure expenses.

The SRS development for JVSAWS demonstrates that a cost-effective geolocation capability is critical to precisely defining each alert's related area of coverage so that an IVSAWS-equipped vehicle can ascertain its presence in that zone. With such a mechanism, only relevant warnings or alerts are presented to drivers at the appropriate distance from a hazard. Hence, both the general public and safety professionals will have high confidence in IVSAWS.

SYSTEM ARCHITECTURE SELECTIONS

In the IVSAWS initial operational concept, transmitters placed near road hazards or in emergency vehicles provide advanced warnings to approaching vehicles equipped with receiver units. With this additional driver reaction time and distance, the severity of the impending situation could be mitigated. All the warning nodes were viewed as operating independently. Broadcasts were of relatively low power so that only drivers in the immediate vicinity are notified.

The initial engineering studies determined that relative range between a warning unit and an approaching vehicle was necessary so that motorists are notified at an appropriate distance from the hazard. However, the system engineering methodologies demonstrated that relative range by itself was not sufficient to provide expected discrimination so that irrelevant or "false alarms" would not be presented to motorists. Rather, a more feasible concept is that each warning unit at a hazard site or in a mobile emergency has associated with it a specific alert zone area of coverage. This electronic warning zone is defined by a set of navigation coordinates from a supporting geolocation subsystem. The alert zones can be irregularly shaped as needed to guarantee proper notification. For example, zones can be tailored to discriminate between parallel roads; to notify drivers on only one of two non-intersecting roads, such as at an overpass; or to project a narrow, but lengthy, alert area in front of a moving train, A motorist is notified of the alert only if their vehicle is in an alert area of coverage and if their vehicle is at the proper vehicle-to-hazard separation. This geolocation-subsystem enables a motorist's vehicle position to be continually compared with the navigation coordinates of all active alert zones. Also, the vehicle-to-hazard separation is the differences in position measurements of the warning unit and approaching vehicle. Furthermore, a geolocation-based alert zone is fully compatible with the centralized broadcast approaches preferred by the safety professionals. If all alert zones for the temporary and fixed hazards within a given region are broadcast from an operations center, then some form of geolocation system would be necessary to provide the navigation coordinates for a specific area of coverage for each electronic warning zone and then to enable each vehicle to determine whether or not it was present in that alert zone.

The system architecture analysis task examined existing communication and geolocation systems to evaluate which of these available systems could satisfy IVSAWS functional requirements. Deployment-community interviews determined that the operational concept should be centralized alert broadcasts from a regional operations center for the majority of the alert scenarios. Trains and mobile emergency vehicles traversing traffic should still function as independently operated warning nodes within this base station architecture. Market assessments determined that providing only relevant alerts is fundamental to motorist acceptance of IVSAWS. By applying quantitative system engineering methodologies, a geolocation capability was identified as the primary mechanism to provide a precise zone for each alert and, hence, the primary means to prevent irrelevant alerts. Thus, the IVSAWS system architecture must provide for centralized communications, occasionally distributed mobile broadcasts, and precise position location.

The existing communication architectures and systems are numerous. These architectures can be categorized as local area broadcast systems, wide area broadcast systems, backbone systems, and point-to-point systems. Each of the communication architecture candidates listed in table 4 was examined for its frequency allocation, data rate, area of coverage, infrastructure status, costs, system interface, user-defined formats, and error recovery procedures. On the other hand, the existing geolocation systems are relatively few in number , as shown in table 5. These communication and geolocation systems vary considerably in complexity and cost. After examining each of these communication and geolocation architectures for compatibility with the IVSAWS requirements, two combined viable candidates emerged.

SPECIFIC ARCHITECTURE TRADEOFFS

Based on a system architecture analysis, two architectures satisfied the IVSAWS operational requirements. In particular, the two architectures are both compatible with centralized broadcasts from a regional IVSAWS operations center and both use currently available geolocation systems to provide a precise area of coverage for the hazard advisories and alert warnings. For the convenience of further discussion; these two candidates are labeled system architecture numbers one and two, respectively. The Federal Highway Administration will select the final IVSAWS configuration. System architecture tradeoffs are summarized in table 6.

System architecture number one is an IVSAWS-specific design tailored to the narrowband frequency channels in the 220-MHz to 222-MHz band that are currently available nationwide in the United States. Digital alert messages containing geographic coordinates for the alert zones are combined with the Global Positioning System (GPS) geolocation system to provide warnings to motorists when they are within the precise area of coverage. These digital alert messages can be transmitted from either a regional operations center or from mobile emergency vehicles; however, they are primarily transmitted from the regional operations center. As an IVSAWS-specific design, the message catalog and waveform are optimized for performance with IVSAWS scenarios. A powerful convolutional error correction code is included in the waveform

Table 4. Functional characteristics of the communication architecture candidates.

