TRANSPORTATION RESEARCH BOARD
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IDEA *Innovations Deserving Exploratory Analysis Program*

INTELLIGENT VEHICLE-HIGHWAY SYSTEMS

Emerging Concepts and Products for Intelligent Transportation Systems

Progress Report 1
September 1994

IVHS-IDEA ADVISORY COMMITTEE

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAM

INTELLIGENT VEHICLE-HIGHWAY SYSTEMS (IVHS)

EMERGING CONCEPTS AND PRODUCTS FOR INTELLIGENT TRANSPORTATION SYSTEMS

IVHS-IDEA
PROGRESS REPORT 1
FIRST PROGRAM YEAR

SEPTEMBER 1994

IDEA PROGRAM
TRANSPORTATION RESEARCH BOARD/NATIONAL RESEARCH COUNCIL

Intelligent Vehicle-Highway Systems (IVHS)
Innovations Deserving Exploratory Analysis (IDEA) Program
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PREFACE

This report presents a summary of technical projects initiated during the first year of the Innovations Deserving Exploratory Analysis (IDEA) program for Intelligent Vehicle-Highway Systems (IVHS) The IVHS-IDEA program is jointly supported by the Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA). IVHS-IDEA is managed by the National Research Council's Transportation Research Board (TRB) as part of a broader program that includes highway systems (NCHRP-IDEA) and transit systems (Transit-IDEA).

The IVHS-IDEA program fosters functional discoveries that would provide radically different and new approaches to intelligent transportation systems. The program focuses on new methods, technologies, processes, and systems for application to IVHS. The IDEA program is open to all individuals within the technical community, including entrepreneurs, small and large businesses, and institutions from the United States and abroad.

The products and results from the IVHS-IDEA program match the emerging needs in key functional areas for IVHS application:

- All IDEA concepts offer the potential for advancing the state of the art of IVHS. Several IDEA projects investigate technically credible but unproven concepts that offer the potential for significant breakthroughs and large payoffs for IVHS.
- A few IDEA projects relate to advanced methods or processes that have been developed for other applications but are not yet tested or available to IVHS and include conversion technologies from the defense and aerospace industries.
- IDEA products and results represent a range of new developments for IVHS in several technical areas, including automated lane control and warning systems, automated safety and collision avoidance systems, intelligent traffic management systems, advanced communication systems, human factors application to IVHS, intelligent ridesharing and carpooling, and advanced vehicle identification and classification systems. A few IDEA project results offer the potential for application to IVHS field operations.

Two types of IVHS-IDEA projects are presented in this report. Type 1 projects evaluate the feasibility of new and unproven concepts for potential application to intelligent transportation systems. The projects are generally funded in the range of $30,000 to $100,000 and are completed within a year. Type 2 projects focus on applied testing and evaluation of new products or results for intelligent transportation systems. The goal of Type 2 projects is to test proven concepts and transfer existing engineering products and conversion technologies that have not yet been tested or applied to IVHS. A large number of IVHS-IDEA projects are cost-shared by proposers or by users of potential IDEA products.

Technical expert panels appointed by TRB evaluate all proposals and recommend IDEA awards for approval by the IVHS-IDEA Advisory Committee. The advisory committee approves all IDEA project actions and provides advice to the U.S. Department of Transportation and TRB on the IVHS-IDEA program. A list of technical experts appointed by TRB to serve on technical expert panels and a list of the members of the IVHS-IDEA Advisory Committee are included in the report.

A national expert is elected by the expert panels and by the IDEA program to serve as a voluntary IDEA project advisor on each IDEA project. IDEA project advisor is identified in each project report. The project advisor provides the key linkage for transferring IDEA project results and products to IVHS practice and to the IVHS National Program.

The progress report presents IDEA project results in the order in which they were awarded during the first program year. The projects presented in this report were approved by the advisory committee and processed in two award cycles during the first program year. Several projects presented in the report from the second cycle of awards are at initial stages of commencing project activities. Some IDEA projects cover more than one IVHS technical discipline. The report also contains a listing of projects grouped in various technical areas for IVHS.

The success of the IDEA program relies heavily on the effectiveness with which results and products are made available for application to intelligent transportation systems. Evaluation of new concepts and exploratory testing of products may not by themselves ensure application or implementation of project results and products. The progress report on emerging IDEA products and concepts is prepared to familiarize transportation planners and IVHS practitioners with the results emerging from the IDEA program. A tentative implementation plan on each IDEA project is included in the report.

The IDEA program, project investigators, and project advisors will be working together to achieve the application of IDEA program results and products to the intelligent transportation systems practice.

The IDEA program welcomes any comments, suggestions or recommendations on emerging IDEA products, results, and implementation plans presented in this report.

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'IDEA expert panel members are appointed by the Transportation Research Board for evaluating IDEA proposals and technical program areas for IVHS-IDEA. The number and composition of panels selected for evaluating IDEA proposals vary based on the technical mix of the proposals. Additional members will be nominated to the current pool of experts during the second program year.

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COLLISION AVOIDANCE AND IMPROVED TRAFFIC FLOW USING VEHICLETO-VEHICLE COMMUNICATION

JYHS-IDEA Project 1[1]

Bernard A. Galler,[2] *and Harry J. Asher*[3]
University ***of*** *Michigan, Ann Arbor*

IDEA PRODUCT

Vehicle-to-vehicle communications and an on-board processing system will be developed that (1) provide prediction and driver warning of potential intervehicular collisions and (2) increase roadway throughput and smooth traffic flow by providing deceleration and lane change advice to drivers.

The impact of the proposed IDEA concept is potentially large. Some 20% of all accidents are rear-end collisions. Such accidents result in substantial loss of life and significant cost in the form of delay and property loss. Researchers have stated that 60% of all rear-end collisions could be avoided if the driver were given an additional one-half second of warning before an incident. The IDEA project addresses this issue by providing advanced collision warning.

CONCEPT AND INNOVATION

The approach taken in this project is unique in that the proposed warning system allows vehicles to operate independently, without the level of vehicle control associated with platooning and with the ability to use data from several vehicles ahead, unlike the two-vehicle interaction systems (such as distance warning systems) that have focused on the interaction between the driver's vehicle and the vehicle immediately ahead without regard for other vehicles. In this project, an intermediate level of communication will be shared between nearby vehicles. This is short of platooning and avoids some of the problems of platoon-type systems, but it goes beyond two-vehicle interaction systems by considering data from multiple vehicles in the local area. In addition, the project will explore the use of the data communicated between vehicles to provide lane selection advice to the driver.

IDEA PROJECT INVESTIGATION AND PROGRESS

The basic premise of this work is that congestion, delay, accidents, and other associated problems are often a result of the typical driver's inability to correctly assess the current and impeding driving situations. The driver has incomplete information about the speed, acceleration, position, etc. of other vehicles, especially vehicles occluded by intervening vehicles, and virtually no information regarding the intentions or desires of other drivers (i.e. desired speed, route, etc.). Thus drivers are forced to make basic operating decisions such as when to brake, what speed to maintain, and which lane to **be in** based on incomplete information.

Each vehicle in the system will be equipped with communications devices and an on-board computer. As each vehicle travels along the roadway it continuously broadcasts speed, position, and acceleration data to other nearby vehicles. Any known driver constraints are also communicated, such as desired speed set by the driver on the cruise control. The communication system would most likely utilize spread spectrum techniques, largely due to their ability to provide multiple access to the same frequency via code division multiple access (CDMA), and their low interference to other communications systems. As the information is obtained from other vehicles in the local area, the software in the on-board computer will build and update its model of the local environment. This model is more complete than the driver's **model** because of the driver's limited information and limited ability to accurately interpret the information that is available. The system to be developed will utilize the computed model to advise the driver of a recommended action.

Since each vehicle's computer will have knowledge of information such as the position, velocity, and acceleration

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[1]The IDEA project started December 1993 and will be completed by December 1994. IDEA project advisor: Anthony Hitchcock, Consultant/UK.

[2]Professor, Electrical Engineering and Computer Science Department, University of Michigan.

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of nearby vehicles, the amount of deceleration, if any, required to avoid a collision with the vehicle directly ahead can be determined. This would help in avoiding common rear-end and multiple-car collisions as well as those caused by severe weather conditions such as fog or by inoperable tail lights. To this end, an algorithm has been developed which yields the deceleration required by a vehicle in order to avoid a collision with the vehicle immediately ahead. It takes into account the fact that the vehicle ahead may itself be taking action to avoid a collision with the vehicle ahead of it, and so on. The algorithm developed yields a (constant) deceleration value that the trailing vehicle must employ to avoid a collision and takes into consideration the human reaction time of the drivers involved. The algorithm utilizes more complete data, and thus provides a more accurate evaluation of the required deceleration than previous distance warning systems.

Assuming that the driver of the trailing vehicle reacts to the warning prior to an impact and that the vehicle has sufficient braking ability, any potential impact can be avoided. The minimum deceleration required to avoid collision will be determined.

In the simple case where only a pair of vehicles will be considered, some behavior on the part of the lead vehicle, possibly worst case behavior, will determine the deceleration required by the trailing vehicle. This is the basic strategy used in previously proposed distance warning systems.

The problem becomes more complex when data from several vehicles ahead are considered. The algorithm developed calculates the deceleration required by vehicle V,, utilizing data from vehicles V_2 through V_n ahead. These are the vehicles ahead of V,, in the same lane, and within Vi's communication range. The algorithm, as in the two-vehicle case, makes an assumption about the behavior of the n^{th} vehicle, and then calculates the expected response of vehicle $V_{n-1'}$ to vehicle V,. The algorithm recursively calculates the expected response of vehicle V_{n-2} to vehicle V_{n-1}, and the response of vehicle 3 to vehicle $V_{n-2'}$ and so on, until the required response for vehicle V, is determined.

The in-vehicle warning system device can then be set to indicate the required deceleration, if any. A possible implementation would involve using a series of lights to reflect the severity of the deceleration required, between some adjustable nominal value,a nd the maximum possible deceleration for the vehicle. This procedure is repeated often, for example very lOms., and the on-board warning state is changed appropriately. Each vehicle in the system does similar processing using the (most likely different) data that it receives from nearby vehicles.

The project will evaluate the potential impact to the system using computer simulation. This simulation however will be based on actual highway data collected by the FHWA. The data used is comprised of two days of traffic data collected on Interstate-40 in New Mexico. Each set of data contains the velocity and headways for approximately 30,000 actual vehicles. For a given group of vehicles in this set, we assume random reaction times for each driver in the group, as well as maximum deceleration rates for each vehicle, vehicle size, etc. each drawn from an appropriate distribution. To study the impact of the proposed system, an incident will be generated by assuming a more or less severe deceleration for a given vehicle in a chain of vehicles. IDEA results will establish the degree to which the system is effective for reducing the number of collisions, the impact of collisions which do occur, and the necessary braking power needed to avoid a collision. Among the possible variables to consider are the communication range of the vehicles involved, the number of vehicles ahead from which to consider data, variation in driver reaction times from the expected value, communication rate, and incident severity.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

As part of the IDEA investigation design specifications for an operational test will be developed. An actual operational field test will be proposed after successful development of the IDEA product.

MODELS FOR REAL-TIME INCIDENT PREDICTION

IVHS-IDEA Project 2'

Samer Madanat[2] and Pen-Chi Liu[3]
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IDEA PRODUCT

This IDEA project produces a freeway incident likelihood prediction simulator. The central parts of this simulator are incident likelihood prediction models. The simulator's inputs are (1) freeway geometric characteristics such as section length and ramp locations; (2) segment-wide conditions such as temperature, rain, visibility, and time of day; and (3) section-specific conditions such as traffic volume, speed, speed variance, and truck percentage. The simulator's outputs are the time-varying likelihoods of traffic incidents for all freeway sections for the specified simulation time period.

CONCEPT AND INNOVATION

Predictive models that can be used to provide real-time predictions of freeway incident likelihoods will be developed. The models will serve as the basis for a proactive, corridor-wide traffic control system. In such a system, traffic stream and environmental conditions measured by surveillance sensors would be used as inputs for predicting incident likelihoods in near real-time. Traffic control strategies can thus be immediately implemented to reduce the probability of an incident as well as to mitigate incident-related problems, if incidents do occur.

IDEA PROJECT INVESTIGATION AND PROGRESS

To prove the feasibility of this concept, it is essential to demonstrate the possibility of accurate predictions of freeway incident probabilities, based on near real-time measurements of traffic and weather variables. Models for likelihood prediction of two critical types of freeway incidents have been, crashes and overheating vehicles, have been successfully developed. These models capture the influence of various traffic and weather factors. Both models have high internal and external validity, as demonstrated by their tit to the data and their predictive accuracy, respectively.

Eight-and-a-half months of incident, traffic and weather data for the Borman expressway in Northwest Indiana were used for model development. Samples were made from non-incident data from the non-incident population which comprised those time periods in which no incidents were observed.

A stratified random sample with two strata, incidents and non-incidents were obtained because the outputs of the incident prediction models are probabilities of a binary event, an appropriate methodology to use is binary logit. Examples on two binary logit incident prediction models shown for the following types of incidents: (1) overheating vehicles, and (2) crashes.

For the overheating vehicle incident likelihood model, the variables *peak*, *merge*, *temp* (temperature) *rain*, and *spv* (speed variance) were found significant (see Table 1). The coefficient for the variable *peak* has a positive sign, which suggests that an overheating vehicle incident is more likely to occur in a peak period than a non-peak period which is expected because traveling speeds are slower during peak period. This variable is not significant at the 90% confidence level, as can be seen by the low value of its t-statistic (1.625), possibly because the peak period on the Borman expressway is widely spread out. The coefficient of the variable *merge* represents the effect of location relative to on/off ramps on the likelihood of an overheating vehicle incident. The positive sign of this coefficient indicates that an overheating vehicle incident is more likely to occur in a merge section than a

'The IDEA project started January 1994 and will be completed by December 1995. IDEA project advisor: Steve Richards, University of Tennessee.

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TABLE 1 Incident Likelihood Model for Overheating Vehicles

Independent Variable	Estimated Coefficient	t-Statistic
constant	-2.45269	-5.25041
peak	0.40010	1.62515
merge	0.51087	2.19683
temp	0.03228	4.63282
rain	-1.06644	-2.29946
SPV	-0.05907	-2.37734
number of observations	427	
percent correctly predicted	73.536	
p^2=0.215		

mid-section. The **value** of the t-statistic (2.197) suggests that this effect is significant. The coefficient of the variable *temp* shows the effect of temperature on the likelihood of an overheating vehicle incident. The positive sign suggests that an overheating vehicle incident is more likely to occur in high temperature conditions than low temperature conditions, because high temperatures aggravate engine overheating, The high t-statistic (4.633) strongly supports this explanation. The coefficient of the variable *rain* has a negative sign which indicates that an overheating vehicle incident is more likely to occur in dry (non-rainy) conditions than in rainy conditions. The t-statistic (-2.299) shows a significant effect for the variable *rain*. The coefficient of the variable *spv* represents the effect of speed variance between lanes on the likelihood of an overheating vehicle incident. The negative sign means that an overheating vehicle incident is more likely to occur in lower speed variance conditions than higher speed variance conditions. This is because when the speed variance is low, there are less overtaking opportunities, which increases the likelihood of an overheating vehicle incident. The t-statistic (-2.377) suggests that this result is significant. Overall, this model demonstrates good fit to the data, as can be seen from the value of p^2 (0.215), and high predictive accuracy, as measured by the high percentage of observations correctly predicted (74%).

For the crash model, the variables *merge*, *visi* (visibility), and *rain* are found significant (see Table 2). The coefficient of the variable *merge* has a positive sign, which suggests that a crash is more likely to occur in a merge section than a non-merge section. Though the t-statistic (1.462) indicates that this variable is not strongly significant at the 90% confidence level, it has the correct sign, because there are more vehicle interactions and therefore a higher crash probability in the merge sections, where traffic flow is not as smooth as in the mid-sections. The coefficient of the variable *visi* has a negative sign, which indicates that a crash is more likely to occur in low visibility conditions, as expected. This variable is not strongly significant, as can be seen by its t-statistic (-1.020) possibly because, in our data set, visibility is measured in miles, a unit which is not sufficiently precise to capture the effect of low visibility on drivers. The coefficient of the variable *rain* has a positive sign, which means that a crash is more likely to occur in rainy conditions than non-rainy conditions. This is because the presence of rain reduces visibility and lowers pavement skid resistance. The high t-statistic (3.451) supports this explanation. The fit of this model is satisfactory, as shown by its p^2 value (0.140), as is its predictive accuracy (71% of observations correctly predicted).

TABLE 2 Incident Likelihood Model for Crashes

Independent Variable	Estimated Coefficient	t-Statistic
constant	-0.76655	-2.23940
merge	0.31452	1.46231
visi	*-0.02779*	-1.02077
rain	1.48747	3.45081
number of observations	434	
percent correctly predicted	71.198	
p^2=0.140		

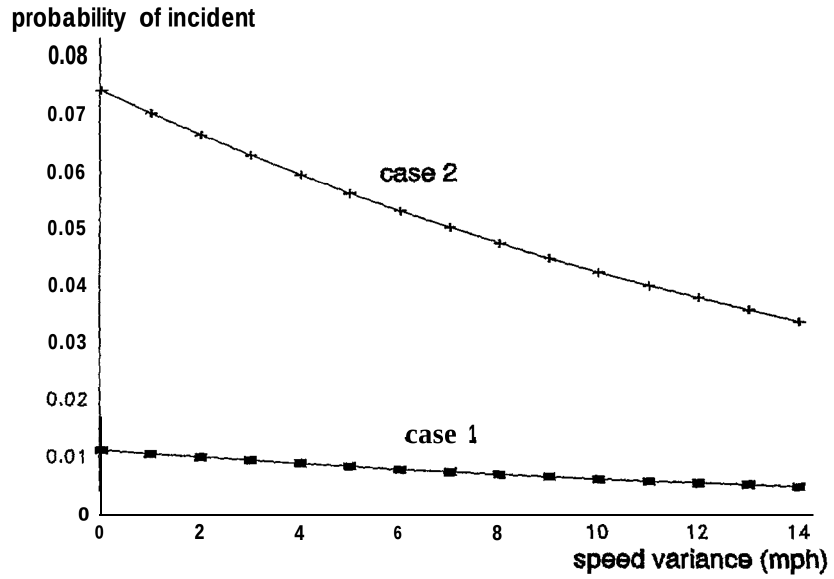

FIGURE 1 Effect of speed variance on the probability of an "overheating vehicle" incident.

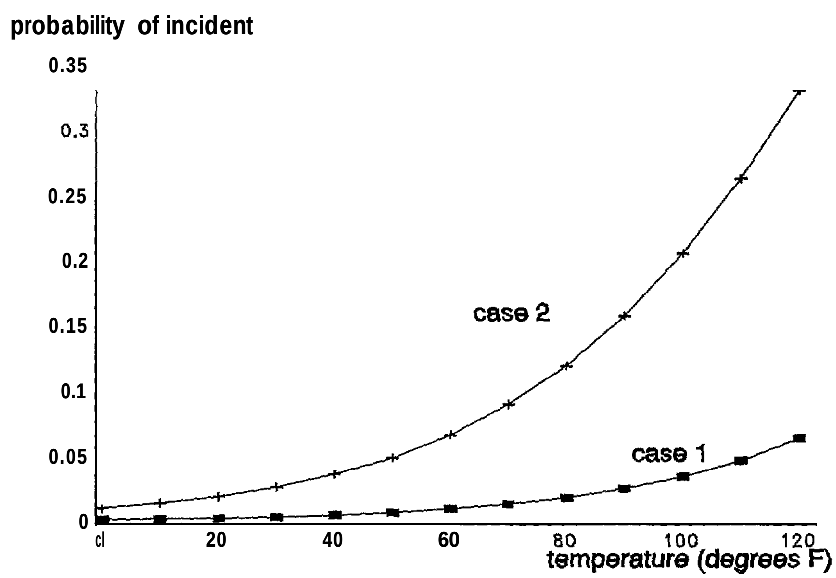

FIGURE 2 Effect of temperature on the probability of an "overheating vehicle" incident.

The effects of temperature and speed variance on the likelihood of an overheating vehicle incident are shown in Figures 1 and 2. In these figures, Case I represents a mid-section of the freeway during an off-peak hour on a rainy day. Case 2 represents a merging section during a peak hour on a dry day. As can be seen in these figures, an overheating vehicle is more likely to occur in peak hours, merge sections and dry conditions than in off-peak periods, mid-sections and rainy conditions. Moreover, the figures show that the lower the speed variance and the higher the temperature, the higher the likelihood of an overheating vehicle incident. It should be noted that the estimated coefficients in these models are unbiased regardless of the use of a stratified random sampling scheme in which incidents are over sampled. The only correction that must be made to account for the non-random nature of the sample is for the constant. The effect of this correction is to reduce the probability of an incident by a factor proportional to the log of the fraction of incident observations in the sample divided by the fraction of incident observations in the population. The predicted incident probabilities shown in Figures 1 and 2 are the corrected incident probabilities.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

The IDEA product can be used for simulation testing of the incident likelihood prediction models. The effectiveness of incident response, route diversion, and ramp metering control strategies that account for the availability of incident prediction can be evaluated using this simulator. The incident likelihood prediction models will eventually be incorporated in the Borman Expressway Advanced Traffic Management System, in conjunction with the traffic surveillance devices that are currently being deployed by the Indiana Department of Transportation. After implementation, the models will be updated using observations of incidents, traffic characteristics, and environmental variables taken by the Borman Expressway surveillance system. This will guarantee that the predictive accuracy of these models is continuously improved.

IMPROVED METROPOLITAN AREA TRANSPORTATION SYSTEM (IMATS); CARPOOLING AND COMPUTERIZED VEHICLE DISPATCHING IN ASSOCIATION WITH A VEHICLE RENTAL SYSTEM

JYHS-IDEA Project 3'

John Chisholm, C.F. International Incorporated, Verdi, Nevada; Rick Brown,' John Kleppe,[3] and Edwin Berry,[4] University of Nevada, Reno

IDEA PRODUCT

This project is focused on reversing the trend toward single-occupant automobile (SOA) use by attracting SOA users to multiple-occupant vehicles (MOVs). Initial emphasis is on carpools. Currently SOA use represents about 75% of vehicles used in transportation practice. The share of MOVs has declined from about 20 % in 1980 to about 13 % in 1990. Reversing this trend could achieve several billion dollars in annual auto-related transportation savings with an attendant reduction in congestion and pollution.

CONCEPT AND INNOVATION

SOA use is the dominant mode of urban transportation because it provides convenient and flexible door-to-door transportation at an affordable cost. To compete with SOA use, carpools must provide equivalent or superior service at lower cost.

To achieve this goal, this IDEA project will test a concept of centralized dispatching and integrated use of two transportation elements: the Multiple Occupant Commuting Taxi (MOCT) and the Instant Rent-a-Car (IRC). MOCT is the carpooling element that schedules use hours, or minutes, in advance (Figure 1). IRAC is a compact auto that is rented where found and left where convenient. IRAC supplements MOCT in that it can be used

- To initiate or complete a MOCT trip,
- For local area transportation for MOCT and transit users, and
- For the commute when most appropriate.

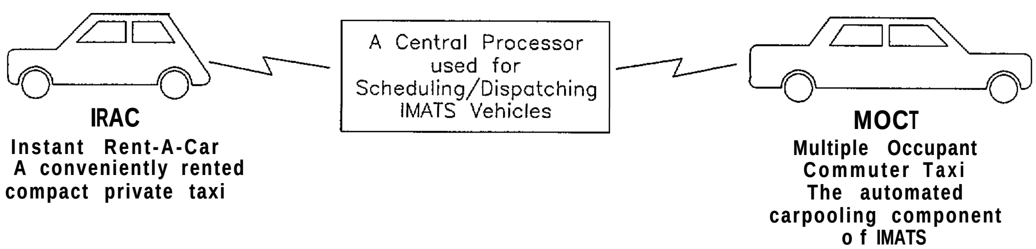

FIGURE 1 IMATS urban transportation concept.

'The IDEA project started December 1993 and will be completed by November 1994. IDEA project advisor: Ron Fisher, FTA.

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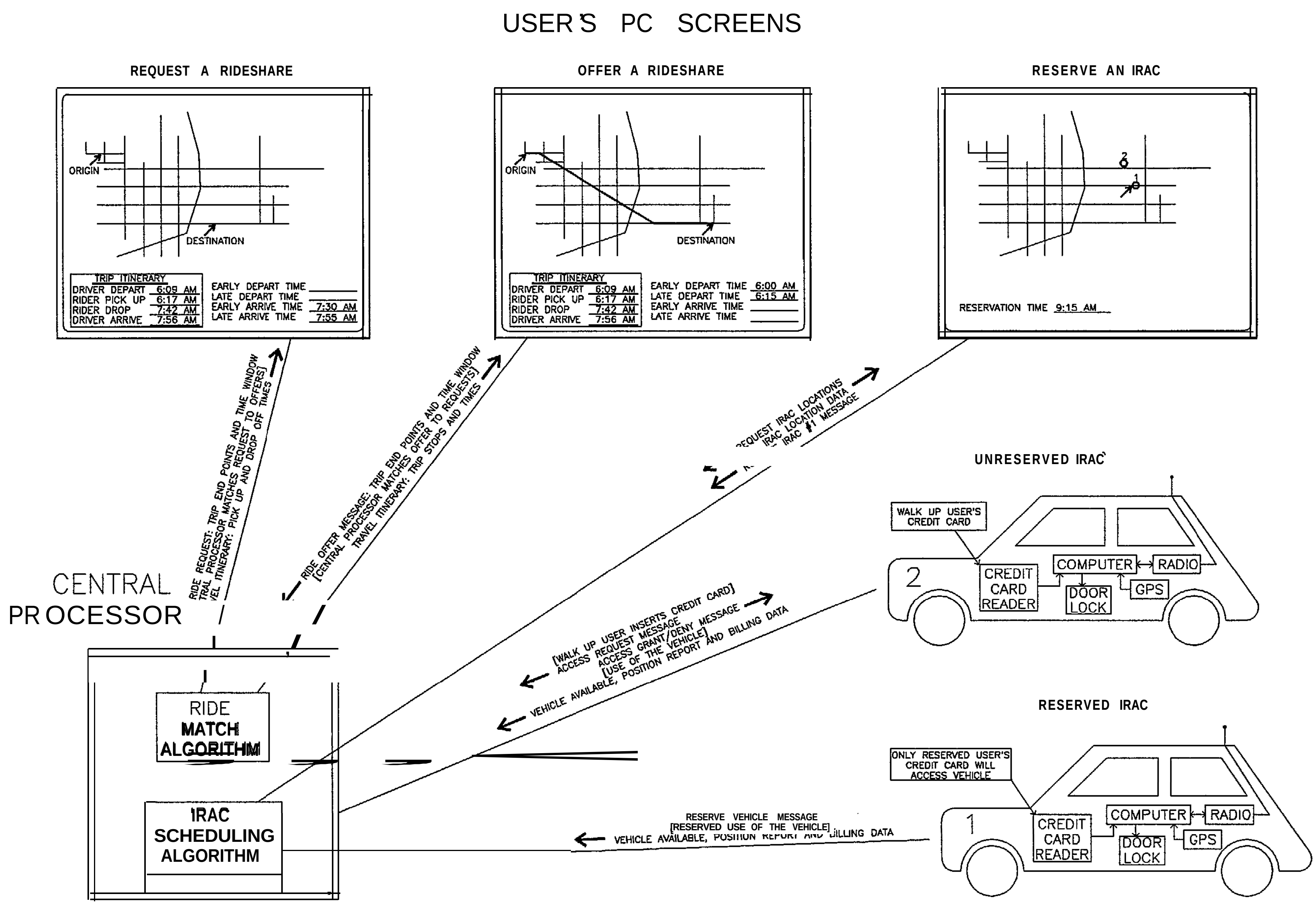

FIGURE 2 TRB IVHS-3 concept demonstration configuration.