SELECTED ARCH	TECHNOLOGY	COVERAGE	INFRASTRUCTURE IN PLACE	FREQUENCY ALLOCATION	END-USER COST	INTANGIBLES
	LPHAR	to 0.5 km	No	N/A	None	Driver Alert
1	220-222 MHz	to 322 km	No	IVHS License	Low	Mobile Alert Zones
	HAR	to 3.2 km	No	TIS License	None	Driver Actions
2	RBDS/SCA	Regional	Qualified	Lease/Own	Low	Own FM Freq.
	SAP	Regional	Qualified	Lease	Low	Uncertain Future
	T-Net	Regional	Qualified	Lease	Low	Uncertain Future
	Analog Cellular	Urban: 3-22 km	Urban	Lease	Very High	Saturation
	Iridium	National: 599 km	Future - 1997	Lease	Very High	Wrong Application
	Impulse	to 16 km	No	TBD	Very High	Uncertain Future
	Packet-Data WAN	Urban: 3-32 km	Some Urban	Lease	Very High	Saturation
	Trunk Radio	Urban: 3-32 km	Urban	Lease/License	Very High	Saturation
	Shared Channel	Urban: 3-32 km	Some Urban	Lease/License	Very High	Saturation
	Microwave	to 48 km	No	Lease/License	Very High	Wrong Application

Table 5. Functional characteristics of the geolocation architecture candidates.

SELECTED ARCH	TECHNOLOGY	COVERAGE	INFRASTRUCTURE IN PLACE	ACCURACY	END-USER COST	INTANGIBLES
1	GPS	Worldwide	Yes	15 m	High	Differential
2	PINS	National	Qualified	15 m	Low	Simplicity
	LORAN-C	Worldwide	Yes	402 m	Very High	Air/Sea Nav

for link robustness and the network architecture incorporates mobile alerts from emergency vehicles and mayday broadcasts from motorists into the overall process.

System architecture number two is the Radio Broadcast Data System (RBDS) with GPS or the Position Information Navigation System (PINS). RBDS is an Intelligent Vehicle-Highway System motorist's information standard originally developed in Europe and since adopted for use in the United States. RBDS modulates digital data onto subcarriers of an FM radio station's transmission for co-transmission of digital data. Again, digital alert messages containing geographic coordinates for the alert zones can be combined with the geolocation system to provide warnings to motorists when they are within the precise area of coverage. As a standard, RBDS includes its own message catalog and waveform. The message catalog is sufficiently large that RBDS can be adopted for use in IVSAWS. However, transmissions by emergency vehicles or locomotives, or motorists in the FM radio band are not authorized, so an RBDS-based approach will not support IVSAWS mobile alert zones at this time.

System architecture number one, with its narrowband channel and GPS approach, alleviates the IVHS frequency congestion issue by obtaining sole use of several nationwide channels recently made available in the 220-MHz to 222-MHz frequency band.1221 Originally, this band was primarily used for Government radar and secondarily used for amateur radio. As part of the agreement that transferred this band from the National Telecommunications and Information Administration to the Federal Communications Commission (FCC), 10 pairs of 5-kHz channels would be reserved for the Federal Government. Rather than imposing a common modulation and signal standard within this band, FCC allowed varied narrowband modulations provided that they conformed to an RF emissions mask. The United Postal Service (UPS) has successfully implemented a half-duplex land mobile and full-duplex base station digital radio network to provide status on package pickups and delivery.1231 The UPS system uses multilevel FM

Table 6 - System architecture comparisons

	220-Mhz to 222 Mhz (System Architecture Number One)	Radio Broadcast Data System (System Architecture Number Two)
Advantages	- Mobile Alert Zones Supported - Safety Asset Controlled by Govt - Map Matching Not Required - Coordinated Base Station Broadcast - Robust Communication Waveform - Portable to Other Narrowband Channels	- No Frequency Allocation Required - Standardized Waveform - Urban Transmitter Infrastructure Exists - Receivers in Production - Good Retrofit Capability
Disadvantages	- Frequency Allocation Required - Retrofit Capability - Infrastructure Cost (No Transmitters in Place)	- Mobile Alert Zones Not Supported - Corporate Control of Safety Asset - Low Message Throughput if Few Stations Support RBDS or Other Services Consume Bandwidth

at nominally 4,000 bits/s with 100-W transmissions. In field tests, the UPS system has demonstrated excellent performance up to 105 km from the base station, thereby indicating the viability of this land mobile channel for IVSAWS application.