IDEA PROJECT INVESTIGATION AND PROGRESS

The overall project is envisioned to consist of several steps. The IDEA project has achieved the demonstration of the system shown in Figure 2.

Figure 2 depicts a central processor (CP), which users access by a residential or office PC (Personal computer). PCs are employed since a first IMATS implementation will involve University of Nevada, Reno (UNR) faculty, students and staff with ready access to such PCs.

The user requests either IRAC or MOCT Transportation. If IRAC is requested the user PC displays the location of nearby IRAC vehicles. The user can reserve a particular vehicle, (1) of Figure 2, via use of the PC graphical pointer. Charges commence against the user's CC (credit card) at that time. The reserved vehicle is accessed via the insertion of only that specific CC into a vehicle receptacle where it is read by an in-vehicle processor. At the termination of any trip the in-vehicle GPS (Global Positioning System) location data is relayed to the CP to establish vehicle location for the next potential user. Also at this time, the previous user's CC is billed for both reservation time and vehicle usage. Unreserved IRAC vehicles (2) can be accessed and used via insertion of any valid CC. The credit card data is relayed via radio to the central processor and if valid, a message is sent back to unlock the vehicle.

The above IRAC Concept Demonstration has been conducted for various groups. A Geo Metro automobile, Trimble GPS, Cellular One Radio Telephone, etc. have been employed in such hardware/software efforts.

If MOCT is requested the user enters travel origination and destination, time windows associated with the trip and desire to be a driver or passenger (or either).

The CP, with knowledge of the requests for and the availability of MOCT services, informs the potential user within minutes or seconds, whether suitable MOCT transportation can be provided and if so exact scheduling.

The MOCT Concept Demonstration is conducted using the same CP used for IRAC. It employs random trips generated from the Reno area Census Bureau geographical distribution of population.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

After successful evaluation of the IDEA project, the IMATS concept will be tested in competing and cooperative operational efforts, one at UNR and one at a California location followed by wide-scale profit-oriented programs operated by taxicab or rental car Companies.

One reason for a parallel Phase 3 effort in California has to do with the California 1998 Zero Emission Vehicle (ZEV) mandate. This mandate states that by 1998 2% (~ 30,000) of the autos sold in California must be ZEVs. The only current ZEV candidate is the electric vehicle (EV), in which batteries supply the required energy. Battery EVs (BEVs) currently cost twice as much (due to limited production) as comparable internal combustion engine autos and go only 50 to 75 miles before a nominal 4-to S-hour recharging interval is required.

These characteristics are not conducive to BEV purchases by individuals. They are not significant detriments, however, to BEV use in short-term, short-trip, IRAC use. Specifically, using BEVs in IRAC fleets may be a practical way of meeting the 1998 mandate. This concept has been discussed at various IMATS presentations in California and has met with interest. The IRAC element of IMATS is a potential way of satisfying at least a portion of that manufacturer's 1998 ZEV quota.

A DISTRIBUTED INPUT/OUTPUT SUBSYSTEM FOR TRAFFIC SIGNAL CONTROL

IVHS-IDEA Project 4'

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IDEA PRODUCT

This IDEA product simplifies the electrical wiring contained in a typical traffic signal cabinet and provides an open architecture for integrating future IVHS type devices (air quality, transponders, transit priority, emergency vehicle preemption, image-based detection). A commercial distributed control technology called **LonWorks** is used to construct several prototype distributed systems. The fundamental building blocks of these distributed modules is a small microprocessor called a Neuron that **costs about** $3 when purchased in significant quantities. These microprocessors have 11 input/output pins, a real-time scheduler, and an embedded communication protocol. The following products have been completed and are available to IVHS application:

- **Distributed Traffic Signal Lamp Control Modules.** These modules are controlled using a "drive by wire" technology where communication messages are exchanged between the module in the signal head and the controller cabinet. The messages are transmitted using a spread spectrum power line modulation technique that permits the control signals to be carried by the power line. As a result, only two conductors run between the signal head and the cabinet. In addition, current sensors located on the module provide feedback indicating which lamps are illuminated so that burned out lamps can be detected. Figure 1 shows a photograph of a prototype control module mounted in the disconnect hanger of a standard five-section signal head.
- **Distributed Ramp Meter Control Module. This** IDEA product is a natural extension of the signal lamp control module described above. In addition to controlling the ramp meter head, the module is used to read loop detectors (queue detectors, check in/check out detectors, and adjacent freeway loops). The ramp meter control cell uses its own cycle timer so that the controller only has to transmit updated metering rates to the signal heads periodically. Also, the data reduction for the loop inputs (volume, occupancy, and speed averages) is performed by the microprocessor and periodically transmitted back to the controller over the power line communication interface.
- **Distributed Pixel Control Modules for Changeable Message Signs.** These modules permit the 35 pixels (5x7 matrix) in a typical changeable message **sign cell** to be controlled using just 2 conductors instead of 35. These modules use the same drive-by wire technology used for the signal lamp control modules, In a typical changeable message sign like that shown in Figure 2, a 2-conductor bus could be used to replace the 2800 conductors (5x7x4x20) required to control all the pixels.

CONCEPT AND INNOVATION

Although cabinet wiring has been growing more and more complex, it is only recently that commercial open architecture control equipment has been looked at for traffic signal control. The innovation of this IDEA project **is** the use of an open architecture distributed control technology manufactured by Echelon called LONWORKS. There are three fundamental components of this technology:

1. Distributed processors called Neurons. These application processors are programmed using the C

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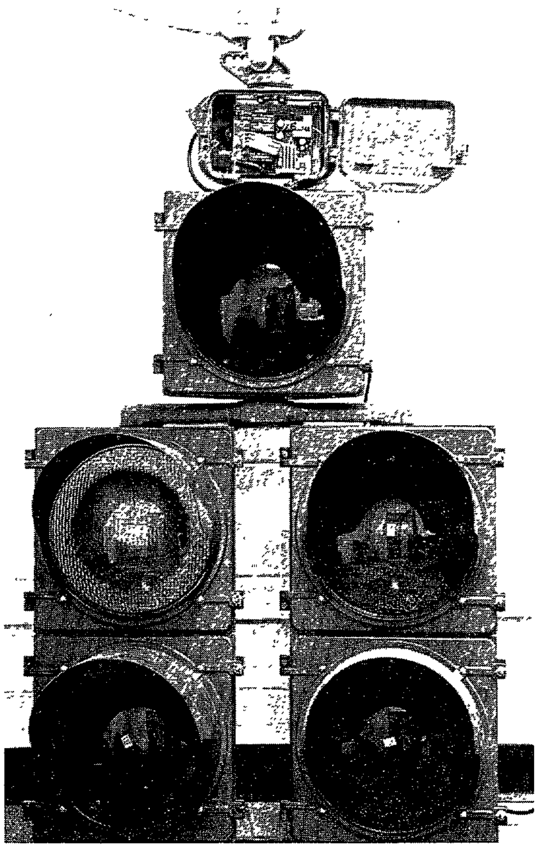

FIGURE 1 Photograph of prototype control module for five-section head mounted in disconnect hanger.

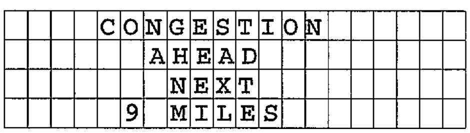

FIGURE 2 Layout of typical changeable message sign.

language and have 11 input/output pins, 512 bytes of EPROM, 2048 bytes of RAM, and about 50,000 bytes of external ROM. These Neurons are manufactured by multiple vendors and cost about $3 per package when purchased in significant quantities. Given this relatively small cost, these processors can provide cost-effective interfaces to a variety of I/O devices ranging from signal load switches to air quality sensors.

2. Standard communication protocols embedded in the Neurons. Since the communication protocol is embedded in the Neuron, developers do not have to write communication drivers. This is an enormous benefit to potential vendors because of the large software development costs associated with writing and maintaining communication software. Furthermore, since the protocol is embedded in the Neuron, vendors do not have to worry about other vendors adding proprietary tweaks to the communication protocol to defeat interoperability.

3. Several media choices. Using the proper transceivers, these Neurons can be attached to several different media. In this project 110 VAC are being used. However, these devices can also be used over DC power lines, twisted pair, radio frequency, infrared, coaxial cable, and fiber optics.

IDEA PROJECT INVESTIGATION AND PROGRESS

Figure 3 shows the wiring model developed by the IDEA project. The goal of the IDEA project is to develop modules that would fit inside the disconnect hanger (small rectangular box that each traffic signal hangs from) **for** controlling each of the lamps in the signal. Each of these modules would communicate back to the cabinet (Figure 3, Network Interface) over the same two wires that provide conventional 110 VAC power. As shown in Figure 1, these modules have been constructed. The following section describes the project stages completed or underway related to the development of these distributed input/output modules.

In the first stage of the project the communication messaging protocol was developed for communicating between the modules in the disconnect hanger and the cabinet. Although the LONWORKS development environment supports the development of explicit methods for sending, receiving, and parsing communication messages, a high level network variable scheme is also supported. This high level network variable protocol is data driven, supports prioritized variables, contains CRC message validation, and can be configured with a variety of handshaking options that confirm network variables have been transmitted and received correctly. This network variable approach was selected since it insured the availability and consistency of all of the above features. Furthermore, it is very easy for multiple vendors to develop modules that interface to the same type of network. In fact, this is very common in other industries using this technology such as Building Control. For example, should these distributed signal control

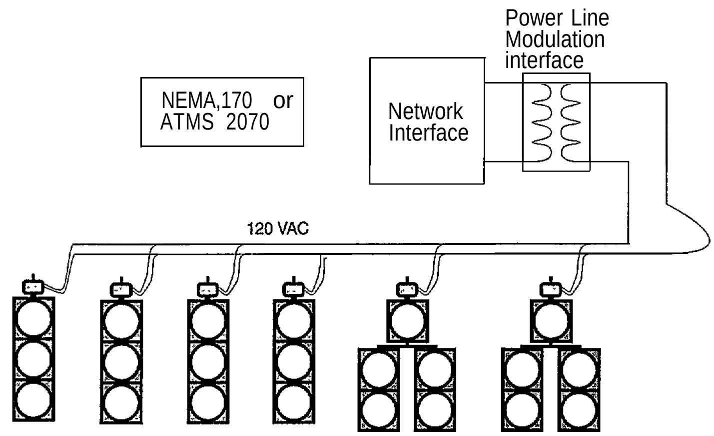

FIGURE 3 Proposed wiring model.

modules be commercialized, multiplevendors would likely manufacture these modules. Provided they used the networks variables defined in the specification, the modules could have completely different internal designs. This network variable model would provide an opportunity for manufacturers to develop competitive designs and still ensure an open architecture system.

The second stage of the project the performance envelope of the power line communication interface was developed. This involved setting up a laboratory test environment similar to that shown in Figure 4. In these tests we used a 2200 foot spool of 12 gauge wire typically used for connecting the traffic signals heads to the cabinet. At one end we put a transmitting device that sent serialized messages and at the other end we put a receiving device that watched to make sure every serialized message came through clean. Any corrupted or missed message was logged as an error. During these tests it was found that traditional load switch triacs caused a lot of ringing on the line that could corrupt up to 40% of the messages when large packet sixes were used. By replacing the triac with a solid state relay the error rate dropped to 0.1% under the worst conditions. Adding a third line (ground) and switching to common mode coupling dropped the error rate to 0 for all tests conducted. Finally extended tests using the reset line on a 1.6 mile section of interconnect line was performed over a two week interval. This was between Monterry Boulevard and Sherwood Forest Boulevard (Figure 5) in Baton Rouge, LA. Although these tests were over interconnect lines instead of signal lines, these lines were thought to provide a good test bed because of known problems with induced voltages. With the biggest message size (76 bytes) the worst absolute error rate encountered was 0.2%. Even after attenuating the output transmitter by 24 dB, the worst error rate never exceeded 1.3%

The third stage modules that would fit in the disconnect hanger shown in Figure 1 were fabricated. In general, this module contains 5 solid state relays, 5 current sensors, some signal conditioning circuitry and an Echelon Neuron chip. The module shown mounted in the disconnect hanger in Figure 1 is currently operational. Seven other modules provided the same functionality have also been fabricated. This concept has also been extended to develop a module for controlling a ramp meter signal head and monitoring the requisite loop detectors.

In addition to fabricating modules for controlling signal heads a module for controlling the cells on a changeable message sign has also been constructed (Figure 2). These signs are made up of a number of cells, where each cell is typically used to display a character, number or symbol. Cells are typically constructed using individuals lamps or flip disks for each pixel. By illuminating a pattern of bulbs or displaying a pattern of reflective disks, characters, numbers and symbols can be displayed.

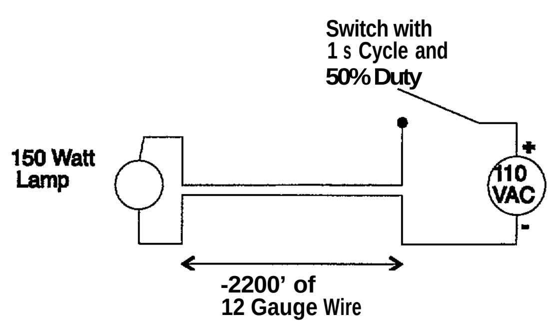

FIGURE 4 Laboratory test setup.

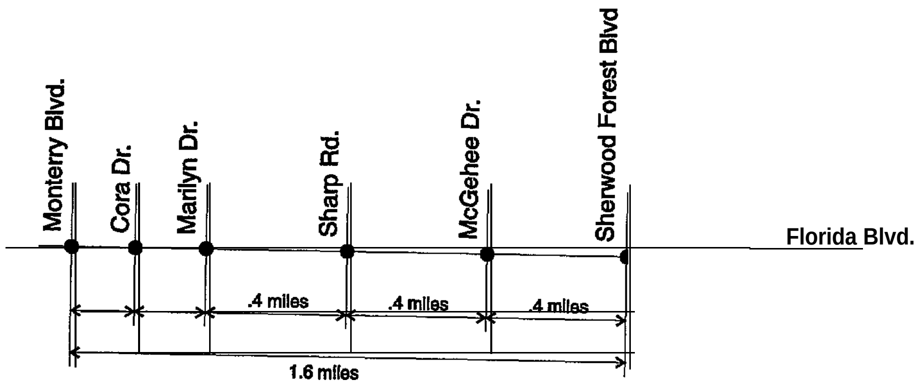

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FIGURE 5 Arterial communication test environment.

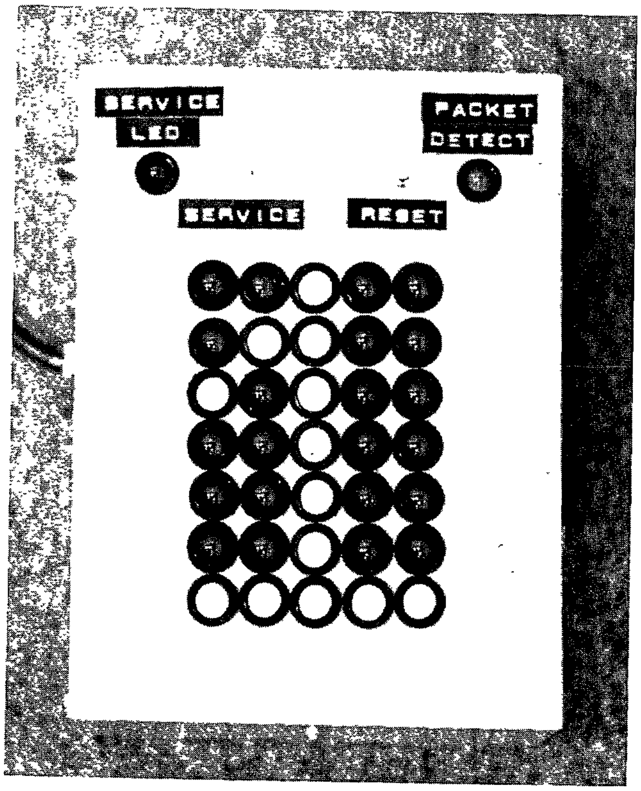

FIGURE 6 Photograph of prototype module for changeable message sign cell control.

Current construction techniques usually rely on running a wire between a central controller and each pixel. Given the sign shown in Figure 2, this would require 2800 different controls lines (4x20 sign and assuming a 5x7 matrix for each cell). A prototype cell, shown in Figure 6, was constructed that uses the same distributed control architecture as that used in the disconnect hangers of the traffic signal. Since only two wires must be run to each cell, single cell modules could be mass produced in a factory environment and plugged into the structural frame. Such an assembly and wiring architecture would dramatically reduce the labor required to fabricate a sign and maintain it after it is in service.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

The most commercially promising field deployment of this technology would be the development of an in-cabinet data communication bus that connects the traffic controller to the detector rack and load switches. In parallel efforts to this IDEA project, Matrix Corporation introduced a controller built to the preliminary ATMS 2070 specification with NEMA connectors at the IVHS America show in April 1994. This controller uses the Echelon **LONTALK** bus for reading and writing the I/O pins on the A, B and C connectors. The project investigators have met with them and discussed the possibility of collaborating on follow-up field tests for commercial deployment.

(The names Neuron, LonTalk, LonWorks, and Echelon are all registered trademarks of Echelon Corporation.)

FEASIBILITY STUDY OF IVHS DRIFTING OUT OF LANE ALERT SYSTEM

MIS-IDEA Project 5[1]

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IDEA PRODUCT

This IDEA product will explore the practicality and feasibility of implementing a low-cost, in-vehicle, automated lane alert system for IVHS. Two candidate technologies under consideration are electromagnetic (EM) and infrared (IR) sensing, using either ferromagnetic or IR reflective paint strips applied to the roadway or driving lane boundaries (Figure 1). It is envisioned that the alert system could be activated by the driver on the open road (like cruise control) or activated automatically once the vehicle reaches a threshold speed. The IDEA project explores the feasibility of a fieldworthy lane control system for IVHS.

Many highway accidents and deaths each year result from one-car accidents. These are usually the result of cars drifting either off the road or out of the lane because of driver inattention, dozing, or driving under the influence (DUI). In 1990, motor vehicle accidents in the U.S. caused 46,300 deaths, of which 28 percent (almost 13,000) resulted from vehicles going out of their traffic lane, and colliding with a fixed object [l]. The proposed system has the potential payoff for significantly reducing the number of one-car accidents and fatalities.

CONCEPT AND INNOVATION

The underlying technical principle is to use either EM or IR technology to detect the presence or absence of the roadway boundary. The roadway boundary will be marked with either a ferromagnetic or IR reflective paint to be detected by the vehicle electronics. It is anticipated that the paint strip may require a new innovation, especially in the case of EM technology, but the basic principle should be similar to that already used to apply paint with glass beads.

Two unique aspects of this IDEA innovation are the relatively low cost of modifications to vehicle or roadway and the fact that focus is placed on *aiding the* driver instead of performing driver tasks. The product serves only to alert the driver of vehicle drifting. It is not anticipated that the innovation will be capable of exercising significant control over vehicle functions or performing corrective actions, such as steering the vehicle back into the lane. The level of technological sophistication in this product should not approach that which has been used in guided vehicle research, yet the output of the system will provide driver cues to correct vehicle heading and thus significantly reduce the rate of traffic fatalities.

IDEA PROJECT INVESTIGATION AND PROGRESS

The project will perform limited theoretical analyses of both EM and IR technologies, and conduct a comprehensive laboratory testing program to evaluate the performance and technical viability of the candidate alert systems.

The following activities are underway for the IDEA project:

1. Limited theoretical analyses of two IVHS model, *i.e.* an inductive sensor/ferromagnetic paint strip model and an infrared reflective paint strip model, as a first step in evaluating the technical feasibility of using each model as

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[1]The IDEA project started February 1994 and will be completed by January 1995. IDEA project advisor: Pete Mills, FHWA.

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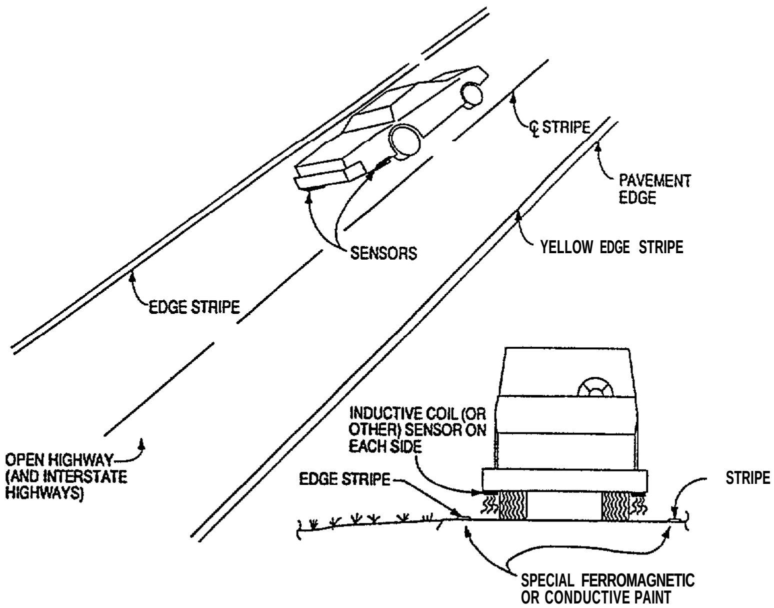

FIGURE 1 Illustration of vehicle-mounted detectors.

an on-vehicle system to alert drivers when they drift out of their lane of traffic;

2. Design of a research and development (R&D) test model of each system based on theoretical analyses;
3. Establishing the primary operational conditions under which the systems must perform; and
4. Conducting a comprehensive laboratory testing program to evaluate the performance and technical viability of the systems.

Specific tasks of the research investigation to evaluate the feasibility of the inductive proximity sensor and its potential to IVHS include parametric studies and instrumented tests of the following:

1. Sensing coil excitation spectrum and related sensing coil sensitivity;
2. Instrumentation for sensor interface and signal processing;
3. Ferromagnetic composition and concentration of the painted boundary strip that is to serve as the sensing system target; and
4. System sensitivity to possible induced fields from external sources.

The project effort to determine feasibility of the infrared reflection sensor and its potential application to IVHS includes the following activities:

@Develop and test prototypical system instrumentation,
@Conduct an analytical study and accompanying instrumented testing of boundary strip composition, reflectivity, and effects of composition on the sensitivity and reliability of the instrumentation developed.

Preliminary Results

A three-month-long Stage I period has been used to roughly evaluate feasibility of using either technology to detect roadway boundaries. The objectives of the Stage **I** tests were strictly to answer the question, "Is it possible or impossible to detect the roadway boundary using these particular technologies?" Several accomplishments were achieved [8] during this time.

The first accomplishment was the selection and testing of an electromagnetic-based technology. Two candidate EM technologies were selected after a short study of metal detection techniques. Both EM techniques use transmitting and detecting electromagnetic coils to probe the magnetic characteristics of the environment. The two candidate EM approaches differ in the type of signals used to excite the emitter coil, and also differ in the signal characteristics observed by the detector. It was decided that the short time period available in Stage I permitted testing of only one EM technology, so the simpler technique that is commonly found in commercially available, portable metal detectors was tested. Such a detector was obtained and tested in the laboratory environment. It is recognized that this particular device will not be optimally suited for an IVHS application, but the basic tests did provide enough data to conclude that it is possible to detect moderate amounts of iron filings, which are a candidate material to be mixed into roadway boundary paint. The preliminary tests confirmed feasibility of using electromagnetic techniques, and the encouraging results confirm that additional issues must be examined. Specifically, the second, more sophisticated EM technique that was selected needs to be experimentally evaluated.

In addition, methods to treat the roadway boundary paint with ferromagnetic particles need further investigation. A host of other issues involving uncertainties in the operating scenarios were described in the original project proposal, and the Stage I tests confirm that these issues are indeed valid, and will need to be addressed in future work.

The second accomplishment was the selection and prototyping of a candidate IR technology. This work was performed in parallel with the study of the EM prototype system. Infrared light emitting diodes and phototransisitors of the type commonly found in consumer electronic products with remote controls were used in a test circuit. The test circuit consisted of an oscillator operating at a fixed frequency to drive the emitter diode(s) in a pulse fashion, and a tuned high-gain amplifier in the detector. Detection of infrared energy by a simple threshold detector was considered unsuitable, since the outdoor environment contains a high level of IR energy. The use of a pulsed signal was considered a suitable coding method to improve the selectivity of the system. The technique tested can be likened to amplitude modulation (AM) used in radio broadcast application. Tests were conducted to examine the reflective properties of several roadway boundary paint specimens and background colors. Results in Stage I testing indicated that IR technology is also feasible for detecting a roadway boundary.

The third achievement is the construction of families of paint strip samples, and development of a simple calibration device for controlling the physical location and orientation of electronics under test, relative to paint strip samples under test. Four types of yellow paint, a glass bead additive, and iron filing powder were procured. From these materials, three broad families of paint strip samples were planned, and two were made during Stage I. The first family of constructed paint strips was simply the plain roadway paint with no additives. This family of strips was used to help confirm that IR technology can discriminate between plain roadway paint and a dark background, such as asphalt. These paints were also used to confirm that the tested electromagnetic technique could not detect plain roadway paint. The second family of constructed paint strips contained a "doping" of iron filings. It was discovered quickly that it is difficult to dope iron filings into roadway paint and also difficult to apply the mixture evenly on the wood strips, especially with a solvent-based paint which dried very quickly. Viscosity of roadway paints was greatly affected by iron filing doping and the resulting paint strip color was quite different from the original roadway paint specifications.

The findings of the work to date are summarized as follows:

1. Technology can be used to detect iron filings, which may be suitable for mixing with roadway boundary paint. Two approaches for detection were considered, and one method was tested. Based on favorable results of the simpler method, it is anticipated that the more sophisticated pulse transmission and detection scheme will also work. It is expected that such testing and evaluation will be accomplished during Stage II;

2. IR technology is capable of detecting yellow roadway paints (all four types tested), and appears capable of discriminating between the paint and a dark background. The pulse modulation scheme for transmitting and detecting IR energy appears feasible for this application. Study to determine noise immunity will be conducted during Stage II; and

3. Addition of iron filing powder to roadway paint presents significant technical challenge. In particular, simple mixing of powder with paint results in an unacceptably thick mixture for brush type application.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

The IVHS lane alert system is a safety system with the potential for significantly reducing incidences of one-car accidents and casualties. Upon successful completion of the Type 1 feasibility work, a Type 2 IDEA applied testing and evaluation effort will be undertaken to move toward implementation as indicated below.

In the Type 2 effort, a prototype sensor/signaling unit will be fitted to an automobile for conducting extensive testing under field operating conditions. If modified pavement paint marking stripes are required (to be determined during the current Type 1 project), then some of these will be emplaced and a more limited field testing program will be conducted. The Alabama Department of Transportation will collaborate and assist in the field testing. It will also assist in identifying potential "obstacles" and operational issues in the highway system environment in which the alert system must operate. Upon successful completion of the field testing, a task force will be established to plan the implementation of the alert system into the automotive highway transportation system. It is envisioned that this task force will include the project investigators along with personnel from the Department of Transportation, Federal Highway Administration, National Highway Traffic Safety Administration, automotive industry, electronic instrumentation manufacturers, and a paint striping manufacturer (if the pavement marking stripe required is different from those currently used). A detailed implementation plan along with a refined IVHS lane alert system will be the deliverables for the Type 2 project work.

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LASER-BASED VEHICLE DETECTOR/CLASSIFIER

IVHS-IDEA Project 6'

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IDEA PRODUCT

The vehicle detector/classifier (VDC) concept employs a scanning laser range finder to measure three-dimensional vehicle profiles that can be used for very accurate vehicle classification. The narrow laser beam width permits the detection of closely spaced vehicles moving at high speed (even a 2-in-wide tow bar can be detected).

The VDC shows good promise for applications to electronic toll collection from vehicles at freeway speeds. Electronic Toll and Traffic Management (ETTM) can reduce congestion around toll plazas through automated highway-speed toll collection. However, this requires highly accurate vehicle detection and classification to ensure compliance with toll-rate schedules. The VDC has promise to satisfy the ETTM compliance-monitoring requirement.

CONCEPT AND INNOVATION

The VDC beam-scan geometry is shown in Figure 1. The VDC relies on an inherent laser characteristic -- narrow angular beam width -- to provide the high resolution required for accurate vehicle profiling. The VDC's 5-mm beam thickness and high scan rate (720 scan/s) facilitate the accurate profiling of vehicles, even when the vehicles are closely spaced and traveling at high speeds.

The IDEA system scans two narrow laser beams, at a fixed angular separation, across the width of a lane at a rate of up to 720 scans per second. Pulsed time-of-flight range measurements provide accurate (**f** 3 in.) transverse height profiles of a vehicle on each scan. The vehicle speed, determined from the time interval between the interceptions of the two laser beams by the vehicle, is used to space the transverse profiles appropriately to

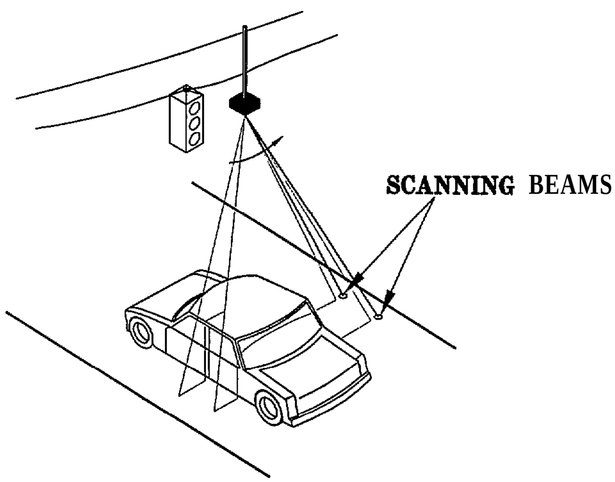

FIGURE 1 VDC beam scan **geometry.**

'This is type 2 IDEA project started December 1993 and will be completed by March 1995. IDEA Project advisor: David Gibson, FHWA.

obtain the full three-dimensional vehicle profile. An algorithm similar to those developed for military target recognition is applied to the three-dimensional profile for vehicle-classification purposes.

IDEA PROJECT INVESTIGATION AND PROGRESS

The vehicle detector/classifier program comprises two stages. During the first stage, which has been completed, product design requirements were established and a system design was developed. A prototype system is being fabricated and tested under highway operating conditions and its vehicle classification performance will be evaluated during the second stage of the program to be completed by March 1995.

Selecting VDC Design Specification

In order to determine product features most important to potential users, a vehicle sensor questionnaire was mailed to 80 prospective VDC users. The mailing list for the survey was selected from the Council on IVHS listed in the Institute of Transportation Engineers Directory. Twenty-six of the questionnaires were returned.

The survey revealed that the most common VDC requirements that are not satisfied by current sensors are vehicle separation and classification, particularly under high-volume, high-speed traffic conditions. Survey responses indicated interest in the following areas of application (in order of interest): (1) traffic data collection, (2) traffic signal control, (3) temporary installations, and (4) electronic toll collection. For the most part, it was not possible to categorize questionnaire response according to application area because respondents indicated an interest in more than one area. This was not true for the electronic toll collection area, however, which was of singular interest in three out of four cases, viz Hughes Transportation Management Systems, Amtech Systems Corp., and MFS Network Technologies. These potential VDC users want sensors that are very accurate (99.9 to 99.9999% detection accuracy, 95 to 99.95% classification accuracy), highly reliable, and have a long lifetime (2 to 5 years). They are concerned about the effect of environmental conditions on sensor performance, particularly weather (rain, fog, snow) and temperature (-40” to +85°(C).

The product design specification presented in Table 1 was established based upon: (1) the results of the vehicle sensor survey of potential VDC users, (2) discussions with major IVHS companies -- MSF Network Technologies and Hughes Transportation Management Systems, and (3) previous research experience in developing diode-laser-based vehicle sensors.

Designing the VDC System

The VDC design employs a rotating polygon to line scan a diode-laser rangefmder across a l2-foot-wide lane of a highway. The polygon scanner rotates continuously in one direction at a constant speed. The angle between each facet and the base of the polygon alternates between 85” and 90” for adjacent facets; as a result, successive scans are made with an angular separation of 10°, which provides the two separate beams needed for speed measurement. The 0.5 by 12 mrad laser beam illuminates a 5 by 120 mm spot on the pavement that provides good in-lane resolution and optimum cross-lane coverage when the laser is pulsed once per degree of scan angle.

The VDC’s laser rangefinder employs an InGaAs diode-laser transmitter and a silicon avalanche photodiode (APD) receiver in a side-by-side configuration. The transmitter consists of the diode laser and its driver circuit and a collimating lens. The optical receiver is comprised of an objective lens, spectral filter, detector/amplifier and threshold detector. A block diagram of the VDC is shown in Figure 2.

The laser diode used in the VDC is an InGaAs injection laser diode having 12 W output at 10 A pulsed current drive. The laser driver produces a 10 A peak current pulse with a 3 ns rise time and an 8 ns pulse width. A trigger pulse from the scanner control circuit triggers the laser at the proper scan angles. This diode emits at 904 nm, which is an ideal wavelength for the silicon APD receiver used.

The optical detection circuitry converts optical radiation reflected from the vehicle/road to first, an equivalent electrical analog of the input radiation and finally, a logic-level signal. The receiver has two detectors which are time multiplexed using a high-speed analog multiplexer. The multiplexer is controlled by a single logic-level control line from the microprocessor. The output of the multiplexer is connected to a threshold detector which converts the analog return pulses to logic-level pulses. The logic-level signals are processed within the range counter logic to yield analog range data, which is read by the microprocessor.

An analog range-measurement technique was chosen for the VDC because of its better resolution, smaller size, simpler circuitry, lower power consumption, and lower cost when compared with digital techniques. The analog range measurement circuit, known as a time-to-amplitude converter (TAC), has an accuracy of 1 percent of

TABLE 1 Design Specification

Scan Rate	720/SEC/Beam
Field-of-Regard	30°
Scan Resolution	1°
Beam Separation	10°
Range Measurements per Scan	30
Maximum Range	50 ft
Minimum Range	2 ft
Range Accuracy	3in
Range' Resolution	3in
Interface	Serial, lMBIT/S, RS422/DMA RS232 Solid State Relay-Presence Logic-Level Presence
Laser Beam Geometry	In-Lane Axis - 0.5 mrad Cross-Lane axis - 12 mrad
Laser Beam Wavelength	902 nm
Laser Peak Power	15 w
Laser Pulsewidth	8 ns
Laser Burst Rate	43.2 kHz
Power Supply Voltage	115 VAC, 24, VDC, 12 VDC
Temperature Range	-40° C TO 60° C
Vehicle Classification	12 Classes, TBD
Speed Accuracy	2 MPH @ 60 MPH

measured range and a resolution of +3 in. The TAC employs a constant-current source to charge a capacitor to obtain a linear voltage ramp whose instantaneous value is a measure of elapsed time. The circuit is designed so that the voltage across the range-measurement capacitor begins ramping down from the positive power supply when the laser fires. The ramp is stopped when either a reflected pulse is received or the end of the measurement period is reached. The TAC output is then converted to digital by a fast 10-bit A/D converter.

Algorithm Development

The VDC software will process the range data and output vehicle classification, vehicle speed, etc., via a serial interface to a remote computer. The algorithms that must be implemented for each function have already been developed and tested, to some extent, in previous projects. The vehicle detector and the speed calculator are used in an auto sense unit. The real-time range loop, calibration, and gain adjustment routines have been used in several

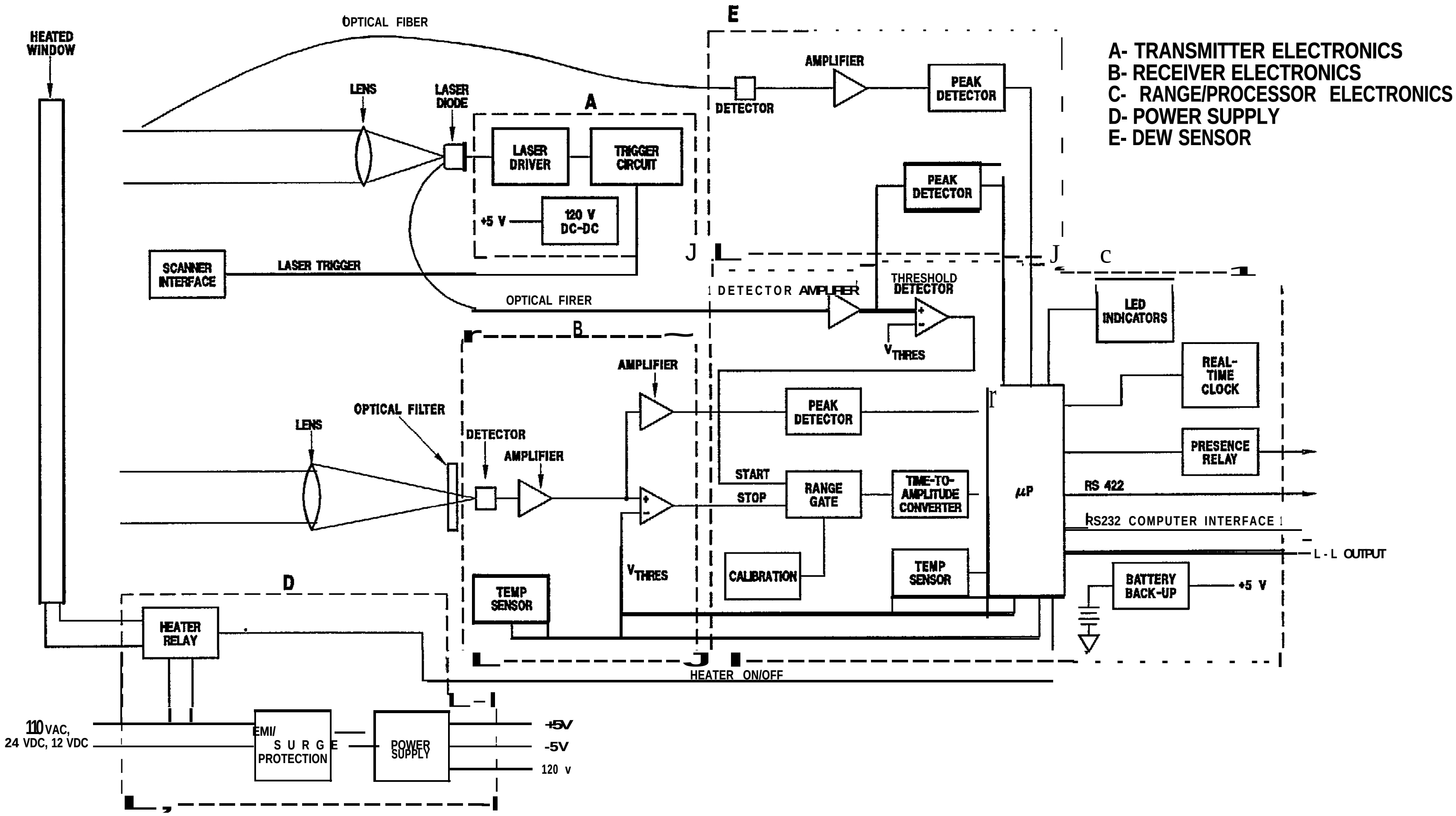

FIGURE 2 VDC system block diagram.

other projects. The vehicle profiler and vehicle classifier will consist of modified versions of algorithms that have been designed and tested under military research programs. The VDC algorithm will classify the 11 different types of vehicles listed below:

- Passenger car,
- Motorcycle,
- Pickup truck,
- Cargo van,
- Delivery truck,
- Bus,
- Car with trailer,
- Tractor without trailer,
- Tractor with 1 trailer,
- Tractor with 2 trailers, and
- Tractor with 3 trailers.

The range data will be used by the vehicle detection algorithm to determine when a vehicle is present. The vehicle detection algorithm first calculates the range to the road, then sets a threshold above the road that is used to determine the presence of a vehicle. A certain number of used non-scanning vehicle sensor -- Auto sense -- in ETTM demonstration tests for the Toronto FTMS and the consecutive range samples above the detection threshold are required to accurately detect the presence of a vehicle and to reduce false alarms.

The vehicle-profile generator will begin comparing consecutive range samples to see if the range is **increasing,** decreasing, or remaining constant as soon as a vehicle has been detected. The profile generator will encode the range data as a series of profile trends. Three types of profile trends are generated; a plateau, which is a series of consecutive samples at the same range, a rising

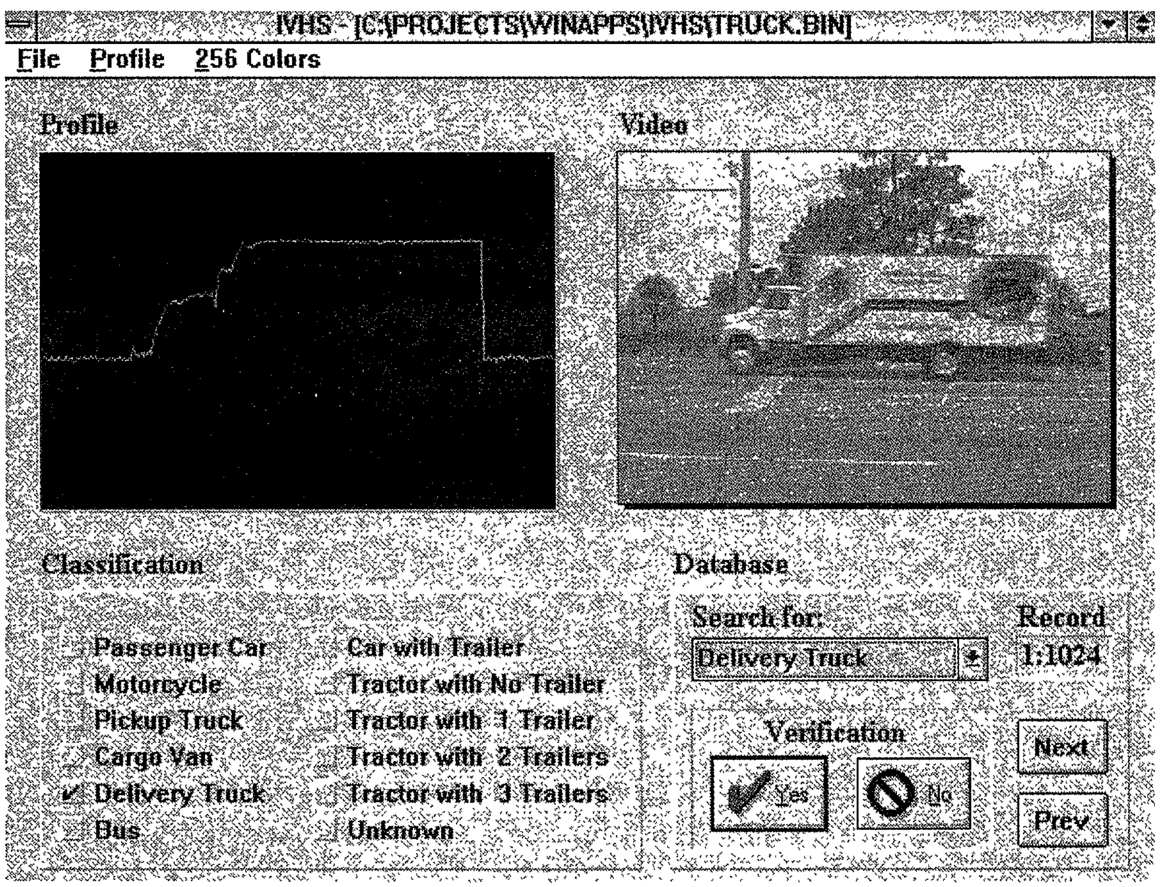

FIGURE 3 Computer display of VDC classification data including vehicle profile and video image.

edge, and a falling edge. Profile trend characteristics are calculated for each trend. For a plateau, the average height across the plateau is calculated. For a rising or falling edge, the slope of the edge is calculated, where a positive slope indicates a rising edge, and a negative slope indicates a falling edge. The average signal strength, which is derived from the intensity data, and the length of each trend are also calculated.

A set of features is calculated using the profile trend data from the VDC embedded microprocessor. The feature set is used to accurately classify vehicles. The length and height of the vehicle are used as primary features and are weighted more heavily than any of the other features. The remainder of the feature set consists of a series of ratios that characterize the profile.

Testing

The system will be tested at a site on Florida SR 441. The VDC will be mounted to a mast arm extending over the curb lane of this major Orlando arterial. Twenty-four-hour-per-day testing will be carried out for an extended period of time. This will permit testing under varied traffic conditions, including rush-hour, off-peak,and stop-and-go, and under varied environmental conditions such as rain, fog, and high temperature.

During testing, the VDC algorithm will be modified, as required, to optimize vehicle detection and classification capabilities. Program code will be uploadable to the VDC via the serial interface, making possible the real-time optimization of VDC performance. The vehicle profiles that are collected will be organized in a database. Using a database, specific vehicle types can be extracted and used for vehicle classification algorithm development. After the classification algorithm is developed, a search of the database will provide data from similar vehicles for classification algorithm testing. The data base will contain fields that include the vehicle class, height, length, speed, etc., corresponding to each vehicle detected. A video will be captured and stored for each vehicle for easy verification of the vehicle classification algorithm (see Figure 3). Approximately 1,200 vehicles per hour can be verified using the database display software. The data base is expected to grow to over 100,000 vehicles within a 3 month period.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

Hughes Traffic Management Systems and MFS Network Technologies have expressed their desire to purchase VDC units when they become available. Both companies have used as non-scanning vehicle sensor -- Auto sense -- in ETTM demonstration tests for the Toronto FTMS and the Autobabn. The system will encourage Auto sense performance by providing the full-lane coverage, three-dimensional profiling, and tow-bar detection capabilities and improve vehicle detection and classification accuracies.

DRJS'ER-ADAPTIVE WARNING SYSTEM

M-IS-IDEA Project 7[1]

Christopher A. Miller, Steven Harp, Thomas A. Plocher, Robert P. Goldman
Honeywell Technology Center, Minneapolis, Minnesota

IDEA PRODUCT

The machine learning system developed from this IDEA project will provide individualized warning thresholds in crash countermeasure systems. The system would have the ability to adapt the warning threshold to the individual differences in driving style found in the driving population; thus, it increases system reliability and user acceptance.

The IDEA crash countermeasure system will include an on-board learning module that analyzes the individual driver's control actions relative to the lane markings and other vehicles on the road (as provided by the on-board sensors integral to any countermeasure system). Over a short period of time, the learning system can modify its default driver model to conform to the individual driver's driving style. The model will then be used to interpret the driver's behavior and predict the future state of the vehicle. Wherever a current state indicated a hazardous future state for *that driver,* based on predicted state from the learned model, the proposed system will trigger a warning. By adapting warning systems to the individual driver's behavior, false alarms should be reduced and user acceptance and trust should be increased.

CONCEPT AND INNOVATION

The project explores the potential of a hybrid software system, based on neural networks, temporal-difference, and Markov modeling techniques, for learning patterns of individual driving behavior, predicting the vehicle's future state, and adaptively setting alarms. The IDEA concept develops an adaptive prediction model for individual drivers. Such a system is a necessary precursor to the development of an overall driver-adaptive warning system.

Traditional warning systems (Figure 1A) accept input about the state of the vehicle, perform an assessment of danger according to a rigid rule (e.g., lane deviation at such and such a rate is dangerous), and sound an alarm whenever the rule is met. Given the variability in driving behavior in the population, the warnings provided by these normative model-based systems correlate poorly with actual behavior. An adaptive driver warning system (Figure 1B) adds a sensitivity to the individual driver to the traditional warning system. By learning about the driving behavior of the individual, the IDEA product will be able to make predictions about conditions that will and will not be dangerous for that individual and thus to sound alarms only in conditions that are pertinent for that driver.

To date, most research on crash countermeasure systems has focused on the on-board sensors that provide data to the countermeasure system. While sensors are critical to the success of a crash countermeasure system, the state of sensor technology would suggests that sensors will not be the major contributor to unreliable performance. Rather, the greatest potential for lack of reliability lies in the warning system itself. That is, in all future crash countermeasure systems, drivers will be warned (or control of the vehicle automatically assumed) on the basis of the system's interpretation of driver behavior and prediction of his/her intent. Reliable system performance that provides warnings that the driver perceives as relevant to his/her behavior will depend largely on the sophistication of the software that interprets the driver's actions. The IDEA approach takes into account individual differences among drivers that have the potential for high payoff in terms of countermeasure system performance and acceptance.

IDEA PROJECT INVESTIGATION AND PROGRESS

The development of technology for a driver-adaptive warning system will be accomplished by developing learning techniques for individual differences in the

[1] The IDEA project started April 1994 and will be completed by November 1994. IDEA Project advisor: August Burgett, NHTSA.

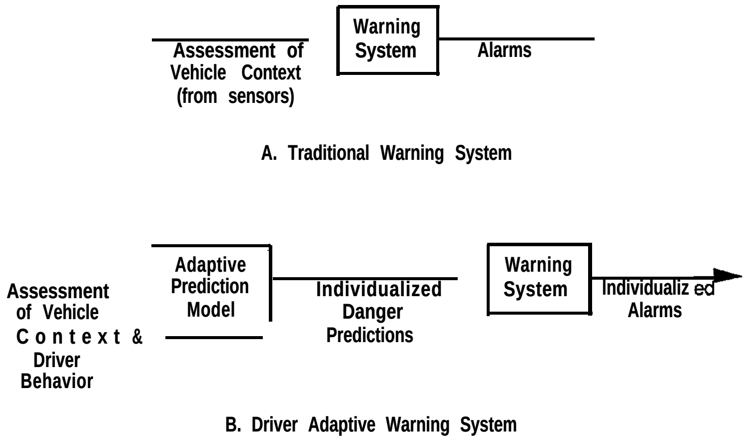

FIGURE 1 Traditional and driver-adaptive warning systems.

specific domain of lane-keeping behavior and related maneuvers such as lane-changing and learning algorithms. These technologies are being developed and tested using existing data on driver lane-keeping performance. An evaluation and laboratory demonstration will be performed comparing position prediction reliability using learned, individualized models versus reliability using a normative driver model. Future studies will explore ways to use this individualized knowledge of driving style to provide individually appropriate warnings.

The high-level architecture of the individualized driving style model is presented in Figure 2. In essence, the plan is to learn a driver-specific *predictive model* for each of several different "intent states" that is, intents which the

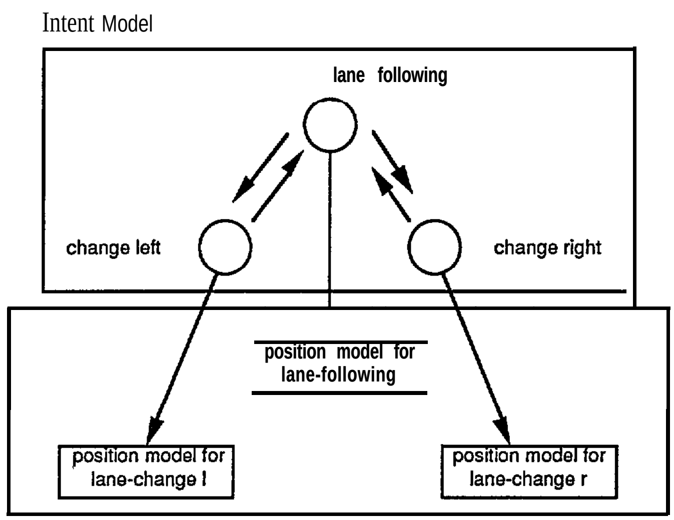

FIGURE 2 High-level architecture for the planned driver-adaptive prediction system.

driver may have and then learn *an intent model* which will enable the system to ascertain driver intent based on combinations of features from the vehicle, driver and external world. Exercising the intent model will enable the system to decide which predictive model or models to use to predict the vehicles future position. By separating the intent model from the actual predictions of vehicle position an increased accuracy will be achieved in the process.