The coverage of the base stations transmissions will have a significant impact on IVSAWS infrastructure costs. For example, over flat terrain, extending the communication range by a factor of 2.5 will reduce the required base station density by a factor of 7. In the 220-MHz to 222-MHz band, effective radiated power for the base station is limited to 500 W for antenna heights up to 150 m above average terrain. However, since IVSAWS will operate without co-channel users, exemptions to the restrictions are anticipated provided that out-of-band emissions are not exceeded.

This narrowband channel with GPS approach has an IVSAWS-specific network architecture and waveform. The network is organized around l-s frames. Each frame contains three time slots. Each time slot contains allocations for 5 alerts, each 405 bits in duration. Each alert message has 5 guard bits, 6 ramp bits, 29 sync bits, 167 data bits, and 16 error detection bits. Data and error detection bits are protected by a half-rate, constraint length, seven convolutional error correction code. This digital data is modulated using a p/4-shifted, differentially encoded quadrature phase shift keying at a 6,075-bits/s rate. The combination of this modulation and error correction code requires only a 4.7-dB signal-to-noise ratio to demodulate a signal with a 10^{-5} bit error rate

(BER). The convolutional code provides 5 dB of coding gain at this 10^{-5} input BER. Similarly, the 16 bits of error detection reduce the probability of accepting an erroneous message to 1.5 • 10-5. Square root raised cosine filtering is used to meet the FCC emissions mask.

System architecture number two, based on RBDS with GPS or PINS, has a network architecture and waveform designed to be compatible and inaudible in monophonic and stereophonic FM radio programs. RBDS is organized by a predefined message catalog with 15 different group categories, such as navigation information and radio paging. About 11 groups are transmitted each second. Each group contains four blocks. Each block contains a 16-bit information word and 10 bits of error protection. This forward error correction is a Kasami burst error code. These data are bi-phase amplitude-modulated onto a 57-kHz subcarrier with an on-the-air rate of 1187.5 bits/s. The resulting usable information rate is 730 bits/s. Most groups can be sent in arbitrarily, but a few have minimum repetition rates so that execution of main applications are problem-free.

RBDS alleviates the IVHS frequency congestion issue by sharing the frequency channel with existing FM radio stations.[24] The Federal Highway Administration is studying this generic approach for data dissemination in other driver services as well.[25] This frequency may not be just one nationwide allocation, but a series of frequencies across the United States all in the FM radio band. The radius of the coverage area depends on the transmitter power of each individual station selected. Such stations are readily available in urban and suburban areas, but coverage is spotty in some rural areas. Since most FM radio stations are under corporate control, licensing and contracting for this safety asset will proceed on a station-by-station basis.

For geolocation reference, RBDS divides the continent into grid with a given resolution (1/R) expressed as a fraction of a degree. Resolution varies from l/2 to l/5. At l/5° latitude and longitude resolution, the grid rectangles are roughly 22.5 km by 14.5 to 20.9 km each, depending on the latitude. Obviously, depending on the host FM station's transmitter power, an RBDS station services many grids.

CONCLUSIONS

The Invehicle Safety Advisory and Warning System is a Federal Highway Administration program to develop a nationwide vehicular information system that provides drivers with advance, supplemental notification of dangerous road conditions using electronic warning zones with precise areas of coverage. The goal is to ameliorate the severity of scenarios that are hazardous and have remained hazardous despite the application of traditional crash-reduction techniques. IVSAWS provides increased safety by enhancing the real-time interaction between the general driving public and safety professionals. Extensive market investigation with these two user groups revealed that while they both liked the IVSAWS concept, safety professionals wanted maximum compatibility with existing procedures and motorists were concerned with avoiding false alarms. Hence, the operational concept was changed to centralized broadcasts from a regional IVSAWS operations center. System design methodologies showed that an electronic warning zone with a specific area of coverage is the proper means to guarantee relevant alerts. Furthermore, a geolocation capability is a cost-effective means for implementing these electronic warning zones. Based on system architecture analysis, two candidates are compatible with centralized broadcasts from a regional IVSAWS operations center and use available geolocation systems to provide precise area of coverage for hazard advisories and warnings. Regardless of the final choice, land navigation has a vital role within IVSAWS.

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