Stage 1

This IDEA project is performing a three stage investigation to develop the IDEA product. The first stage, currently being conducted, focuses on the development of machine learning techniques for rapidly and accurately acquiring *an individualized* position prediction model from simulated sensor data. A "testbench" of learning algorithms has been constructed operating on a large body of driver data from simulations at the University of Iowa. Work is proceeding towards identifying the best combination of learning techniques to rapidly and accurately learn a single predictive model for one simple, context-dependent behavior corresponding to a single intent state (lane following). By looking at cases where there is only one intent, to maintain straight driving behavior, it has been feasible to temporarily simplify the problem of learning individual behaviors by eliminating the need for an intent model.

Specific machine learning techniques under investigation include:

- Multi-layer perceptron neural networks (trained by variants of back-propagation) [5],
- CMAC neural networks,
- Statistical regression techniques, [1,2],
- Temporal difference (Q-learning) [6], and
- Gaussian modeling techniques using codes for these algorithms.

The project is experimenting with several techniques using the same data set. This approach allows for a better ability to choose a method appropriate to the task at hand. The position-prediction task is not expected to be difficult for any of the above learning techniques.

Multiple learning methods are currently being tested in order to pick one that will meet four criteria:

- Robustness,
- Accuracy,
- Speed of learning, and
- Ease of integration with an intent model and with a warning system.

Evaluation against these criteria should provide an optimal method for continuously adapting a predictive model of a simple driver behavior to differences in driving style. An evaluation of the resulting, learned, individualized models will be conducted as described in the next section. This evaluation will provide initial data on the speed with which the system adapts to behavioral differences, as well as relative benefit measures for incorporating individual driver difference parameters in predictions of driver behavior within the single intent state.

Stage 2

The second stage will emphasize the development of an intent model to take into account the context in which observations are made. A model of different driver intent states for simple, yet multi-state lane following or lane deviation behavior (e.g., lane changing) will be developed. The goal of this stage will be to incorporate an individualized intent model on top of multiple intent-specific predictive models. The individualized driver-behavior modeling techniques developed in stage 1 for a single intent state, will be expanded to recognize different driver intent states and to interpret behavior relative to these different possible intentions. A Markov model will be developed in which the various possible intents are the states. For each such state, a predictive position model (as illustrated in Figure 2) will be developed and methods for determining which state the system is in, and which positions are outside the parameters of normal behavior for the various states (e.g., lane departure is abnormal in the lane-following state, but not in the lane change state)will be explored.

The Markov model will decompose the problem of prediction into two sub-problems: first, the problem of intent recognition and, second, the problem of future position prediction given the possible intents. The system will combine the transition probabilities from the Markov chain of intent states with the prediction each state makes to determine the probability of each state. For example, it will be extremely unlikely that the driver will go from changing lanes to the left to changing lanes to the right. She/he will probably continue to the left or settle into lane-following. The system will generate a predicted position for each of these intentions and those will be compared with the observed situation, e.g., if the lane change left model predicts further motion to the left and such motion is not observed, the lane change left hypothesis will be disconfirmed. This probability distribution, taken together with the position models will give us a probability distribution for the future position of the vehicle. Having the probability distribution simplifies the problem of determining warning policy: the warning policy can be made in terms of expected utility. For example, it will be within the system's capabilities to generate a warning for a very unlikely, but catastrophic, future state; or to ignore future states which seem quite likely, but which are safe.

Evaluations will be conducted at the end of each of the first two stages. These evaluations will involve using the learning techniques developed to provide predictions of driver behavior over a novel set of driving data. The automobile position predictions of the learning system (with its learned individual driver models) will be compared to the predictions of a static (non-individualized) "average" driver model.

Stage 3

Stage 3 will focus on delivering a prototype system that will display, in an animated fashion, the system's assessments of various situations drawn from the simulator data. This software system will simulate the operation of the prediction model on actual data obtained in man-in-the-loop simulations, making it possible to see how the model's situation assessment evolves over time. A final report, with results of evaluations, data analysis and a discussion of the promise of the system for practical application in an adaptive warning system will be prepared and released.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

Following successful completion of this project, the driver-adaptive warning system algorithms must be tested on data collected from actual vehicles. With this further refinement of learning algorithms, a road test will be possible that comprises a more complete warning system. That road test will be the first opportunity to combine the learning system technology developed on the IDEA project with the emerging deviation sensor technologies from the IVHS program.

LASER OPTICS OPEN-AIR COMMUNICATION SYSTEM

IVHS-IDEA Project 8[1]

Sheldon S. L. Chang[2]
State University of New York at Stony Brook

IDEA PRODUCT

This IDEA project develops and tests an optical communication system between the highway and vehicles. Optical communication between a highway system terminal (HWST) and a vehicle terminal (VT) will be achieved using a laser optics open-air communication system (LOOC). Infrared lightwave transmitting-receiving terminals are linked via commercial telephone lines, computer networks, or the information superhighway to a traffic information and control center. Each terminal has a built-in two-way signal storage and forward device. The highway terminal is mounted on an overhead structure (e.g., an overhead bridge), and a similar terminal device is installed within each vehicle. As shown in Figure 1, the terminals communicate with each other as the vehicle passes under an overhead structure without stopping or slowing down.

LOOC is based on an electronically directed and focusing laser @AFL), which automatically directs the signaling laser beam onto the receiving lens from the HWST to the VT and vice versa. The advantages of a DAFL versus a conventional laser are that the DAFL saves laser power, eliminates cross-talk, and does not harm the human eye.

CONCEPT AND INNOVATION

The IDEA product offers a potential alternative to the prevailing concept of using the global positioning system (GPS) as a foundation for locating vehicles. Uncorrected GPS is generally not accurate enough for unambiguous determination of position in an automotive navigation environment. This product offers an attractive low-cost alternative channel for delivering position data as well as other types of information that can be useful to IVHS.

IDEA PROJECT INVESTIGATION AND PROGRESS

Two Stages of IDEA Project

Stage 1: Assessing the Feasibility of LOOC for Use in IVHS

The feasibility conditions are as follows:

1. Sufficiently strong laser signal to assure satisfactory communication under all weather conditions,
2. Sufficiently weak laser signal to assure a margin of safety to the eye at all times, and
3. Operability under all traffic and weather conditions.

To be more specific, operability under highway conditions implies the following:

1. The system's operation will not impede the flow of traffic in any way, and
2. Under heavy traffic conditions (i.e. a traffic jam), there is neither crosstalk nor interference between communication links.

Established theoretical and test results show that infra-red light scattering due to rain, snow, or fog causes an exponential decay of the light intensity with distance. While a few hundred meters can be almost impenetrable in foggy conditions, a distance under thirty meters gives relatively little attenuation of the transmitted light intensity. The feasibility conditions are met when

1. The HWST is mounted sufficiently high and toward the right side of each traffic lane (so it communicates only with the leading on-coming vehicle).
2. The vehicles are given instructions to keep a distance of approximately 15 meters from the vehicle ahead and

[1] The IDEA project started February 1994 and will be completed by November 1994. IDEA Project advisor: Richard Mandelbaum, AT&T.

[2] Professor, Department of Electrical Engineering, SUNY at Stony Brook.

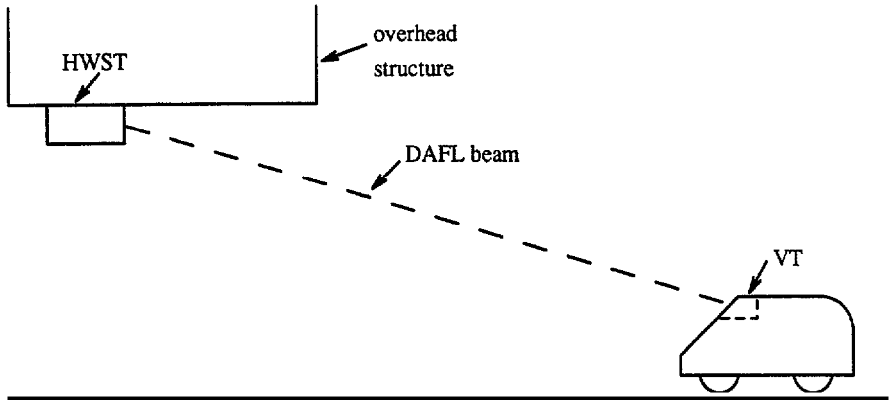

FIGURE 1 Communication between vehicle and highway system.

to proceed at no more than 100 kilometers per hour.

3. DAFLs are used for transmitting information by beaming automatically at the opposing terminal.

4. Error detection codes are used with provision for retransmission as needed. The costs for coding and decoding are low.

Under these conditions an assured one million bytes of information can be exchanged reliably during each encounter with a HWST.

Stage 1 of the investigation is successfully concluded. It not only proves feasibility of the LOOC-DAFL (IDEA product) but also outlines a workable design of the LOOC-DAFL system.

*Stage 2: Electronics Design and Computer Simulation **of** the LOOC-DAFL Performance*

A. DAFL Engineering Parameters, Optimum Design, and Simulation

DAFL can be described as a phase controlled lightwave antenna array in an integrated semiconductor chip. Each phase-controlled lightwave channel is an antenna element in the array. By controlling the phase delay in each channel, the direction and focus of the laser beam can be controlled.

The index of refraction of a semiconductor material, *n,* depends on both the material composition and the carrier concentration, which is controlled by the injection current. Since the velocity of light is proportional to ill/n the phase shift in a lightwave channel can be controlled by varying injection current along the channel.

There are three primary technical issues related to the evaluation of the DAFL concept:

1. Does the variation of *n* along a control channel result in multiple reflections which may interfere with the proper operation of the channel?

2. How close can we calculate the performance of a single control channel?

3. What is the best way to isolate the control channels so that they will not interfere with each other?

The project investigated the first problem analytically and checked the results with computer simulation. If the variation of *n* is sufficiently gradual, the Maxwell equations can be satisfied by a single forward-moving wave with continuously varying wave number along the channel path. The wave number at every point is very closely approximated by *dn/c,* where *n* is the local index of refraction and c the speed of light.

An important parameter for (2) is the coefficient of dependence of *n* on carrier density. This coefficient varies with the semiconductor material and lightwave frequency. There is no record of its measured data in the published literature, yet it is an important parameter for designing and predicting DAFL performance.

Based on statistical quantum mechanics, an expression was derived for calculating *n.* Instead of an expensive and time consuming systematic measurement of *n* for all plausible materials, all various material compositions, and at all pertinent ranges of lightwave frequencies, our work is now reduced to spot checks to verify the expression's validity.

B. LOOC System Design and Simulation

The project has completed work on coding and decoding hardware, as well as the protocol for computer control of the communication system. The laser beam searching and automatic alignment algorithms are being worked out.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

The following three options are being explored for implementing the LOOC system into IVHS practice.

Automated Highway System Using DAFL

An automated highway system (AHS) takes control of the driving while allowing the driver to work or rest. It is a potential part of M-IS. A proven IDEA product's ability to support AHS will attract the interest of car manufacturers and other potential users.

It is a common practice to implant small bumps on highway lane dividing lines to wake up a dozing driver. The IDEA system can implant semispherical infrared reflecting objects. As shown in Figure 2, each DAFL automatically beams at a reflecting object. There are six steering signals in the system: angle and distance of the reflecting objects on the left and right lane dividers and from the vehicle in front. These six signals are sufficient for guiding a car for IVHS.

Follow-Up Field Testing

A follow-up Phase 2 IDEA project will be planned for field testing of the LOOC-DAFL system for IVHS.

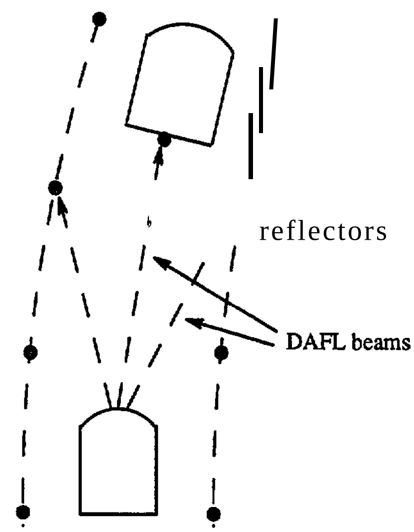

FIGURE 2 Use of DAFL in automated highway system.

Collaborative Activities with Industries

The University of Maryland has facilities for device fabrication and testing and has agreed to work in partnership with the investigation for performing field tests.

Telephonics and Grumman have been supporting the IDEA project at no cost. U.S. car manufacturers and other potential users for future collaborative activities will be contacted to perform field testing of the LOOC concept.

DECISION-THEORETIC REASONING FOR TRAFFIC MONITORING AND VEHICLE CONTROL

IVHS-IDEA Program 9[1]

Michael P. Wellman[2] *and Stuart J. Russell*[3]
University of Michigan, Ann Arbor

IDEAPRODUCT

This IDEA product consists of models and algorithms for deriving high-level descriptions of traffic conditions and individual vehicle maneuvers and intentions from visual observation of a traffic scene. The IDEA project builds on recent, successful work on visual processing of real and simulated traffic images that is capable of identifying and tracking individual vehicles accurately. From these inputs and general traffic knowledge, IDEA algorithms will generate and evaluate probabilistic models to assess the overall traffic situation.

Situation assessment from probabilistic models can be employed for traffic management, emergency response, near-accident detection (for intersection safety analysis), and intelligent traffic signals, among other applications. Decision-theoretic models can also be applied to the intelligent control of IVHS vehicles. Such control modules can be used to provide high-fidelity models of human drivers for full traffic simulation, with significant applications for highway operations and design.

CONCEPTANDINNOVATION

Recent advances in probabilistic modeling technology by artificial intelligence researchers have led to significant improvements in the flexibility of specifications for probabilistic knowledge. Specifically, formalisms based on *Bayesian networks* support the representation of arbitrary patterns of probabilistic interdependence and algorithms for exploiting the structure of relationships in the model. This standard probabilistic network framework has been extended to handle reasoning over time, by adding nodes to represent state variables at progressive time slices. This IDEA project is the first to apply such dynamic probabilistic networks to problems in traffic monitoring.

Because traffic patterns evolve unpredictably, it is impractical to generate a probabilistic model in advance that fits the actual situation encountered during monitoring. Therefore, the IDEA project implements automated facilities to generate a model structure on-line, exploiting the specific features of interest for the given situation. In this project, recent techniques were applied for *knowledge-based model construction* to produce customized Bayesian networks that address the special features of traffic patterns observed dynamically by the visual input system.

IDEA PROJECT INVESTIGATION AND PROGRESS

Development of this IDEA technology consists of the following components.

Vehicle Models--The IDEA project is developing Bayesian network models to represent vehicle state, including position, velocity, driver intentions, sensors, and other features. A fragment of such a model is depicted in Figure 1. Fragments corresponding to vehicle states at successive time stages can be linked together automatically to form a dynamic probabilistic network. Such models have successfully been constructed and evaluated using the Hugin™ system for probabilistic inference.

Traffic Models--In addition to models of individual vehicles, it is also important to model aggregate traffic variables, such as flow on road segments, travel time across various locations, etc. Starting from standard

[1]The IDEA project started January 1994 and will be completed by April 1995. IDEA Project advisor: Jeffrey **Woods,** NHTSA.

[2]Assistant Professor, Department of Electrical Engineering and Computer Science, University of Michigan.

[3]Associate Professor, Computer Science Department, University of California, Berkeley.

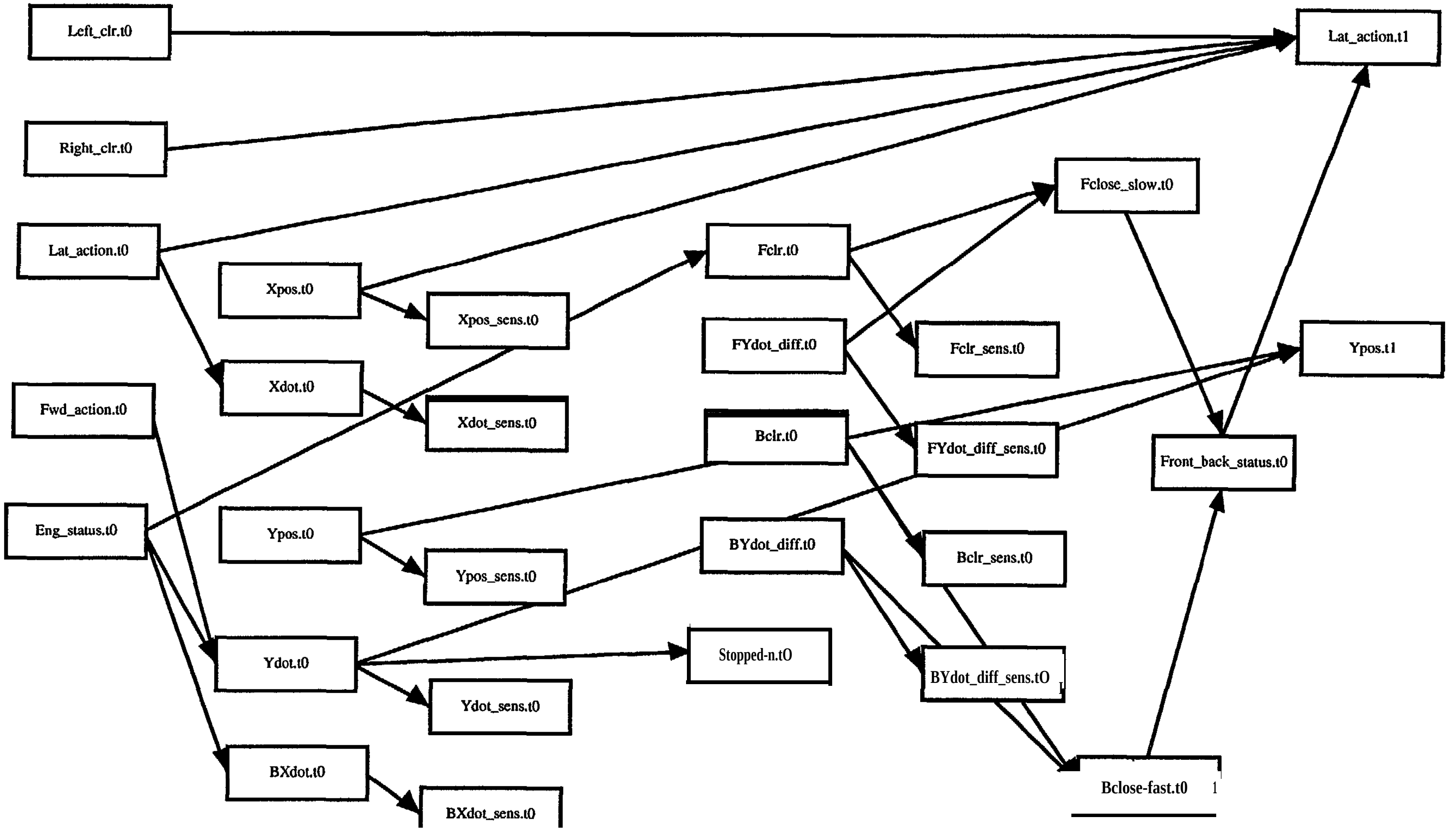

FIGURE 1 Fragment of Bayesian network model.

deterministic models of traffic flow from the literature, the IDEA project is developing Bayesian networks that capture the inherent uncertainty in congestion and the dynamics of traffic interactions. A schematic of the highest-fidelity model explored to date is presented in Figure 2.

Evaluation Algorithms--Complex Bayesian networks such as those presented above are not feasible for real-time inference in practical traffic monitoring contexts. Therefore, simplification and approximation approaches that produce the most accurate predictions possible given the available time for inference are being investigated. As more computation time is allocated, the algorithms become increasingly accurate. In particular, algorithms have been implemented and tested based on (1) stochastic simulation, and (2) abstraction of state spaces on versions of the models presented above. These approaches will be combined in an integrated approximation algorithm in the next phase of the project.

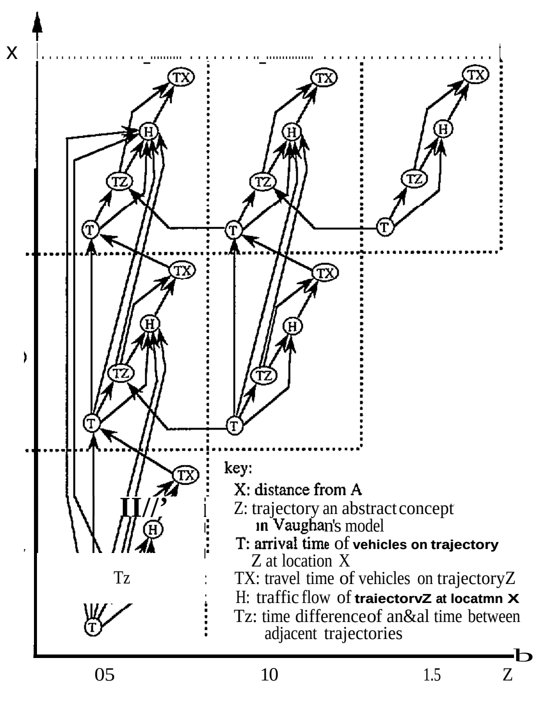

FIGURE 2 Schematic of highest-fidelity model explored.

Traffic Simulator and Visual Input Processor--The IDEA project is integrating these models with available traffic simulators, in order to evaluate their performance. The simulator has been revised to permit continuous motion in two dimensions, and has been integrated with the SmartPath animator. This in turn has been integrated with our decision-modeling environment, so that the automated driving in simulation, albeit using simple driving algorithms, can be demonstrated. The project has shown that the Hugin-based probabilistic reasoning system is capable of maintaining a sensible estimate of the current traffic situation from simulated sensor inputs, and further refined the probabilistic models used for this purpose.

Knowledge Base--To support more flexible generation of dynamic Bayesian networks, we are assembling a general knowledge base for highway traffic, concentrating initially on tactical and strategic traffic maneuvers that are available to the vehicles. For example, the initial knowledge base includes basic information about lane changes, signaling, passing, taking exits, and similar actions.

Model Construction Algorithms--The ultimateuse of this knowledge base will be to generate customized Bayesian networks dynamically depending on the evolving traffic situation as indicated by the visual inputs. Investigations are planned to apply both general-purpose model constructors (such as our SOAR-DMC system) and special-purpose techniques designed specifically to support generation and recognition of sequential traffic maneuvers.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

The results of this investigation will be used in a follow-up project to develop a full-scale traffic monitoring application for a special purpose task, such as near-collision detection. The models, algorithms, and knowledge bases developed for this project will form the core of the full system.

The application of IDEA-developed learning algorithms will have the potential to generate empirically accurate, probabilistic models of human driving directly from observational data. This potential will also be explored in a follow-up project activity.

EFFICIENT RESOURCE MANAGEMENT IN ATIS SYSTEMS

IVHS-IDEA PROJECT lO[1]

Ravi Jain
Bellcore, Livingston, New Jersey

IDEAPRODUCT

Innovative algorithms and heuristics will be developed to reduce the mean time required for an Advanced Traffic Information System (ATIS) to respond to user's traffic information queries. Concepts of resource scheduling from the disciplines of computer science and communications networking will be incorporated into processing schemes applicable to the ATIS environment. Efficient scheduling of computational and communications resources can improve the efficiency of both the data processing and communication tasks, resulting in quicker user response times and lower system cost.

An ATIS in an urban setting may have hundreds of thousands of users. The frequency with which traffic information must be delivered to these users can be very high, especially during peak traffic hours. The information should be delivered within a short time and must be filtered and personalized so as to give each user only the information which he or she needs. The quantity of information that must be processed can potentially be very large, especially if it becomes necessary to integrate travel information from several sources, e.g., parking, public transport, and weather advisories. This project will develop and evaluate techniques to utilize and manage these resources efficiently. Doing so should lower the computational requirements of the data bases and computers that store, filter, and personalize traveler information; it should also reduce the traffic due to ATIS on the communications infrastructure and hence reduce the communication cost.

CONCEPTANDINNOVATION

The processing time of a query is the time from when it is received at the central processor to the time when the response is ready to be transmitted to the user. Typically, user queries are collected into batches by the central processor at the appropriate time and satisfied by searching the traffic data base. The order in which data base accesses are made determines the mean processing time. A natural question is, Can an algorithm be designed that, given any batch of queries, generates an ordering of the data base accesses such that the mean query processing time is minimized? This is essentially a scheduling problem for which no solution has previously been presented. Preliminary work has shown that it is highly unlikely that such an algorithm can be found that will remain computationally tractable as the number of observation points (information nodes by which routes are defined) increases. The practical significance of this result is that one can avoid searching for algorithms that minimize processing time and concentrate on developing heuristics which, while not guaranteeing minimum processing time, produce good results in practice.

For example, it is highly probable that there will be a great deal of overlap among different users' requests for traffic information; thus, a heuristic scheme could be developed to sort database inquires by observation points along the requested routes, thereby considerably decreasing the number of times information on **each** observation point must be recalled from the data base.

The investigator's prior experience in algorithm and heuristic design suggests a sequence of heuristics, each generating better orderings (i.e., more likely to deliver results in closer to the minimum processing time) in exchange for increased computational overhead. This sequence of heuristics will be analyzed experimentally and analytically to quantify the quality of the schedules obtained and the amount of computation required, thus enabling future system designers to choose an appropriate heuristic in accordance with the performance desired and computation resources available.

As ATIS programs develop, information from several physically dispersed sources will need to be presented to the user simultaneously. A situation in which

'This IDEA project is under negotiation, pending resolution of indemnity provisions of the IDEA contract required by the National Research Council.

synchronized information transfers are required is where a user is to be delivered a map, drawn from a geographic information system, as well as a voice message which describes the traffic conditions along the way, drawn from a traffic data base. The transfers must arrive simultaneously to be most useful. For various business, administrative, and technical reasons, it is likely that the data bases will be physically dispersed. The utilization of the communication medium will be maximized if the transfers can be completed in the minimum time possible.

It is also important to reduce the traffic due to ATIS on the communications infrastructure. In many deployment scenarios, information will be delivered to travelers using wireless personal communication devices, such as personal digital assistants, in-vehicle monitors, or pagers. The scarcity of spectrum for wireless communications makes its efficient use essential. In addition, studies have shown that delivering information via wireless networks also places heavy loads on the supporting wired signaling network. Once again, scheduling the use of the communication links and switches so as to minimize the time to complete any given set of information transfers can effectively reduce these loads.

For multiple sets of information sources (data bases) and sinks (users), each source and sink can take part in one data transfer at any time, and data are sent in fixed sized packets. The amount of data sent from each source to each user is known, as are the data items to be synchronized. Algorithms are designed to complete the transfers in minimum time with a small amount of buffer memory at each user terminal for alleviating the requirement for precisely synchronized transfers.

IDEA PROJECT INVESTIGATION AND PROGRESS

Contract is in negotiation. No results at this time.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

Contract is under negotiation. Implementation plans will be developed after the contract is awarded.

SCALEMODEL AHS RESEARCH FACILITY (SMARF)

IVHS-IDEA Project **11'**

Raul Vera and Edwin Lyon III,
SRI International, Menlo Park, California

IDEA PRODUCT

This IDEA project develops a scale-model approach for testing IVHS sensor and control systems specifically for automated highway systems (AHS) and serves as an excellent bridging technology between computer simulation and full-scale development and testing. Through the development and implementation of dynamic scaling laws, SMARF will provide data on inter-vehicle station-keeping dynamics, cornering, acceleration, and maneuver rates that can be readily converted to full-scale data. SMARF, coupled with computer simulation, would lead to a judicious selection of full-scale tests and can safely and cost-effectively provide a significant research and development test bed and data base for testing vehicle dynamics and IVHS sensor and control system operations.

CONCEPT AND INNOVATION

The SMARF system will embody the dynamics realism necessary to portray an automated driving process on specialized roadways while saving development cost and time, reducing safety risks, and offering repeatability and accuracy of test scenarios. Upon completion of the IDEA investigation, a working scale-model AHS will result that will faithfully reproduce the dynamics of a full-scale longitudinal control system. An integral part of the current investigation is the development of scaling laws that will be designed to allow AHS developers to translate small-scale vehicle results to full-scale vehicles. Careful design of the scaling laws will permit researchers to determine, prior to full-scale system or subsystem component development, what the various operating requirements for the full-scale system should be. This would apply particularly to actuator components, control loop cycle times, actuator position and velocity sensors, and to larger subsystems such as advanced vehicle control systems (AVCS) and associated sensors. Further, a comprehensive set of SMARF small-scale tools would encompass the interaction of the vehicle with the roadway infrastructure. Various competing schemes are being proposed to tradeoff sensing, communications, and processing loads required by any AHS between on-board vehicle components and infrastructure-based components. SMARF could be employed to aid in evaluating competing schemes by actually implementing each one and running a statistically significant number of tests to make meaningful performance trade-offs.

During SMARF development, a methodology for determining the applicability of scale modeling to AHS and subsystems was devised. Fundamental to the methodology was the selection of candidate AHS systems and subsystems that are amenable to scaling. There are four central issues to be resolved:

1. Restrictions placed on sensor and associated subsystems at scale sixes,
2. Feasibility of accommodating sensor and control processing hardware in a scale vehicle,
3. Scaling requirements of sensor operating frequencies (as may be the case with some radar and radar mode ranging systems), and
4. Scaling laws necessary for treatment of vehicle static and dynamic parameters such as velocity or turning rate with highly nonlinear scaling characteristics.

IDEA PROJECT INVESTIGATION AND PROGRESS

Significant progress has been made on several fronts in the current investigation. First, after careful consideration of previously discussed scale payload requirements and limits, a scale factor of p=1/4 has been selected for SMARF vehicles. The l/4 scale selection will allow a comprehensive payload complement to be accommodated

'The IDEA project started January 1994 and will be completed by January 1995. IDEA project advisor: Dick Bishop, FHWA.

while providing the required dynamic fidelity. Three factors contributed to the selection of l/4 scale:

1. Scale parameters (acceleration, velocity, weight, and energy) in a l/4 scale model are well within measurable tolerances;
2. Vehicle volume constraints are such that straight-forward application of miniaturized sensors, actuators, and telemetry is possible; and
3. Low cost, off-the-shelf l/4 scale vehicle components including chassis, articulated suspension systems, power plants, and actuators are readily available.

Radar has been selected as the headway maintenance sensor for the current investigation. Radar is a mature full-scale technology which in recent years has been rejuvenated by the advent of VLSI, micro-miniature components, and surface mount technologies. The potential problem for SMARF, as mentioned earlier, is the ambiguous requirement to scale sensor frequencies. However, SMARF research team experience and expertise coupled with a thorough review of technical literature on the subject reveals that several methods exist to circumvent the perceived need to scale up radar frequencies. Pulsed radars would probably be prohibited for the scale vehicles due to the signal bandwidths required to clock the time of arrival of the return pulse to derive range to the lead vehicle. To meet a lcm range resolution requirement with a pulsed radar the clock would have to be able to resolve timing down to 0.04 nanoseconds (ns). These timing requirements imply a radar sensor system having a 20 GHz bandwidth, and make it impractical for our purposes. Frequency Modulation (FM) altimeter radars suffer from a similar timing problem in that the frequency ramping required of the carrier must be tightly controlled by a clock for later comparison with the return pulse. However, by combining waveform ranging modulation with echo carrier phase measurement, these timing and bandwidth requirements can be alleviated.

Carrier phase radar ranging employs a simple transmitter and a homodyne receiver. Small amounts of transmitted carrier energy are leaked into the receiver front-end, where they heterodyne with the returning echoes. Thus the radar return phase is compared directly with the transmitted carrier phase, thereby eliminating the need for precise waveform modulation, clocking, and demodulation. The phase comparison yields a phase difference (angle), between the transmitted and received energy, which is directly proportional, in this application, to the distance to the lead car. At 1 gigahertz (GHz), 1 cm will exhibit an easily-measured 12 degree phase difference. By also applying waveform modulation, or, conversely, multiple radar carrier frequencies, ambiguities in range, inherent in phase-measurement ranging systems, are eliminated.

Significant progress was also made in the development of dynamic scaling laws which will be required to replicate, with high fidelity, full scale vehicle dynamics. By employing the scaling laws it was possible to identify potential scaling infidelities which arise due to nonscaling parameters. In each case non-scaling parameters were analyzed and incorporated into a computer model of vehicle dynamics. The complete set of dynamic equations that fully describe the motion of a full-scale automobile in three dimensions are both non-linear and complex. Fortunately, to illustrate the physical scaling issues that arise when a p ($p < 1$) scale model is used to represent the full-scale automobile only a much simpler set is needed. Consider the motion of a vehicle traveling in the positive x-direction (along the vehicle longitudinal axis) on a relatively flat surface. The differential equations that describe this motion are given by:

$$x^{11} = [T_x(t) - ax'^{2} - bxmg]/m$$

and

$$z'' = [T,(t) - mg - kz\ dx']/m$$

where x, x', and x" are the distance, velocity and acceleration in the x-direction, z, z', and z", are the distance, velocity and acceleration in the z-direction, m is the mass of the automobile, T_X and T_Z are the applied forces in the x- and z-directions, a is the coefficient of drag, *b* the coefficient of friction, g the gravitational acceleration, *k* the suspension spring constant, and *d* the damping constant associated with the automobile struts/shock absorbers. To differentiate between the parameters associated with the full-scale automobile and small-scale model the subscriptfand s will be used.

By choice the length of the scale model is *p* times the length of the full-scale automobile, hence, the volume of the scale model is p^3 times the volume of the full-scale automobile. Assuming the density of the materials in both the scale-model and full-scale automobile are similar the mass of the scale-model (m_g, is p^3 times the mass of the full-scale automobile (m_f). Similarly, distance, velocity, and acceleration for the scale model (x_8, x_8', x_8'') are *p* times the values for the full-scale automobile (x_f, x_f', x_f'').

Multiplying p times the full-scale equations of motion gives

$$x_8 = px_f'' = [pT_{xf}(t)]/m_f - [pa_f x_f'^2]/m_f - [pb_f m_f g_f]/m_f$$

and

$$z_s = pz_f = [pT_{zf}(t)]/m_f - [pm_f g_f]/m_f - [pk_f z_f]m_f - [pk_f z_f]/m_f$$

Equating term by term with the small-scale equations of motion and inserting $m_8 = p^3 m_f$ gives for the x-component,

$$[pT_{xf}(t)]/m_f = T_{xs}(t)/(p^3 m_f)$$
$$[pa_f x_f'^2]/m_f = [a_s x_s'^2]/p^3 m_f)$$
$$[pb_f m_f g_f]/m_f = [b_s m_s g_s]/(m_s)$$

and for the z-component,

$$[pT_{zf}(t)]/m_f = [T_{zs}(t)/(p^3 m_f)$$
$$[pm_f g_f]/m_f = [m_s g_s]/(m_s)$$
$$[pk_f z_f]/m_f = [k_s z_s]/(p^3 m_f)$$
$$[pk_f z_f]/m_f = [k_s z_s]/(p^3 m_f)$$

Finally, substituting $x_8 = px_f$, $z_8 = pz_f$, and their derivatives gives

$$p^4 T_{xf}(t) = T_{xs}(t)$$
$$p^2 a_f = a_8$$
$$pb_f = b_8 \text{(using the fact } g_f = g_8)$$
$$p^4 T_{zf}(t) = T_{zs}(t)$$
$$pg_f = g_8$$
$$p^3 k_f = k_8$$
$$p^3 d_f = 4$$

The above equations determine the values of scale-model parameters that are required for the model to represent accurately the full-scale automobile motion. For example, if the scaling *p* is chosen to be l/4, then the applied x and z thrusts are l/256 of the full-scale thrusts, the drag coefficient is 1116 of the full-scale drag coefficient, the spring and damping coefficients are l/64 of the full-scale spring and damping coefficients, and the scaled gravitational acceleration is l/4 of the full-scale gravitational acceleration. By appropriate design of the scale model all of the variables can be set to their appropriate values except, of course, for gravitation. For precise representation of the full-scale automobile dynamics the actually-encountered scale-model gravitational acceleration is seen to be four times the value required for the scale laws of motion.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

Although the SMARF concept is still in its infancy, it has become clearer that the applicability to AHS development is significant. The true advantages of SMARF will be realized if it is fully implemented early in the AHS development cycle. With SMARF as a research and development tool, AHS development can proceed at a much accelerated pace since trade-off studies between competing and complementary AHS architectures, subsystems and components can be quickly executed with concrete results.

During initial stages of the current investigation, the bulk of the research was focused on determining the applicability of scale modeling to the AHS development problem. All of the literature reviews, and dynamics analysis indicate that scale modeling the AHS milieu will be effective if employed in the following manner:

- Determining optimum maneuvering strategies for lane changing, platoon merge and de-merge, and entry and exit from the AHS. In this case the l/4 scale model AHS could be used as a precursor to provide direct input to full-scale AHS vehicle design, determine where full-scale testing should focus, and actually design and test the proposed full-scale tracks;
- Rapidly prototyping and implementing control algorithms and control hardware schemes to perform feasibility testing prior to full-scale AHS development;
- Evaluating various vehicle-infrastructure trade-offs by actually implementing and evaluating them in the l/4 scale AI-IS; and
- Validating existing computer simulations and animations of full-scale AHS.

Investigation results obtained to date have been encouraging enough to proceed with acquisition of a l/4 scale automobile chassis, powerplant, control actuators, and remote control equipments. A follow-up testing with the “follower vehicle” in a two-vehicle SMARF implementation mode instrumented with carrier phase radar and remote controls of the lead vehicle is proposed to be carried out for implementing the SMARF system for model testing of the AHS.

VEHICLE LANE CONTROL SYSTEM

IVHS-IDEA Program 12[1]

E. William Bush,
Compuline Inc., La Jolla, California

IDEA PRODUCT

This IDEA product alerts the driver if the vehicle being driven on the highway is not in the center of lane and automatically keeps the vehicle centered in the lane. Lane centering control with this system is analogous to the ubiquitous “speed control” in most modem vehicles.

CONCEPT AND INNOVATION

Utility and simplicity are the focus in configuring this IDEA system. The operation involves a simple, continuous wave and phase comparison electronic module in the vehicle and evenly spaced inexpensive electronic elements imbedded in the road surface. The imbedded elements are completely passive and unaffected by any reasonable combination of snow, salt and water. Also, because the link between the road and the vehicle utilizes radio frequency, the visibility impediments either in the air or on the road surface have no effect on the system operation.

The vehicle module transmits a continuous wave signal to energize or excite a resonant inductive loop in the roadway, sequentially receives the return signal from the road inductive loop, and determines the position of the vehicle relative to the roadway center line. Figure 1 shows a plan view of the configuration.

A phase sensing circuit provides a nulling signal as the vehicle adjusts to the center of the lane as shown in Figure 2. The orthogonal transmitter and receiver coils are mounted in the middle of the vehicle with the trans mitter coil vertical and the receiver coil horizontal. When a road coil is approached it is activated by the signal received from the transmitter coil only if it is slightly out of alignment with the transmitter coil. The transmitter coil will induce a clockwise current into the road coil if the vehicle is on one side of the coil and a counterclockwise current into the road coil if the vehicle is on the opposite side of the coil. In all cases the road coil signal is essentially repeated both in phase and amplitude in the vehicle receiver coil.

A phase detector circuit detects the position of the orthogonal vehicle coils. The circuit provides a positive output when the vehicle coils are on the right side of the road coils, a negative output when the vehicle coils are on the left side of the road coils, and a null when the vehicle is exactly over the center line of the road coils.

IDEA PROJECT INVESTIGATION AND PROGRESS

A test and evaluation effort will be undertaken to optimize the road coil. The cost of this particular item is most important because it will be fabricated and installed in the largest quantity. Every effort will be made to simplify the circuit to arrive at the most cost-effective configuration.

The IDEA project will be performed in the following two stages.

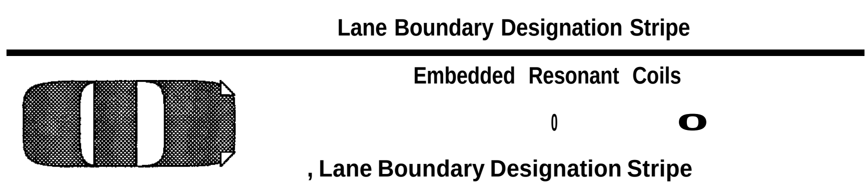

FIGURE 1 View of configuration.

[1] The IDEA project started July 1994 and will be completed by February 1995. IDEA project advisor: Gabriel Heti, Ontario Ministry of Transportation.

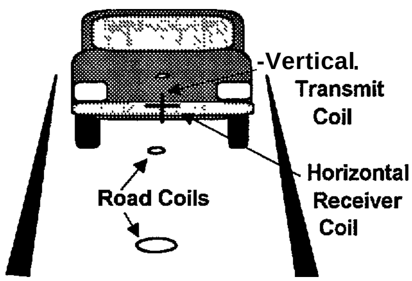

FIGURE 2 Road coil.

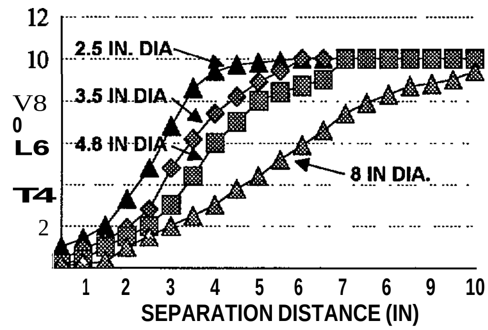

FIGURE 3 Proximity detection data.

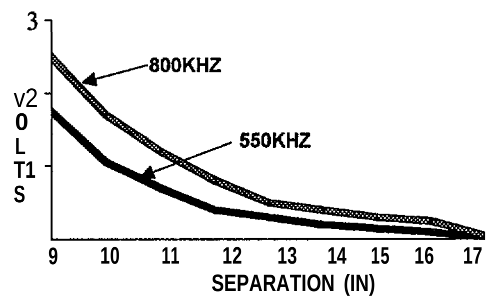

FIGURE 4 Orthogonal coils.

Stage 1 testing will include static tests, dynamic tests and limited environmental testing. The static tests will determine any special limitations such as the separation and orientation of the road coil and the vehicle' coil detector. Dynamic tests will insure satisfactory performance under the worst case vehicle velocity relative to the road coil.

A limited road test will be accomplished as a part of the Stage 2 testing. The instrumented distance for the road test will be limited by the cost of fabricating the road coils as well as the cost of installing the road coils. One hundred road coils will be fabricated and placed in an oval track configuration. The vehicle will proceed around the track with the driver using the analog meter to stay within the designated ares and then a servo controller will be used to automatically follow the road coil track. Next the road coils will be arranged in a straight line so the vehicle can make passes at various speeds. This will verify the established readout time constant and latency design.

A number of tests were conducted to establish the feasibility of the proposed system. One test was conducted to check the coupling between two coils and the affect of changing the coil diameter. The receive coil output was held constant by increasing the voltage on the transmitter coil as the separation was increased. Several different coil diameters were checked at the same transmitted frequency. The results of this test are shown in Figure 3.

Next two coils were arranged in an orthogonal configuration so that one coil could transmit and the other coil could receive. Then a third coil representing the road coil was used to couple energy from the transmitter coil to the receiver coil. As the third coil was removed from the two other coils the received amplitude was recorded with respect to **the** separation distance. The results of this test are shown in Figure 4.

Another series of tests were conducted to determine the effects of covering the road coils with a layer of salt water, concrete or asphalt. The tests were conducted at frequencies of 1.05MHz and 1.47MHz. The salt water was mixed at 1 teaspoon of salt per cup of water and 2 teaspoons of salt per cup of water and the saltwater depth was increased to 1 3/16 inches. Within the limits of the instrument resolution, there were no perceptible or discernible changes in the output when the salt water was placed on top of the road coil and directly between the road coil and the orthogonal transmit/receive coils. The results were the same when 2 inches of asphalt or 2.25 inches of concrete were placed between the road coil and the orthogonal transmit/receive coils.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO M-IS

The IDEA project results will enhance application of lane control systems in IVHS and automated highway systems practice. The successful development of the IDEA product may lead to larger-scale testing as part of a field operations program.

DEVELOPMENT OF AN INTELLIGENT AIR BRAKE WARNING SYSTEM FOR COMMERCIAL VEHICLES

MIS-IDEA Project 13[1]

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University of Washington, Seattle

IDEA PRODUCT

The project focuses on developing an intelligent on-board brake warning device (IBWD) for air-brake equipped commercial vehicles. This device will warn the driver of brake degradation or impending failure in advance, allowing the driver adequate time for corrective action. The device will also be designed to consider off-board information, such as grade severity data, that could be transmitted to the vehicle from fixed stations near steep downgrades using IVHS technology. The IBWD will assess braking performance from the standpoint of the total vehicle system.

Malfunctioning brakes are the leading mechanical cause of commercial vehicle accidents, and they constitute the most common safety violation. The IBWD, which will be low cost, will mount in the cab or tractor of a truck or bus and will monitor a relatively small number of parameters associated with brake system performance. The most significant benefit from the IDEA product will be the safety of truck drivers, automobile occupants, and the general public. The IBWD will also give inspectors a readily accessible, electronic means of evaluating the hidden and most commonly deficient aspect of commercial vehicle safety, without requiring close physical proximity to the passing vehicle. As such, the proposed device will enhance the efficiency of commercial vehicle operations by reducing delays at inspection stations, improving the identification of maintenance needs at trucking terminals, and promoting the deployment of other IVHS technologies.

CONCEPT AND INNOVATION

The IBWD will assess braking performance from the stand-point of the total vehicle system; as such, it will not necessarily identify specific brake malfunctions (e.g., at a particular wheel location), but it will be sensitive to brake degradation from *any* cause. It is intended to be passive, so the driver will not have to calibrate the device or enter any information related to the vehicle, road, or load. The IBWD will provide a real-time assessment of brake performance, as related to important vehicle and roadway parameters. It will use an algorithm to instantaneously compare current data inputs with the following criteria: (1) on-board rules for the absolute threshold of safety, (2) trend data representing the vehicle's past performance, and (3) predictive guidelines that will trigger an alarm if trend data are unfavorable. Results of the multidimensional analysis will be stored and communicated to the driver, vehicle maintenance personnel, or authorities. An audible or visual go/no-go warning will be issued to the driver at the first instant of actual or predicted brake degradation beyond an established threshold. It is also anticipated that this information will be useful in diagnosing the cause of warning.

IDEA PROJECT INVESTIGATION AND PROGRESS

Commercial vehicle air brakes are hazardous for a number of reasons. The majority of such brakes are currently comprised of drum-type S-cam foundation brakes, with diaphragm actuators and manual slack adjusters. Diaphragm actuators are very sensitive to adjustment condition; the actuator pressure-versus-force characteristics are highly nonlinear and have a sudden and frightening drop-off in force when the pushrod stroke

[1]The IDEA project started August 1994 and will be completed by July 1995. IDEA Project advisor: James Brittel, NHTSA.

[2]Associate Professor, Department of Mechanical Engineering, University of Washington.

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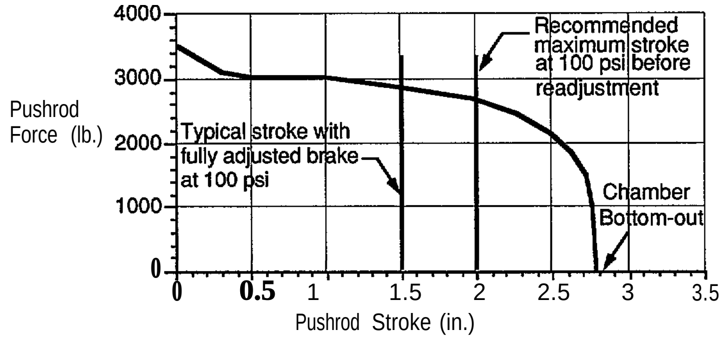

FIGURE 1 Pushrod stroke vs. force for type 30 brake actuator at 100 psi [Radlinski 1982].

exceeds the recommended level (Figure 1). Actuator pushrod stroke increases normally as the brake shoes wear, or as the drums expand at higher temperatures. When the recommended adjustment level is exceeded, the design of a typical actuator is such that the diaphragm diminishes in effective area as stroke increases. This characteristic, along with other design-related factors, causes the force output at a given pressure level to diminish. When the pushrod stroke becomes so great that the pushrod bottoms out in the actuator chamber, brake force drops to zero. Note that the recommended pushrod stroke adjustment range exists in the flat portion of the curve, thereby ensuring a constant force output for pushrod strokes within that range. Outside of the acceptable range, the brake force drops off sharply in a nonlinear fashion. If this occurs on the road, sudden and unpredictable loss of brakes can result.

Sensitivity to adjustment is compounded by the lack of feedback to the driver. Unlike hydraulic brake systems, wherein brake pedal depression acts to pressurize a fluid, application of an air brake pedal (treadle valve) simply opens a pressure valve to divert already-compressed air from the storage tank(s) to the wheel actuators. As such, the treadle valve is insulated from the direct energy input to the brakes and provides the driver almost no tactile sensation of a problem. Hence, as braking efficiency diminishes (through loss of adjustment, thermal loads, or other factors), there is very little sensation transmitted through the treadle valve; in essence, it doesn't necessarily feel spongy or low, as is usually the case in an automobile. The driver's only real feedback is a "seat of the pants" sense of deceleration for a given (perceived) pedal application position.

Sensitivity to adjustment is further heightened by an increase in the time for all the brakes to reach full operating pressure. As the actuator stroke increases, not only does the force level drop, but it also takes longer for the brakes to reach the desired application pressure (air transmission lag time). It can take as much as three quarters of a second for air to reach the rear-most axle of a triple trailer combination. At 60 mph, this can greatly add to stopping distance.

Thermal loading is more significant for commercial vehicle brakes than it is for automobile brakes. Heavy truck brakes have a disproportionately high thermal loading; studies have shown that at 55 mph, a typical 80,000 lb. tractor-trailer, on a per-pound basis, requires about six times the braking horsepower of a 3,000 lb. automobile [Radlinski 1987]. In addition to providing adequate braking torque, heavy truck brakes must have adequate thermal capacity to dissipate heat, which can degrade brake performance. Excessive heat not only degrades the braking components' frictional qualities, but it also causes brake drums to expand, thereby further increasing the actuator stroke requirement (thus reducing braking force). Because of these compounding effects, hot brakes cause a significant reduction in braking performance, which further underscores the need for proper adjustment. For a fully adjusted brake operating at 600°F, the available brake torque is only 85 percent maximum, and drops to only 50 percent of maximum when the stroke reaches the upper adjustment limit.

An additional factor further complicates the understanding of brake performance as measured by pushrod stroke on a stationary vehicle. A phenomenon known as dynamic stroke increase has been observed; pushrod stroke (at a given pressure) has been found to increase beyond the statically determined value when the vehicle is in motion [Radlinski 1982]. This effect, caused by self-energization of the brake mechanism and by elastic deformation of the foundation brake components, has called into question the widespread practice of using static brake stroke adjustment to assess brake condition.

The IDEA project is aimed at understanding these effects (and the collective compounding of these effects) through the measurement of just a few parameters. Focus will be on an indirect, innovative approach to the assessment of brake condition. This will involve consideration of the entire vehicle as a system, as opposed to consideration of individual brake performance at each wheel. It will first be necessary to select a small number of measurable input variables that can be correlated to a measure of current and expected braking performance. These input variables are readily obtainable from the vehicle and environment. Second, an analytical algorithm will be developed to assess braking performance via a three-tiered approach. This algorithm will be developed on the basis of vehicle-acquired real-time data. The algorithm will analyze braking performance on the following bases:

- On an absolute basis (e.g., compare input data with general standards for minimum deceleration);
- On a vehicle-specific basis (e.g., compare input data with "expectations" of minimum brake performance for the particular vehicle); and
- On the basis of trends for the specific vehicle (e.g., compare input data with braking history from the specific vehicle).

The computerized algorithm will include predetermined "warning flags." When measured brake performance falls outside an "acceptable" window, the IBWD will warn the driver. Some representation of braking history, as well as evidence of any issued warnings will also be recorded. These data will be available for off-board transmission to roadside readers near inspection stations for use by commercial vehicle enforcement authorities.

Initially, only two variables, brake input pressure and vehicle deceleration, will be studied to determine their relationship in the context of a given brake and vehicle combination. It is expected that a five-axle tractor-semitrailer model equipped with standard Type 30 air chambers will be used to explore the effects of brake application pressure on deceleration, with all other variables held constant. An analysis matrix will be set up to assess the effects of variation of other key factors, including brake adjustment, vehicle weight, speed, air volume transmitted to the tractor and trailer, and roadway grade. Initially, these parameters will be assessed for the "static" case, meaning each vehicle or environmental parameter will be varied against deceleration, without the confounding effects of heat and brake fade. Once these parameters have been assured for the static" case, the "dynamic" effects of heat and time will be scrutinized.

This analysis matrix will allow the selection of the minimum set of input variables necessary to characterize brake performance (Figure 2). Six readily measurable parameters will be considered:

- Brake input (control) pressure,
- Vehicle deceleration,
- Vehicle speed,
- Vehicle gross weight,
- Transmitted air volume (to tractor and trailer), and
- Road grade.

Once a set of critical vehicle and environmental parameters has been selected, an algorithm will be designed to process the data and to develop the warning function. Initially it will be designed as a rule-based artificial intelligence system, i.e., it will make go/no-go decisions based on measured vehicle and environmental conditions and absolute performance thresholds. The next stage will be to incorporate the use of artificial neural

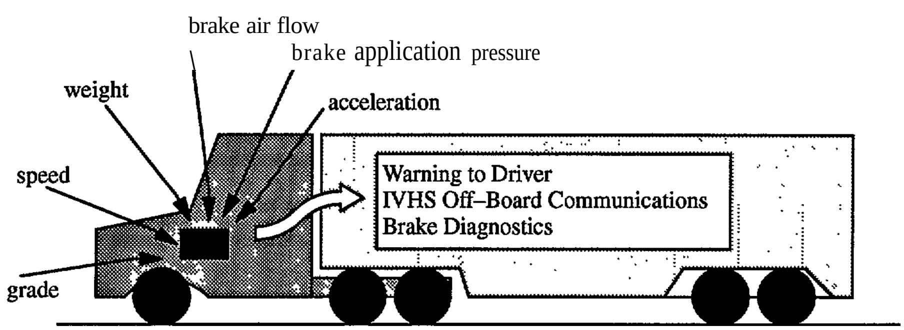

FIGURE 2 Intelligent air brake warning system concept.

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networks and/or fuzzy logic to perform historical trend analyses. This will extend the warning algorithm to encompass "knowledge" of changes in the characteristic parametric patterns that indicate brake deterioration.

Validation of the algorithm will be made by comparing it to existing computer braking models, if any are applicable. A prototype intelligent warning system will be developed, and limited full-scale road testing will likely be performed at the Paccar Technical Center, in Mt. Vernon, Washington.

The project will be carried out in the following two stages: Stage I encompasses a literature search and selection of a minimum set of measurable parameters that characterize brake performance. A parametric study of these variables will define first "static" and then "dynamic" interrelationships and mappings for conditions wherein braking efficiency is changing over time. Experimental determination of these relationships will be accomplished through full-scale vehicle testing. Initial study of IVHS technologies related to vehicle safety (such as automated inspection systems and road-to-vehicle communication) will also be conducted.

Stage II will develop an algorithm to process measured parameters and to predict truck braking performance. Tbis algorithm will be based on two types of technology: (1) the go/no-go warning of brake malfunctions will be based on comparison of real-time data with previously defined thresholds, and (2) artificial neural networks and/or fuzzy logic that draws upon a base of "knowledge" of less stringently defined parameter trends. Stage II will also involve formulation of acceptance and rejection criteria ("warning flags") for measured brake performance conditions. Experimental and analytical validation of a prototype brake warning system will be conducted through full-scale vehicle testing and through computer modeling.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO M-IS

IBWD has the potential for application to commercial vehicle braking systems. Extensive in-vehicle testing will be necessary following the IDEA project. A fully developed product will complement anti-lock brake systems (ABS) by providing assurance that the brake system has adequate stopping power at all times. If the system proves reliable, it may become a standard safety device, much like ABS. The IBWD will be demonstrated to the National Highway Traffic Safety Administration and to other relevant authorities in an effort to demonstrate its potential for increasing the efficiency of vehicle inspection programs, and to promote the use of related IVHS transparent borders technologies.

A host of potential partners are interested in participating. Index Sensors and Controls, in Bellevue, Washington, has expressed interest in assisting with sensor development, packaging, manufacturing concerns, and prototype development. Negotiations are under way with the Paccar Technical Center to obtain its assistance with full-scale vehicle testing for initial exploratory research and for verification of the prototype model. Consultation on IVHS issues and applications will be provided by the Washington State Transportation Center and by the Washington State Department of Transportation.

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ADAPTIVE FILTERING FOR IVHS AND ADVANCED VEHICLE CONTROL

IVHS-IDEA Project 14[1]

Laura R. Ray,'
Christian Brothers University, Memphis, Tennessee

IDEA PRODUCT

This project provides quantitative techniques for intelligent driving decisions. The results would have potential application to the following:

1. Determining information that is essential to IVHS decision making for automated driving, emergency intervention, and driver safety aids; and
2. Providing signals for advanced vehicle control systems (AVCS) to improve vehicle stability and drivability.

Processing algorithms will determine parameters such as road coefficient of friction, stopping distance, safe following distance, safe vehicle speed, and vehicle maneuverability as well as provide feedback signals for real-time control to improve vehicle stability and handling qualities.

CONCEPT AND INNOVATION

The algorithms to be developed will be based on *extended Kalman filtering*, a nonlinear adaptive filtering method. Similar methods have been used successfully in analogous problems concerning modeling of aircraft dynamics. The adaptive filtering algorithms require a dynamic model of the vehicle and data that is gathered continually from sensors on board the vehicle. The motion of ground vehicles depends largely on the tire forces; forces that cause deceleration and traction and that can prevent a vehicle from losing lateral stability or "spinning" during severe maneuvers. The tire forces are nonlinear, and they depend on uncontrollable factors, such as road coefficient of friction, tire pressure and wear, and vehicle loads. While the latter parameters can be measured using standard sensors, there is currently no way to measure or otherwise determine road coefficient of friction. In this project, the tire forces and motion will be determined using extended Kalman filtering and measurements from standard off-the-shelf sensors. The forces and motion serve as inputs to a Bayesian decision making procedure to determine the correct road coefficient of friction from a set of hypothesized values. Road coefficient of friction is extremely important to prediction stopping distances, safe following distances, and maneuverability; given an estimate of coefficient of friction, information required to make on-the-spot driving decisions can then be determined.

The uniqueness of this project is its focus on providing high-quality information for decision making and feedback control. Information required to make intelligent driving decisions depends on many factors, changes continually, and must be continually updated. During both normal driving and emergency situations, IVHS for automated and driver-assisted control must know whether a vehicle is capable of performing a required maneuver; if information on which decisions are based is inaccurate, IVHS systems may fail to choose the best course of action. In addition, prior AVCS research has shown that feedback signals such as wheel slip, wheel slip angle, and vehicle velocity improves performance gains over control systems.

IDEA PROJECT INVESTIGATION AND PROGRESS

The project will be performed in the following two stages. The first stage will determine whether the algorithms to be developed are feasible and can be implemented in real-time; what type of hardware (transducers and microcomputer) and sampling rates are required for implementation; whether necessary hardware is available

'The IDEA project started August 1994 and will be completed by July 1995. IDEA project advisor: Martin Lipinski, Memphis State University.

'Assistant Professor, Department of Mechanical Engineering, Christian Brothers University.

commercially; and what vehicle safety and performance improvements can be expected if such algorithms are implemented in a commercial product. Stage 1 will be done with computer simulation and will include the following five tasks:

1. Development of Nonlinear Estimation Algorithms

Adaptive filtering algorithms based on extended Kalman filtering and Bayesian decision-making methods will be developed and validated using computer simulation. Simulated data from an eight degree-of-freedom vehicle will be used to generate sensor measurements that serve as inputs to estimation algorithms. The outcome of this task will be estimated time histories of vehicle motion, tire forces, and road coefficient of friction.

2. Determination of Vehicle Parameters

Parameters required for IVHS decision making will be determined based on the estimated road coefficient of friction and the vehicle dynamic model. Examples of parameters such as stopping distance, safe following distance, and lateral maneuverability along with uncertainties in these parameters will be provided.

3. Robustness Assessment

The robustness of the algorithms to reasonable uncertainties in vehicle modeling will be assessed by computer simulation. Uncertainties in vehicle modeling will be introduced by mismatching the vehicle loads and tire force model of the actual vehicle and the estimation model.

4. Assessment of Performance Benefits

The benefits of the algorithms developed to a typical advanced feedback control system will be assessed by quantifying potential performance gains in a simulated antilock braking systems.

5. Implementation Requirements

Implementation hardware will be determined from sensing and computation requirements of the computer simulation. These requirements will be matched with off-the-shelf transducers and microcomputers that could be used to construct an IVHS product based on the algorithms developed in this project.

The second stage of the project will involve refinement of the processing algorithms, and a final verification stage using existing experimental data from a vehicle testing facility. Contingent on the availability of an appropriate data set, the computer model of the vehicle will be replaced with actual data and the algorithms will be verified using that data. If such data are available, this stage provides a low cost method of rigorous verification before launching an applied testing and evaluation project. Universal applicability and robustness of the algorithms will be assessed by using data from different vehicles, if available. The final product of the second stage will be expanded verification of the algorithms developing stage one and readiness to initiate real-time implementation.

Figure 1 shows a conceptual block diagram of an IVHS/AVCS vehicle that incorporates adaptive filtering for providing feedback signals and decision-making information. The major components of this project appear inside the dotted line, and the relationship of this project to other components (the control systems and IVHS decision-making logic) appear outside the dotted lines. In Figure 1, vehicle motion is measured using a set of standard off-the-shelf sensors. The smallest sensor set needed to achieve adequate results will be selected; preliminary results indicate that this sensor set includes longitudinal acceleration, lateral acceleration, yaw rate, roll rate, wheel angular velocities, steer angle, and brake line pressure. Such measurements can be obtained using accelerometers, rate gyros, tachometers, a pressure transducer,and a potentiometer. Sensor measurements serve as inputs to the extended Kalman filter and the Bayesian selection procedure. The extended Kalman filter provides estimates of the longitudinal (F_x) and lateral (F_y) tire forces and vehicle motion, including vehicle longitudinal velocity (V_x), lateral velocity (V_y), yaw rate (r), roll rate (p), roll angle, four wheel slips (s_{fl}, s_{fr}, s_{rl}, s_{rr}), and four wheel slip angles ***(a,, a,, a,,, a,). These*** estimates can be used directly as feedback signals in advanced control systems. The estimates are also used as inputs to the Bayesian selection procedure for determining the road coefficient of friction, and to determine necessary vehicle parameters.

Figures 2 and 3 show example preliminary results for project task one. Figure 2 shows an example of the output of the extended Kalman filter. Vehicle motion for a braking input 3000 N-m and a front axle steer angle of 0.15 rad (8.6 degrees) is simulated on road surface where the coefficient of friction changes abruptly several times; the steering and braking inputs correspond roughly to those required to initiate a modest avoidance

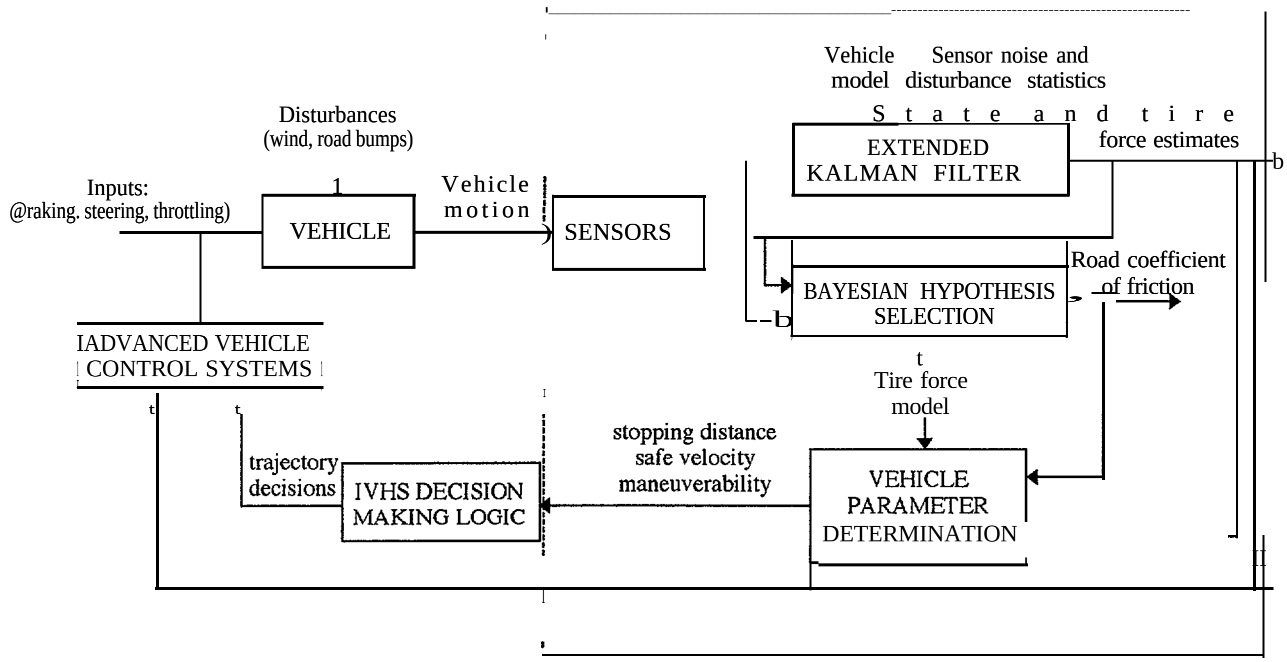

FIGURE 1 Block diagram of the MIS-IDEA project components (inside dashed box) and relationship to other IVHS components.

maneuver on a dry surface. Changes in road coefficient of friction are unknown to the extended Kalman filter. The actual motion along with filter estimates of longitudinal velocity, lateral velocity, roll rate, yaw rate, wheel slips and slip angles, and longitudinal and lateral tire forces are shown. Tracking ability of the extended Kalman filter is excellent, even in the face of abrupt changes in vehicle motion characteristics.

In the Bayesian selection procedure, the road coefficient of friction is estimated recursively by statistically comparing the tire force estimates from the extended Kalman filter with those that result from an analytic tire model for a set of hypothesized values of road coefficient of friction. The most likely value is then chosen from among the hypothesized values based on the statistical comparison. Figure 3 shows an example of the output of the selection procedure for the inputs and road surface of Figure 2. The solid curve shows the actual road coefficient of friction and the dashed curve gives the estimated road coefficient of friction. Tracking of the actual road coefficient of friction is excellent, with convergence in less than one second for each abrupt change in road coefficient of friction. The selection procedure responds nearly instantaneously to the sudden decrease in road coefficient of friction between t = 1 sec and t = 2 sec. Preliminary results of this task alone demonstrate the basis for a significant driver safety aid, such as warning device for dangerous road surfaces.

The final block inside the IVHS IDEA project box of Figure 1 is labeled vehicle parameter determination. The vehicle parameters serve as inputs to existing IVHS decision-making algorithms. Given the extended Kalman filter estimates and road coefficient of friction, vehicle parameters can be determined in a number of ways. In this project, examples of such parameters will be provided, based on table look-up or linearization methods.

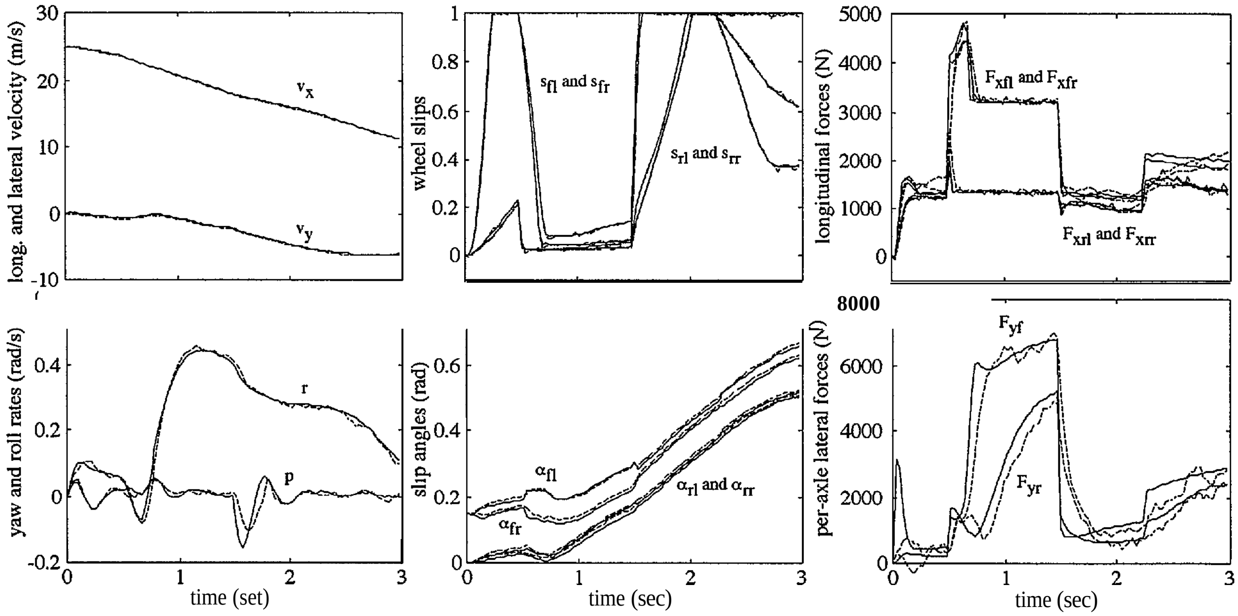

FIGURE 2 Actual motion and estimated motion from an extended KaIman filter for braking input of 3000 N-m and a steering of 0.15 rad.

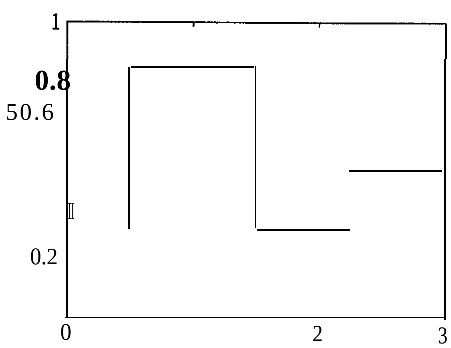

FIGURE 3 Actual (solid and estimated (dashed) road coefficient of friction for the steering and braking inputs and road surface variations of Figure 2.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

Efforts are under way to identify public-domain data sets for the validation task of second-stage project investigation and to identify businesses interested in product development and use of the algorithms in control system design. Project reports and papers published will be made available to industry and the IVHS/AVCS community for promoting partnership interests.

EFFICIENT USE OF NARROWBAND RADIO CHANNELS FOR MOBILE DIGITAL COMMUNICATION

MB-IDEA Project 15'

Michael P. Fitz,[2]
Purdue University, West Lafayette Indiana

IDEA PRODUCT

The IDEA product resulting from this project will be a communication architecture for efficient use of narrowband land mobile radio channels for digital communication. The project tests the proposed architecture with the goal to provide greater than 15Kbits/s transmission capacity on the 5KHz channels in the 220MHz band currently available to IVHS applications. The application will provide a resource for data communications in traffic management systems, travelers' information systems, and/or commercial vehicle operations.

CONCEPT AND INNOVATION

The innovation in this IDEA project is the use of advanced digital communications and signal processing theory to provide a dramatic increase in the bandwidth efficiency of infrastructure over narrowband (< 7KHz) radio channels. The best modems currently achieve efficiencies of about 9 bits/s/Hz with wireline communications; current narrowband wireless modems seldom achieve greater than 1 bit/s/Hz. While the wireless channel presents a greater challenge due to the location dependence and multipath characteristic of the wireless channel, the gap in bandwidth efficiency does not have to be this large. This project will apply many of the techniques used in wireline modems (e.g., large signal sets and complex coding schemes) and many techniques specifically for wireless communications (e.g., time and spatial diversity). Narrowband wireless communications with vehicles is characterized by a time-varying channel with deep fades in data transmission between moving vehicles. The techniques for improving the performance of a wireless modem address these issues and include pilot symbol aided modulation (PSAM), antenna diversity, and interleaving combined with error control coding. PSAM provides a simple method to track the channel variations and demodulate bandwidth-efficient digital modulations. Antenna diversity and interleaving combined with coding provides the redundancy needed to achieve high performance in the presence of deep fades in the received signal. The combined use of all of these techniques provides a radio architecture that will provide high performance and bandwidth-efficient communications.

IDEA PROJECT INVESTIGATION AND PROGRESS

Narrowband Wireless Communications and IVHS

An effective IVHS requires significant communication of data between the highway infrastructure and the vehicles using the highway. The only available means of accomplishing this communication is radio. Unfortunately, radio spectrum is a scarce commodity and digital radio communications with mobile units impose significant technological constraints. The IVHS program must compete with other mobile and personal communication services for the spectrum resource and in all likelihood the amount of dedicated spectrum to IVHS will be small and will likely be partitioned into narrow channels. As au example, a number of narrowband (5kHz) channels have

[1] The IDEA project started July 1994 and will be completed by July 1995. IDEA Project advisor: James Arnold, FHWA.
[2] Assistant Professor of Electrical Engineering, Purdue University.

been allocated to the IVHS program in the 220MHz band. To achieve maximum utility from this spectrum, IVHS must achieve the highest bandwidth efficiencies (bits/s/Hz) technologically feasible.

Narrowband wireless communication channels create a frequency nonselective time-varying fading channel for mobile digital communications [1]. Frequency nonselective implies that the bandwidth of the signal is small enough that all the different propagation paths combine at the receiver to effectively induce a time-varying multiplicative distortion on the signal. Figure 1 is a pictorial representation of the output envelope from this type of channel. Often for land mobile radio the variations in the envelope are accurately modeled as a Rayleigh random variable. Consequently, mobile radio channels are often referred to as Rayleigh fading channels. High efficiency (> 2 bits/s/Hz) digital communication is possible on these types of channels with a properly designed system. The instantaneous signal-to-noise ratio (SNR) of the channel output can be quite small, but the overall performance can be maintained at a desirable level by using time diversity (interleaving and forward error control (FEC) coding) and spatial diversity (multiple antennas). Time and spatial diversity mitigate the effects of the frequently occurring deep fades inherent to mobile radio by adding redundancy in the received signal. Figure 2 is a block diagram of a generic digital communication system that can achieve the desired level of performance for data transmission (< 10-4 bit error probability (BEP)) on the narrowband mobile radio channel. Much of the technology and algorithms needed to implement the system in Figure 2 are currently available but the resulting performance and bandwidth performance can be significantly improved.

Proposed System Architecture

General Architecture

The IDEA project is planned to achieve high performance mobile digital communication at a 3bits/s/Hz transmission efficiency. The communication architecture is being designed such that a baseline system can be relatively simple and inexpensive to build and yet also support significant additional enhancements achieved by more sophisticated processing of the same transmitted signals. Figure 3 shows the characteristics for the baseline architecture. Achieving a 4000Hz symbol rate while simultaneously meeting the FCC spectral emission requirements requires a sophisticated implementation of the modulator and pulse shaping circuits. The IDEA

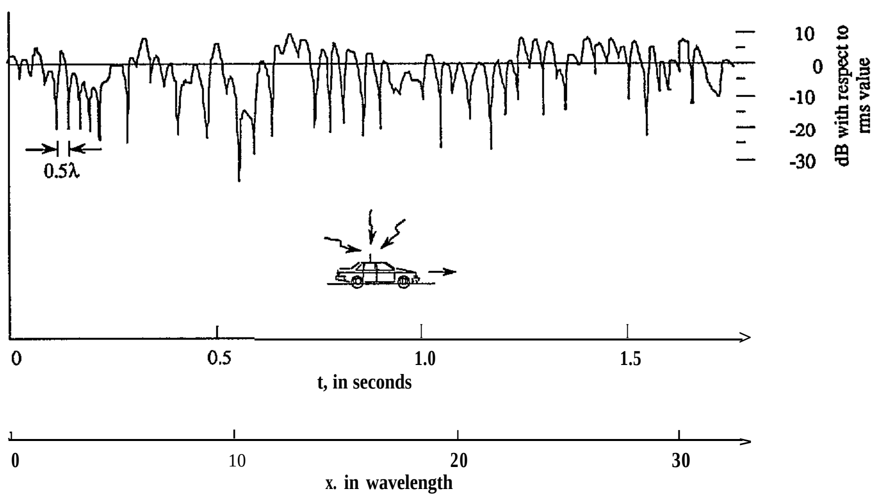

FIGURE 1 The envelope of the multiplicative distortion typical of narrowband radio channels.

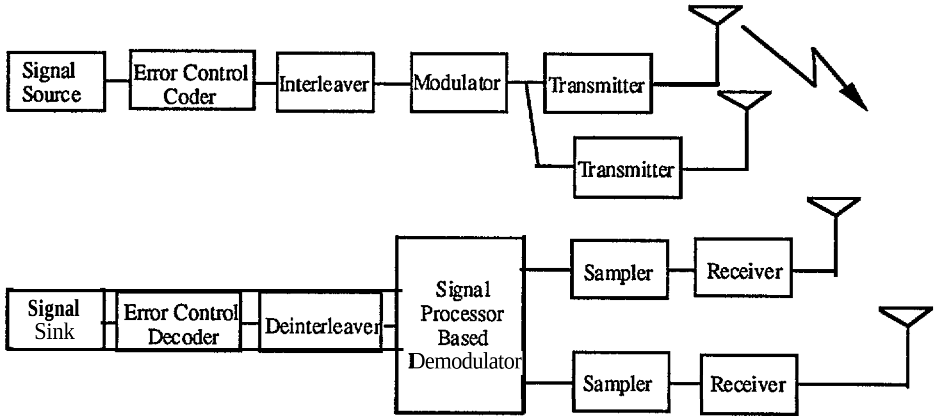

FIGURE 2 An architecture for high-performance narrowband radio data communications.

- 4000 Hz symbol rate
- QAM modulation
- 5000Hz bandwidth
- ~220 MHz center frequency
- Pilot symbol assisted modulation (PSAM)

3 bits/s/Hz

FIGURE 3 System characteristics.

project will use a digital signal processor (DSP) based modulator implementation based on the Motorola 56000 DSP. A large spectral efficiency requires a modulation scheme that transmits many bits per symbol [2]. Examples of this type of modulation are 16QAM or 64QAM which transmit 4 and 6 bits per symbol, respectively. Pilot symbol assisted modulation [3] is the simplest way to support large modulation alphabets like 64QAM in mobile channel applications. Higher dimensional signal constellations like 64QAM are linear modulations that produce a more complicated power amplifier design since most efficient power amplifiers are nonlinear. But, modern amplifier linearization methods allow operation over a substantial fraction of a saturated power limit without incurring too great a penalty in adjacent channel interference.

Infrastructure to Mobile Link

The baseline system will try to minimize the cost of the equipment for the mobile. To achieve this only one antenna will be used at the mobile. The fixed infrastructure portion of the link will use multiple antennas to provide transmitter antenna diversity. The benefits of diversity can only be obtained if diversity is used in conjunction with an error control coding scheme. For the forward link we propose using 64QAM modulation with a rate 2/3 code to achieve a 3bits/s/Hz efficiency.

Mobile to infrastructure Link

Again the baseline system will use only one antenna at the transmitter. The infrastructure portion will again provide antenna diversity. Since this diversity is at the receiver no coding is required to achieve the desired benefit. Consequently for the reverse link we propose using 16QAM modulation with no coding will be used to achieve the 3bits/s/Hz efficiency.

Performance Enhancements

A significant number **of** performance enhancements can be implemented within this architecture. Model-based signal processing [4-7] can be implemented to improve the performance of PSAM modulations. These types of algorithms can add l-2.5dB of link margin. Multiple antennas can be used at the mobile as well as at the fixed infrastructure and can greatly increase the performance capability. The amount of diversity provided in wireless communications is actually proportional to the product of the number of antennas at the transmitter and at the receiver. Consequently implementing multiple antennas at the mobile provides a more significant improvement than adding more antennas at the fixed infrastructure. Antenna arrays can also be used to combat co-channel interference (CCI) which is typically the predominant degradation in land mobile radio. CCI will usually arrive from different directions than the desired signal and this directionality can be exploited by appropriate processing of the signals output from each element of the array.

Design Tasks

The architecture design phase will produce a documented narrowband communication architecture optimized for digital vehicular communications. This design will specify the open air/wireless interface and provide performance verification through extensive simulation studies.

Error Control Coding Design

The selection of the error control coding scheme is the only design task that remains to be completed. A tentative plan to examine rate 2/3 convolutional, trellis, Reed-Solomon or turbo codes and select the scheme that provides the desired performance for the lowest complexity has been developed. A significant simulation effort will characterize the performance of the resulting architecture.

Performance Validation

This task will examine the overall system architecture performance. The simulation studies to be carried out in this phase will quantify the resulting performance when the dual transmitter diversity is combined with pilot symbol demodulation.

Transmitter Design

Hardware implementations of the transmission portion of the open-air interface will be completed in this task. This work will design and develop both integrated circuits and digital signal processor assembly language code to implement the needed functions.

Receiver Design

The IDEA project will produce a digital receiver design implemented in software. This receiver design will take samples stored in the data acquisition unit during testing and process them to produce bit decisions. These bit decisions can then be compared to the transmitted sequence to ascertain the resulting performance of the communication link.

Radio Frequency Unit Design

This IDEA project will specify a radio frequency (RF) transmitter (up-converter) and an RF receiver (down-converter) subsystem (including antennas). The construction of the specified unit will be carried out by a subcontractor after examining bids and capabilities of a variety of independent subcontractors.

Verification Tests

Four different tests are planned for this IDEA project and at the completion of this testing a complete characterization of this communication architecture will be completed.

Laboratory Tests

Laboratory tests will be performed in the Communications Research Laboratory at Purdue University. This portion of the project will integrate all the components developed in the other subprojects and test for electrical compatibility. The transmitter and receiver units will be cabled together to separate electrical degradations from multipath propagation induced degradations. Performance assessment will be done with partial integration (i.e., without the RF systems) and with full integration in the presence of thermally generated noise. Field tests will not proceed until the system has been completely characterized and all degradations from theoretically optimum performance have either been corrected or documented, *Purdue Area Tests*

Wireless transmission tests will be performed. These tests will verify the performance in the presence of multipath propagation and demonstrate the viability of the dual-transmission diversity architecture.

Lafayette Area Tests

One of the transceiver units will be mounted in a vehicle for local tests. These tests will verify the performance in the presence of time-varying fading and urban scenarios. The performance envelope in a rural area will also be documented.

Indianapolis Test Plan

Testing in the Indianapolis area will verify performance in dense urban areas and with high speed freeway travel and traffic.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

A joint effort between the Indiana Department of Transportation and Magnavox is being discussed for the application of the IDEA product results to intelligent control of rural traffic signals in Indiana.

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ENGINEERED VISIBILITY WARNING SIGNALS: TESTS OF TIME TO REACT, DETECTABILITY, IDENTIFIABILITY, AND SALIENCE

MIS-IDEA Project 16'

Theodore E. Cohn,[2]
University of *California, Berkeley*

IDEA PRODUCT

This project develops and tests an integrated display of warning signals for the IVHS vehicle driver and alerts the driver to incipient difficulties related to vehicle operation, proximity of other vehicles, driving conditions and vehicle position. The IDEA product will have the potential to maximize detectability and identifiability of such warning signals while minimizing the time to react.

Accumulated research in the human factors and vision literature points to a number of constraints and desirable properties that a warning signal display must satisfy. Using this work, with special attention paid to the known characteristics of the human visual system, a set of specifications for the warning signal display will be developed. Human performance will be tested with a display that satisfies these specifications. The project will provide the IVHS community with a description of design constraints, an example of a design developed within these constraints, benchmark performance, and proceedings for evaluating future prototypes of in-vehicle displays for commercial application.

CONCEPT AND INNOVATION

A warning signal display has been designed that integrates all of the projected warning signals for IVHS drivers using contemporary knowledge of the workings of the human visual nervous system. The project will measure human performance with this display using advanced techniques from visual psychophysics with the largest contrast available to the display using visual modeling techniques.

A proprietary process has been incorporated in the design that is thought to optimize both signal detectability and salience by supplying visual warning signals optimized for processing by the fastest and most sensitive nervous pathway in the human visual system.

IDEA PROJECT INVESTIGATION AND PROGRESS

The IDEA investigations have two separate objectives. The first objective is to develop guidelines that describe how to construct a warning signal array that optimizes a number of known facets related to vision; the second objective is to test a small cohort of typical human drivers in a series of experiments designed to help quantify their ability to correctly identify warning signals. The guidelines will include several features:

- Specification of the relevant attributes of the visual nervous system;
- Specification for a testing system including both software and hardware;
- Benchmark measures of performance (including warning signal detectability, identifiability, and time to react);
- Feasibility study of a Light Emitting Diode (LED) warning signal system; and
- Extrapolated performance measures for a fully implemented system.

[1]The IDEA project started July 1994 and will be completed by June 1995. IDEA Project advisor: Robert Clarke, NHTSA.

[2]Professor of Physiological Optics, University of California, Berkeley.

Aspects of Visual Function Relevant to Warning Signal system

Warning Signal System-Purpose

The warning signal system that will be examined has the simple purpose of alerting a vehicle operator to the existence of one (or more) of a set of twelve possible deleterious events or conditions. Only departures from ambient conditions meeting or exceeding a criterion will be signaled. Thus, this display design only addresses the issue of how best to communicate event existence to the human eye.

Warning Signal System--Introduction

It is assumed that the final design guideline must be as close to optimal as possible. Three factors necessitate this approach: one is the information onslaught to become available as in-vehicle information services under IVHS. Warning signals will have a lot of competition. Another is the high cost of missing a signal coupled with the (sometimes) small amount of time available in which to respond. Driving under IVHS will imply a tightened envelope on acceptable behavior. A most attractive candidate for display modality is the Head Up Display (HUD). The HUD deprives the operator of the full range of contrast ordinarily available with signaling devices, and adds distractors in the relevant field of view, because its signals are superimposed upon signals from the environment. Reduced contrast and distractors have been shown to raise reaction time (RT) and to lower detectability.

Constraints

The warning signal display is assumed not to violate strictures in relevant automotive safety standards (e.g. FMVSS 101/80). As such, Federal Motor Vehicle Safety Standards (FMVSS) will likely be expanded to embrace the new warning signals **needed.** Additionally, tangential issues such as the nature of nearby reflecting surfaces may require refined treatment (cf. FMVSS 107). For example, portions of the vehicle hood and even the roadway ahead, set a contrast maximum for a HUD seen against it.

Color is a traditional cue used in warning signals and its use is specified in FMVSS. Red signals the alarm condition, yellow a cautionary condition and green the "go" condition. Blue is used for in-vehicle indicators but is also used for a caution signal on emergency vehicles. While recent research suggests that greater benefit could be obtained from refined color usage, this project will adhere to traditional use so as to avoid conflict with present standards and to avoid the need for special solutions for color blind observers.

Steady Cue to Accommodation Plus a Reference Signal

It is known that search time is lowered when a cue for accommodation is provided. This is especially important if the warning signal system is embedded in a head up display placed at other than optical infinity. The project approach is to provide a continuous signal to assist driver accommodation that also supplies a fixed coordinate system within which warnings can appear. This accommodation cue will be largely symmetrical in shape so that a departure from normality can be signaled by a unique asymmetries of shape. In this way, the warning signal display takes advantage of the rapid and sensitive human ability to detect asymmetry, a process thought to be performed with "parallel" computations and thus thought to be optimally fast.

Contrast

It is important to maximize the contrast of targets as contrast is known to both (1) raise detectability and identifiability and also to (2) lower search time. Contrast is a very significant issue if the warnings are supplied in a head up display, where maximum contrast is far less than for a directly viewed display.

Position, *Shape*, and *Size*

It is well known that stimulus similarity is a deleterious influence on choice reaction time. Research has shown that signals should have unique position, size and shape.

Size, by itself, adds to detectability but compromises other display attributes (see "Compactness" below). A fully mature design could use enhanced size to code rarely occurring but highly costly events. Data related to the frequency and cost of events to be warned of are not yet available. In the present study we will assume that events are equally likely and equally costly if ignored.

Compactness

Resolution capabilities of the human eye require that information bearing aspects of a given signal (e.g. its shape and/or its affixed message) must exceed 10 arcmin for icons or alphanumeric characters, 2 arcmin for component details, as that is the limit of resolution achievable by operators whose acuity is at the typical licensure limit (20/40). As a practical matter, we want to exceed this value since many operators are licensed by exception and have acuities as low as 20/100. Moreover, the size calculation assumes that the target happens to be imaged on the fovea, an assumption that would generally be unwarranted.

Furthermore, to accommodate 12 separate warnings, one requires a compact display, not a linear one, as the latter will, over one or more of its extremes, exceed the bounds of the region of high resolution in the eye. One could choose to adopt a 3x4 array which lends the appropriate compactness to the system, but even in that case adequate separation must be employed to prevent "crowding" from limiting visibility. On the other hand, one does not want the target too large or parts will be imaged at higher eccentricity where detectability and contrast sensitivity are correspondingly lower. Character or icon height can be increased to as much as 1 deg with proportional reduction of choice reaction time. Finally, the maximum area for efficient search is about 9 deg which limits the area of the display and correspondingly limits the size of components.

Master Warning

A master warning is known to lower choice reaction time provided it is timed to be exactly 200 msec in front of the specific warning although at some cost in increased error rate. We have tentatively adopted a visual master warning signal in the form of a repetitive flash of outlines in the display. A final design would benefit from a redundant acoustic signal as this has been shown to improve miss rate and to lower response time although it will be wasted on severely hearing impaired operators. A tactile warning is potentially important in the case of operator drowsiness.

Stimulus-Response Compatibility

It is known that compatibility between stimulus and response can simultaneously lower error rate and choice reaction time. For this reason, we have chosen to adopt icons, familiar as possible, and naturally or logically related to the desired response (e.g, encroachment upon the left lane edge is indicated by an aversive signal at the left edge of the vehicle icon which prompts the operator to move right).

Spatial/Temporal Considerations

A recent study of visual stimuli best seen by the eye concluded that the best seen stimulus should be specified by the spatial-temporal structure of the most sensitive receptive field of visual system neurons. On that reasoning the optimal stimulus would be a localized oriented grating of about 4-6 c/deg. Where possible we incorporate targets with pronounced contrast energy in this frequency range into the array of warning signals.

Movement is a well-established strategy for enhanced signaling in the periphery where this stimulus attribute is said to be especially attention getting. But movement is also useful for central vision. Contrast thresholds are lower for moving images in both the periphery and the fovea. Moving targets are thought to be more compelling. In addition, the motion pathway allows more accurate contrast discrimination than the luminance pathway. Motion is signaled in the faster, more sensitive, though lower acuity M pathways. We should thus achieve an optimally fast, sensitive response by building motion into our warning signals.

The simplest implementation of a moving luminous warning signal is to put a target into apparent motion by the strategy of flashing two adjacent identical targets in sequence. This also satisfies the requirement to keep the warning signal relatively localized and at a predictable location. The target need move no more than its own diameter (or width) to achieve satisfactory motion.

The attached Figures la and lb show a preliminary sketch of the vehicle icon reference signal and cue to accommodation (panel 1) plus examples of how the base display changes when one of several possible warning signals is presented. Shown in these figures are examples for (2) a vehicle encroaching from the left -- the arrow is placed in apparent motion, (3) intersection hazard on the right -- arrow again in motion, (4) icy roadway (5) left lane edge too close (a lane mark moves toward the vehicle), (6) brake failure (7) engine failure (8) driver inattention and (9) tire pressure failure. In several cases there is text associated with the warning signal as shown.

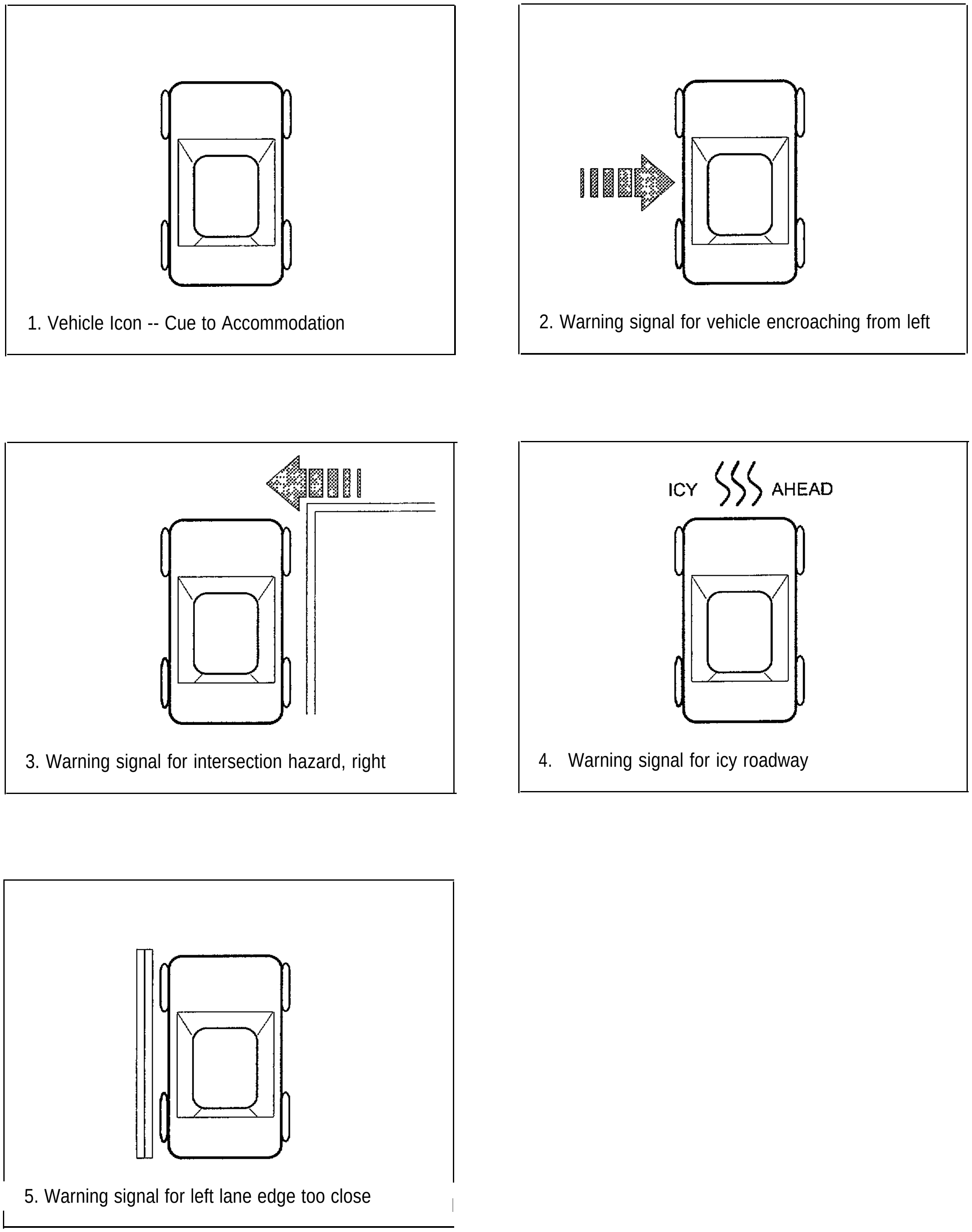
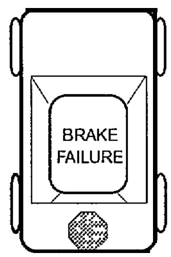
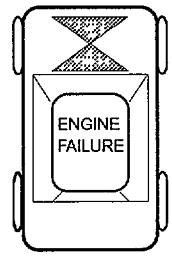


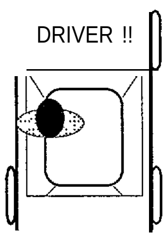
FIGURE la Vehicle icon and possible warning signals.



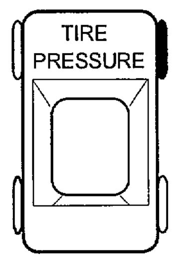
6. Warning signal for brake failure



7. Warning signal for engine failure



8. Warning signal for operator inattention



9. Warning signal for tire pressure failure

FIGURE lb Possible warning signals.

Experiments

Two crucial experiments are planned in the main phase of the study. A small sample of normally sighted adults of typical driver age, in the range of 40-50 years, will be recruited. These observers will be asked to act as subjects in an experiment to test (a) detectability of the individual warning signals, (b) identifiability of the signals, and (c) time to react. Measured performance in these studies will become the "benchmark data" to accompany the guidelines for warning signal development.

Extrapolated Performance

The experiments will center on performance (whether detection, identification or time to react) when display contrast has been lowered enough to place the signals in a measurable performance range (error rates measurably more than zero). This supplies worst case data. However, designers will want to know what performance to expect with contrast in a more favorable range. Extrapolated performance **will** be calculated using a contemporary mode of visual performance.

Testing Facility

To perform the foregoing study the project will develop an inexpensive computer-based testing facility. Software that we develop for this facility will be sufficiently general that commercial entities choosing to explore warning signal development within the guidelines that we publish will be able to conduct their own laboratory studies in preparation for either in-vehicle or simulator testing.

LED Version of Warning Signal Display

The basic elements of the project are sufficiently different from telltale technology that one might ask whether the design can be implemented with standard components or whether an elaborate computer-based CRT display is necessary. The IDEA project will experiment with low cost components such as LEDs, presently used for telltales, coupled with holographic light diffusers and/or light guides in order to examine feasibility of this approach.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

Several steps are necessary to bring the display principles into practice. First, and quite importantly, the performance of the system should be examined for the worst-case vision with the warning system. As the driver population ages, a number of commonly occurring conditions of visual anomaly may be encountered in the licensed driver population. Aphakic observers (in whom the ocular lens has been removed owing to cataract) are common. As stated earlier, many licensed drivers exhibit worse than 20/40 acuity. New tests of visual function have revealed that the worst accident and violation records occur in a subset of the driver population with a poor "useful field of view." These considerations supply examples of a direction that needs to be pursued.

In order to implement the proposed warning signal system, a partnership will be explored with a commercial entity capable of producing prototype warning signal systems for use in either simulator settings or, more importantly, operating vehicles.

A SEQUENTIAL HYPOTHESIS TESTING-BASED DECISION-MAKING SYSTEM FOR FREEWAY INCIDENT RESPONSE

IVHS-IDEA Project 17'

S. M. Madanat,[2] and H. L. Teng,[3]
Purdue University, West Lafayetter Indiana

IDEA PRODUCT

A decision-making system for integrated incident detection and response will be developed. The system will employ sequential hypothesis testing techniques to dynamically optimize incident response decisions by systematically considering the trade-offs between the possible costs of a delayed incident response decision and the improved decision-making capabilities that result from delaying action until additional measurements are taken.

The conceptual product is shown in Figure 1. The input components to this model include traffic stream parameters, their distributions under traffic conditions, detection devices' accuracies, traffic delay costs due to incidents, the costs of implementing response measures, incident frequencies in time and space, and the distribution- of the incident durations. The figure represents the incident response decision process that will be modeled as a sequential hypothesis testing system. The outputs are the optimal incident response policies for each time period. In real-time operations, the derived optimal policies will be used to select the incident response decisions, given various traffic conditions.

CONCEPT AND INNOVATION

The IDEA concept is based on a novel approach to the incident response process. This decision process is modeled as a sequential hypothesis testing problem in which the uncertainties in the measured traffic stream characteristics and the response costs are considered simultaneously.

The incident response decisions process is a sequential decision-making process. In each period, the decision maker selects one of two mutually exclusive hypotheses from the following response conditions:

1. No incident has occurred on the freeway, or
2. An incident has occurred on the freeway.

After each observation, the decision-making process system will

1. Accept and implement no response,
2. Accept and deploy response strategies to manage incident, or
3. Delay the decision to accept either hypothesis for an additional measurement interval.

Because incident detection and response decisions are made simultaneously, this system can also be viewed as an incident detection system. Compared with conventional incident detection systems, the proposed system explicitly accounts for the presence of traffic stream measurement and interpretation errors and simultaneously considers incident detection decisions and possible response actions such as dispatching emergency vehicles and initiating on-ramp metering.

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[1] The IDEA project started August 1994 and will be completed by July 1995. IDEA project advisor: Jeff Lindley, FHWA-CA.

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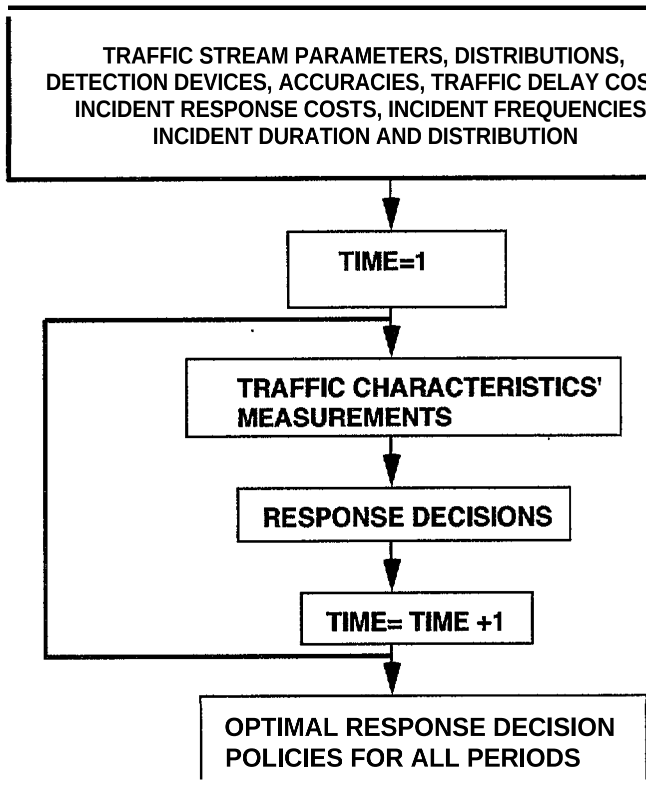

FIGURE 1 Conceptual product.

IDEA PROJECT INVESTIGATION AND PROGRESS

The incident response decision-making system will be developed in two project stages.

In the first stage, the mathematical formulation will be developed using the sequential hypothesis testing framework. Based on this formulation, feasible solution algorithms will be evaluated "off-line" to insure that the computational running time and memory requirements are consistent with the constraints of a freeway traffic management system's operating environment.

In the second stage, the developed model and algorithms will be incorporated into a freeway simulation model which has the ability to emulate the operations of a freeway traffic management system. The model will be tested through extensive laboratory simulations with varying scenarios. The parameters of the model will be varied to reflect different traffic conditions. For each traffic condition, the impacts of the measurement accuracies will be evaluated. In each case, the performance of the algorithm will be evaluated in terms of total costs incurred to the system and will be compared to that of state-of-art incident detection algorithms, for the same assumed conditions.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

The Indiana Department of Transportation is implementing an electronic surveillance and control system on the Borman Expressway (I-80/1-94). This 12-mile freeway links Gary, Indiana with Chicago, Illinois. The heavy traffic flow and high proportion of trucks in the traffic streams contribute to frequent roadway incidents on the expressway. Thus, efforts have been undertaken to design surveillance and control system capable of mitigating operational problems through the timely detection and removal of expressway incidents. The proposed decision-making system will eventually be incorporated in the Borman Expressway traffic management system.

THREEIN-ONE VEHICLE OPERATOR SENSOR

MIS-IDEA Project 18[1]

Sam C. Puma,
Northrop Corp., Pico Rivera, California

IDEA PRODUCT

This project will apply sensor-related technology and techniques to demonstrate the feasibility of performing three separate vehicle operator monitoring functions in one integrated package. The package will include (1) a sleep detector, (2) an operator identification detector for anti-theft protection and (3) an intoxicant detector for alcohol impaired driver recognition.

The investigation of the sensor/monitor concept uniquely contributes to the goal of the national IVHS program to improve the safety of surface transportation. A reduction in the number of accidents caused by intoxicated operators and operators falling asleep at the controls will result in fewer deaths and associated improved economics. The system integrates advanced technologies using a common, practical, multifunction device. Cost, simplicity, reliability, and operator acceptability have been considered in developing this product for demonstration.

CONCEPT AND INNOVATION

The sleep detector will consist of an optical wide-angle sensor to visualize the operator's facial features, particularly the eyelids. Detection and tracking software resident in an electronic processor will track the head, eyelid, and iris movement dynamics for predetermined signs of imminent sleep.

The operator identification detector will consist of a narrow-field-of-view, high-resolution optical sensor capable of rendering highly detailed images of the iris of the eye. Image decomposition, identification, and pattern matching against stored images will reside in the same processor used for sleep detection.

The intoxicant detector will consist of an ultraviolet/visible light illuminator, a broad-band optical detector, and software for the detection and quantification of intoxicants in the tear film of the eye. This sofhvare will also reside in the same processor and will be done simultaneously with iris identification. The same start lockout mechanics (not proposed for this study) will also be shared. Recent sensor advances indicate that a reconfigurable set of optics and single-detector hardware could serve as the sole sensor for all three functions.

IDEA PROJECT INVESTIGATION AND PROGRESS

Drowsy Driver Recognition will be accomplished by identifying behavior characteristic of impending sleep, such as eyelid motion and position, the unique rhythms of pupil dilation known by sleep experts to be predictive of imminent sleep, and head slump/jerk. Drowsy driver recognition is made possible by sensor and pattern recognition/target tracking technology developed for application to expendable munitions. This technology facilitates identification and tracking of the operator's head and eyes. *Anti-theft protection* will be provided by iris identification and verification before vehicle start is enabled. Anti-theft protection relies on the fact that the iris of any human eye is unique to that eye (much as fingerprint is unique to a finger). The investigators intend to use advanced target detection and recognition technology/techniques to rapidly match the stored "iris templates" of authorized vehicle operators with the observed signals from the sensor's detector. Persons whose irises do not match the stored patterns of autho-

[1]IDEA product started August 1994 and will be completed by June 1995. IDEA Project Advisor: Anthony Hitchcock, Consultant/UK.

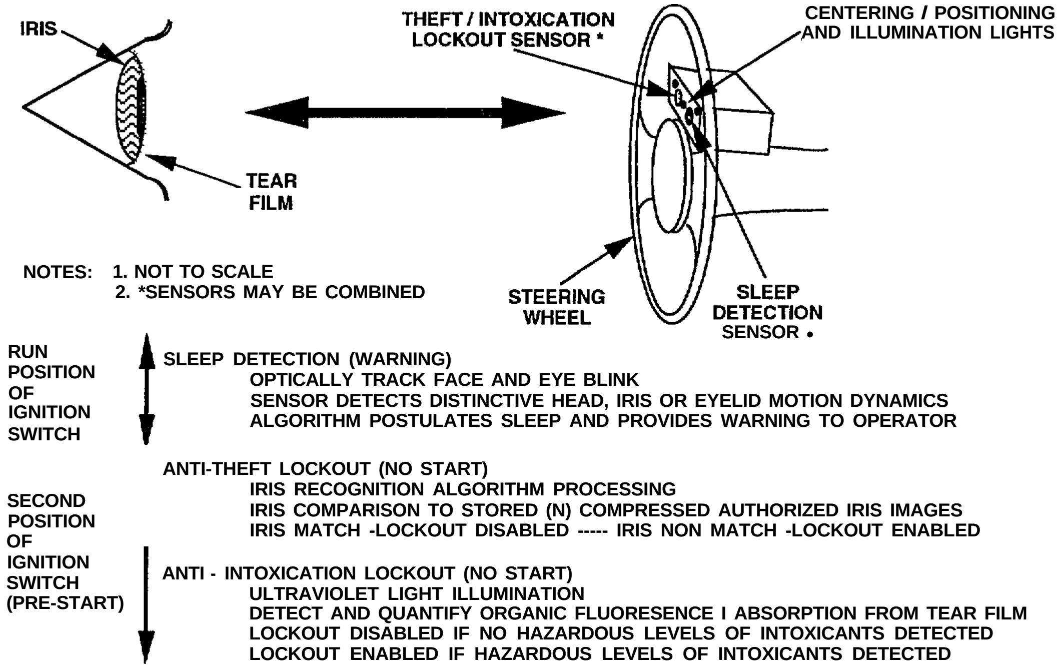

FIGURE 1 Sleep, operator ID, and intoxication sensor/monitor.

rized operators will be prevented from starting the vehicle. In cases where the vehicle is hijacked while running, this sensor could support a "graceful shutdown" technique, such as faking an empty fuel tank after the highjack. The project approach to iris identification and eye and eyelid tracking will use conventional methods of pattern recognition combined with advanced artificial intelligence learning type algorithms. *Alcohol-impaired driver recognition* relies on the fact that alcohol is present in the tear films of the eyes after alcohol ingestion. Alcohol impaired driver recognition will be accomplished by exposing the operator to eye-safe UV-light before engine start. Alcohol present in the tear films of the eyes will show characteristic ultraviolet/near-IR absorption and fluorescence emission patterns that can be used to identify and quantify intoxicants that have diffused from the blood into the tear film covering the eyes (see Figure 1 for an example).

PLANS FOR IMPLEMENTATION OF IDEA PROJECT AND RESULTS TO IVHS

Initial application of this monitor system should be tested in commercial transportation vehicles. This approach is warranted due to the high workload demand placed on operators of commercial transportation vehicles, the high value of cargo, the large number of miles logged, and the large number of persons exposed, such as passengers on a bus, train, or aircraft. This monitor can be adapted for use in land-, air-, or sea-borne vehicles. Ultimately, this integrated monitor will be sufficiently cost-effective for use in private vehicles.

AUTOALERT: AUTOMATED ACOUSTIC DETECTION OF TRAFFIC INCIDENTS

IVHS-IDEA Project 19'

David A. Whitney,
The Analytic Sciences Corporation (TASC), Reading, Massachusetts

IDEA PRODUCT

The AutoAlert IDEA project will provide a prototype demonstration and test of a new all-weather automated incident detection system that is based on new AutoAlert algorithms, in conjunction with existing acoustic sensor technology. The AutoAlert algorithms will provide direct incident detection and alert systems by capturing dynamic characteristics of acoustic patterns. AutoAlert can also be integrated with other types of incident detectors, such as video cameras and magnetic induction loop detectors, to allow for incident verification and reduced false alarm rates through fusion of detection information from a varied set of sensors.

The underlying algorithms that will form the core of AutoAlert have already been developed for military acoustic detection problems. They will be tailored to the traffic domain to build the AutoAlert prototype detection system for the IDEA project.

CONCEPT AND INNOVATION

Figure 1 illustrates the general AutoAlert concept. The IDEA product will provide performance innovations that offer significant improvements over today's most advanced acoustic and other traffic sensor systems. They will

1. Provide nearly immediate detection, with no alertment delays, before congestion builds, and react to an incident directly, not just the symptom of an incident, such as congestion;
2. Provide low false alarm rates by use of simultaneous analysis of short-, medium-, and long-term acoustic feature patterns;
3. Offer reliable, all-weather, day or night detection under varying traffic conditions through the use of sophisticated data models;
4. Account for the fact that no two incident signatures (e.g. "screech," "crunch") are identical by using probability-based modeling; and
5. Report a confidence level for detections that can be used by AutoAlert as a "self-test" of algorithm performance.

This will be achieved through the use of signal analysis techniques based on hyperstate analysis (using nested hidden Markov models) and canonical variates analysis that allows AutoAlert to

1. Adaptively characterize time-varying background noise, continually adjusting for varying environmental **and** traffic conditions;
2. Look for abrupt changes from background noise (such as sudden changes in energy patterns at certain frequencies) that could signal an incident;
3. Automatically account for expected random variation in incident signatures using built-in stochastic models; and
4. Use sophisticated simultaneous analysis of both long-term (several seconds) and short-term (milliseconds) acoustic patterns to accurately identify incidents while lowering false alarm rates.

IDEA PROJECT INVESTIGATION AND PROGRESS

The overall AutoAlert system is illustrated in Figure 2. To implement and test a prototype of this system, two stages of project investigations are planned. In the first stage, the

'The IDEA project started August 1994 and will be completed by May 1995. IDEA project advisor: Milt Haywood FHWA.

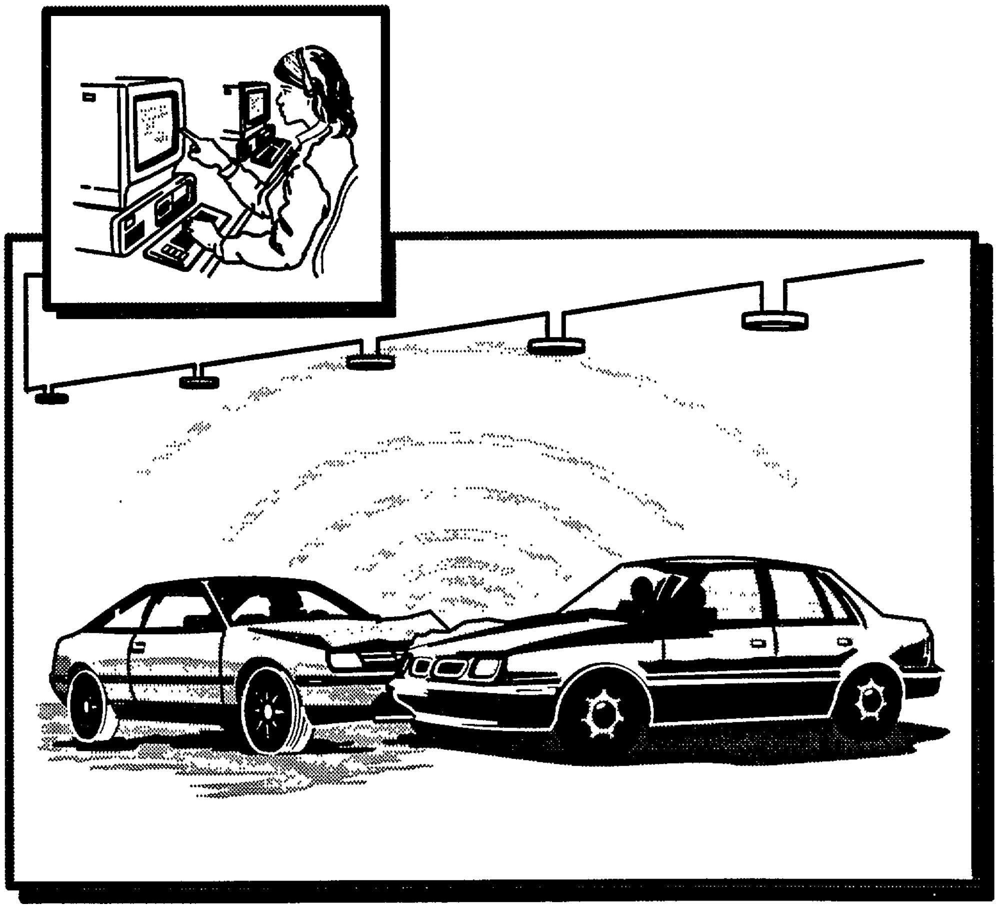

FIGURE 1 Automated acoustic detection with AutoAlert.

system design and preliminary evaluation will be performed. This will be accomplished through five major tasks as described below:

Assemble Acoustic Data Base

Identify and obtain available prerecorded accident data from sources such as the Insurance Institute for Highway Safety, vehicle crash tests performed by U.S. auto manufacturers, National Highway Traffic Safety Administration, and commercially available audio "sound effects." Collect background traffic noise data under varying operational conditions and sites, such as Boston's Central Artery. These data will serve to build the very important data base component of "incident-free" data.

Acoustic Feature Analysis

Analyze the acoustic database to define accident and incident types, and to determine the optimal set of features for acoustic discrimination of different incident types. These features may include spectral energy, bispectral energy, and transient types, for example. Determine the range of dynamic time scales required to capture both transient and longer duration sounds. For example, a transient burst of acoustic energy around 500 Hz lasting 0.5 to 3 sec may be one feature of a vehicle-to-vehicle impact.

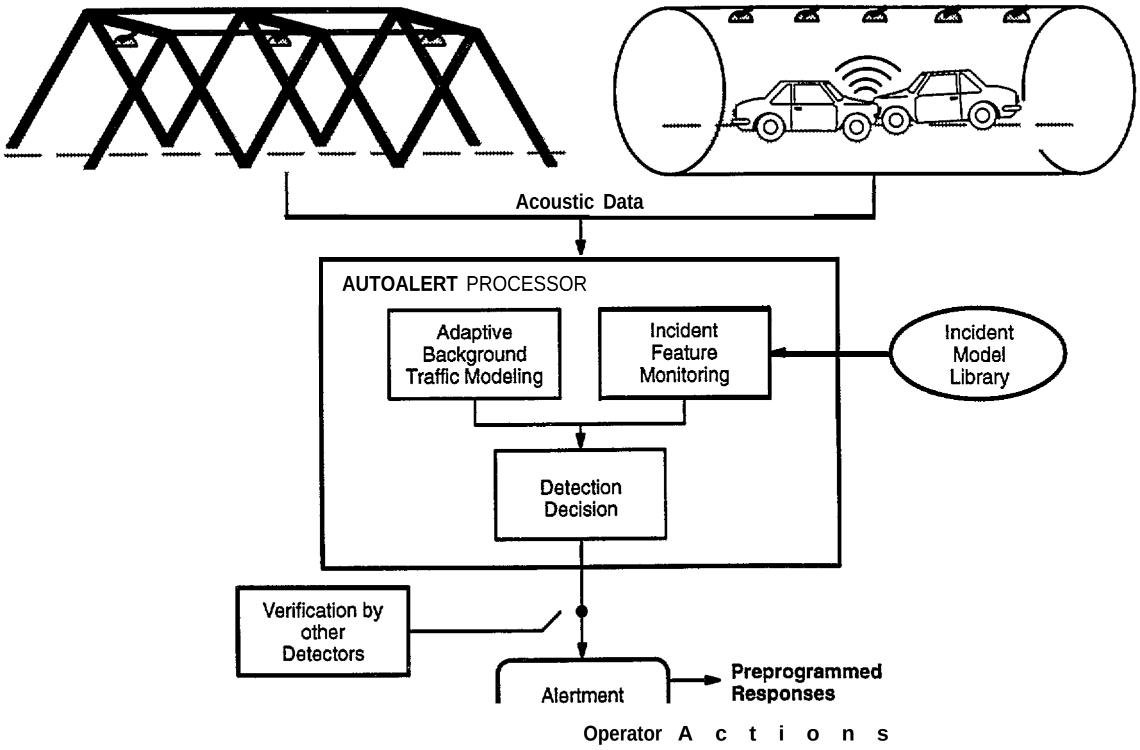

FIGURE 2 AutoAlert processor automatically monitors for incident features that appear against time-varying traffic background noise.

Optimized Algorithm Architecture

Tailor the AutoAlert algorithms to provide a processing architecture that is optimized for incident detection and classification. Select appropriate Hyperstate model parameters, such as the number of mode states, length of time scales, and number of different time scales to be analyzed. Identify appropriate metrics for model goodness of fit to data. Select decision procedures and criterion for operator alerts based on AutoAlert processing. Implement a prototype AutoAlert software system on a 486 or Pentium-class PC, or a low-end workstation.

Preliminary Performance Testing

Using controlled experiment data extracted from the acoustic databases, perform preliminary AutoAlert performance evaluation. The data will be used in a simulation mode to develop and test data sets that reflect varying signal-to-noise ratios (SNR). AutoAlert's false alarm and correct detection probabilities as a function of SNR for selected incident types will be evaluated.

In the second stage of the project, a feasibility demonstration for operational data is planned. This will be accomplished through the task discussed below.

Final Performance Testing

Demonstrate the overall feasibility of AutoAlert processing in the laboratory. Additional analysis of controlled experiment data begun in the first stage will be completed. Based on lessons learned, the algorithm will be modified as required. In addition, field data that is planned for collection in "uncontrolled experiments", e.g., from recordings made on-site at the Central Artery in Boston, will be evaluated in the laboratory. This will allow important features of the algorithms, such as real-time background noise characterization and response to random variations in incident characteristics, to be evaluated.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

The IDEA project results will demonstrate the feasibility of the AutoAlert processing concepts. Upon successful completion of the IDEA project, a follow-up project would be performed to develop a fully functional, real-time system that could then become a product. One potential near-term implementation of AutoAlert is the Boston Central Artery/Tunnel (CA/T) project's integrated project control center for incident management and system control. Partnering relationships with Massachusetts Highway Department and Parsons Brinckerhoff Quade & Douglass, consultants for the CA/T project in Boston are being developed for the IDEA project. This will provide close links between this IDEA project and potential users of this acoustic detection technology.

REAL-TIME, COMPUTER-MATCHED RIDESHARING USING CELLULAR OR PERSONAL COMMUNICATIONS SERVICES (RTCMR/C/PCS)

IVHS-IDEA Project 20[1]

Edward W. Walbridgh
National-Louis University, Evanston, Illinois

IDEA PRODUCT

This IDEA project ascertains the effectiveness of using hand-carried wireless telephones to access a computer that does rideshare matching in real time (within a minute or two). The phones can be the familiar cellular phones or personal communications services (PCS) phones that are currently under development. RTCMR/C/PCS provides flexibility and convenience that is simply unavailable with conventional ridesharing and is thus much more attractive. This project focuses on a matching algorithm optimized for RTCMR/C/PCS, evaluates the potential of RTCMR/C/PCS, and identifies candidate RTCMR/C/PCS demonstration projects.

CONCEPT AND INNOVATION

The key innovation in RTCMR/C/PCS is the use of cellular telephony or PCS to access the matching computer in real time. This IDEA technology provides uniquely flexible and convenient access that is not possible with conventional, wire-based telephones.

Every working day in the United States about 100 million people go to work by private vehicle (car, light truck, or van), according to the 1990 census (ORNL 1993). At an average occupancy of 1.1 persons per vehicle, these 100 million workers require 90.1 million vehicles for their commutes. With 1.9 empty seats per vehicle, these vehicles will have a total of 171 million empty seats. Many of these empty seats travel between origins and destinations in the suburbs, where public transportation is not an effective option. By contrast, in 1990 public transportation modes carried only 6 million people per day to work.

IDEA PROJECT INVESTIGATION AND PROGRESS

RTCMRICIPCS provides technology "intelligence" communicated from cellular and PCS subscribers to the matching computer and from the computer to subscribers. The IDEA investigation will be performed in the following 3 stages:

Stage 1

The requirements that must be met by an RTCMR/C/PCS algorithm will be specified. Existing matching algorithms will be reviewed to see to what extent they meet these requirements. The review will consider dial-a-ride matching and car pool matching, with particular attention being given to matching in systems whose vehicles can be notified by radio of new ride requests. The performance (rider waiting times, driver detour times, driver detour distances) of these systems will be evaluated.

The IDEA project will develop a fine-tuned algorithm for real time, computer-matching of ride seekers with ride providers in a system where the ride seekers and ride providers communicate with the matching computer and with each other via cellular or PCS telephones.

'The IDEA project started July 1994 and will be completed by July 1995. IDEA project advisor: Fred Wegmann, University of Tennessee.

professor, National-Louis University.

Stage 2

Since, in general, riders and drivers participating in this type of ridesharing will be strangers, the seriousness of the personal security issue in RTCMR/C/PCS will be evaluated and a set of measures for dealing with the issue will be identified.

One measure for enhancing personal security in a RTCMR/C/PCS system could be to have the computer screen both driver and rider prior to matching them up. Also, an alarm button could be provided on each cellular or PCS phone. Pushing the alarm button would alert a human system attendant and he/she would call the person who sent the alarm. The police would also be alerted and given a description of the driver's car and the car's location.

Stage 3

Strategies will be identified for inducing drivers to offer rides. The driver could be paid by his/her passenger, or could get access to high-occupancy vehicle lanes on expressways. Drivers should be covered for liability by some sort of group policy (and in turn should have their safety records checked so that riders feel more secure). There may be other ways of making RTCMR/C/PCS participation attractive to drivers; the goal is to have as many offers of rides per hour as requests for rides.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

Interaction will take place on an ongoing basis with transportation manager's associations (TMAs) and other organizations potentially interested in supporting demonstration projects, such as the Center for Neighborhood Technology in Chicago, the Chicago Area Transportation Study, Argonne National Laboratory, and cellular/PCS providers. At least three candidate demonstration projects will be identified. These would most likely include

1. The suburban area just north of Chicago represented by the Lake-Cook TMA,
2. The suburban ares west and southwest of Chicago represented by the Illinois Corridor TMA, and
3. Either the northwest suburbs represented by the Prairie Stone TMA or an area of Chicago itself.

Collaborative activities are already under way with the Lake-Cook TMA and such activities will begin soon with the Illinois Corridor and Prairie Stone TMAs.

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INTERFERENCE RESISTANT SIGNALS FOR COLLISION AVOIDANCE RADAR

IVHS-IDEA Project 21’

Mark Hischke and Warren Guthrie,
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IDEA PRODUCT

This project examines signal structures for application in collision avoidance radar that will minimize interference, such as blinding and triggering by other systems.

Collision avoidance radar can potentially help automobile drivers by providing advance warning of impending accidents (and possibly applying brakes automatically). In normal conditions, collision avoidance radar can also be used as part of a smart cruise control system, which adapts to the speed of the vehicle ahead.

CONCEPT AND INNOVATION

This IDEA project will examine a select set of radar types for typical IVHS scenarios. Each type of radar will be tested against the likelihood of adverse interference when many radars are operating. The results will assess the strengths of each radar type with respect to interference immunity. New radar approaches will be considered to improve interference immunity.

Only a few collision avoidance radars are used in transportation systems today. It is anticipated that as the number of installations increases, the likelihood of signals from one automobile’s collision avoidance radar adversely interfering with another automobile’s collision avoidance radar will increase. This interference can result in blinding where the radar cannot see potential collisions or in false alarms where a collision is signaled when there is no real problem.

IDEA PROJECT INVESTIGATION AND PROGRESS

Figure 1 illustrates a typical problem in traffic situations. The problem is defined from the observer’s perspective. Both the observer and the interferer are automobiles equipped with collision avoidance radar. The radars have half power beamwidths o. The observer’s radar must identify the target ahead of it and quickly determine if the target is a potential hazard to the observer’s vehicle.

A problem may arise when the interferer is positioned as shown in Figure 1. At the observer’s receiver the signal power from the interferer may be greater than

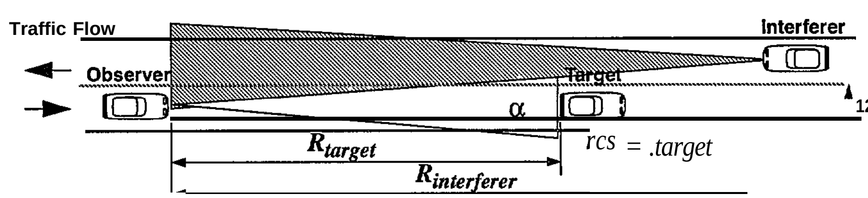

FIGURE 1 The problem.

‘The IDEA project started August 1994 and will be completed by April 1995. IDEA project advisor: Arthur Carter, NHTSA.

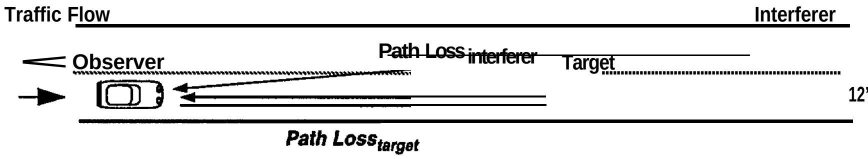

FIGURE 2 Path loss description.

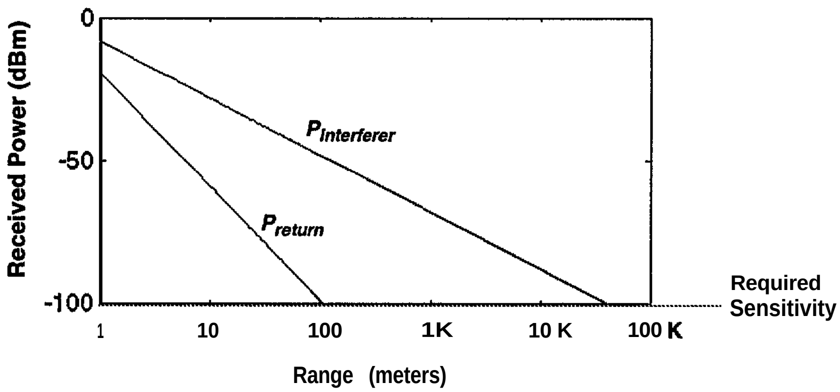

FIGURE 3 Observer's received power for inteferer and target's radar return.

the signal power returned from the target (assuming both transmit the same power). This is due to the difference between the one way and the two way free space path loss, *Path Loss,,,,,, and Path Loss,,,,,* respectively (see Figure 2). The interferer's radar signal travels only one way, from the interferer to the observer, while the target's radar signal travels from the observer to the target and back to the observer.

The observer's received power due to an interferer is

$$P_{\text{interferer}} = \frac{P_t G_t G_r A^2}{(4n)^2 R^2_{interferer}}$$

The observer's received power due to a target's return is

$$P_{return} = \frac{P_t G_t G_r A^2 o_{target}}{(4n)^3 R^4_{target}}$$

Where P_t is the transmitted power, G, is the transmit antenna gain, u is the rf camera wavelength, and $R_{interferer}$ *and* R_{target} are the ranges to the interferer and target, respectively. o_{target} is the target's radar cross section, which ranges from $o_{min\ target}$ = 1000 m^2 to $o_{max\ target}$ = 1000 m^2. Figure 3 shows a-plot of the two received powers versus range *(P,G,G, = 60 dBm and* o_{target} *= 1* m^2*)* To detect the target's return at a maximum desired range (say $R_{max\ target}$= 100 m), the observer's receiver must have the indicated sensitivity. However, with this sensitivity, interferers can be received at much greater distances than the maximum desired target range.

This IDEA project will be performed in 3 consecutive stages as follows:

Stage 1

The collision avoidance radar problem is complex; system design must balance and trade off many constraints, As a result several candidate radar designs have been applied toward the problem: FMCW (uses

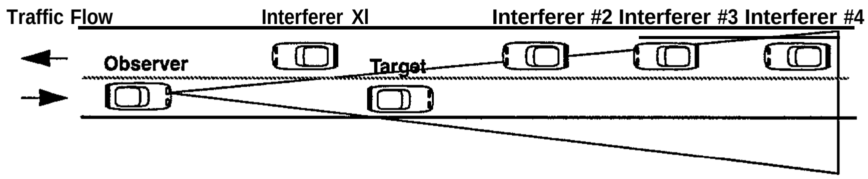

FIGURE 4 Multi-Interferer scenario.

frequency modulation on a continuous wave system), diplex (uses doppler phase differences on two or more separate frequencies to determine range), and pulsed (time delay to receipt of return signal determines range). In task 1 a set, *R*, of common radar approaches will be selected for the simulation part of this project. One or two new systems or variants of the above mentioned systems will also be included in the set.

Interference to the observer radar can cause three effects:

1. Blind the observer to the target,
2. Alter the true information about the target, and
3. Cause false alarms.

Which effect occurs depends mostly on the received power due to the interfering signal relative to the target's return signal. It also depends on the particular system architecture and signal structure, The effects of system design on interference resistance will be identified during this phase.

Stage *2*

Figure 1 depicts one of many possible scenarios in which a collision avoidance radar would be required to operate. This is a one interferer scenario. Although systems are being installed on some buses and trucks, even this limited interference scenario seldom occurs due to the small number of fielded systems. As collision avoidance radars proliferate the frequency with which this scenario occurs will increase. Likewise, additional, more complex and severe scenarios will undoubtedly occur (see Figure 4).

In Stage 2 of this project a set, S, of several scenarios that represent real life situations will be selected. This scenario set will be programmed on system simulation, modeling, and analysis tools that Northrop Grumman currently applies to Electronic Warfare problems. The simulator will aid in determining the level of interference that can be expected in realistic environments.

Stage *3*

In this stage each radar design in *R* will be individually applied to each scenario in S. The degree of interference observed will be tabulated for all combinations. The new radar approach(es) will be optimized to perform with increased interference resistance. After optimization of the new approach(es), typical architectures utilizing the new approach(es) will be described.

PLANS FOR IMPLEMENTATION OF IDEA PRODUCT AND RESULTS TO IVHS

The investigators plan to incorporate the results from this IDEA project into ongoing International Research and Development for Transportation Systems concerned with collision avoidance radar development and are currently pursuing relationships with automotive electronics suppliers.

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The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate the information produced by the research, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 330 committees, task forces, and panels composed of more than 3,900 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

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