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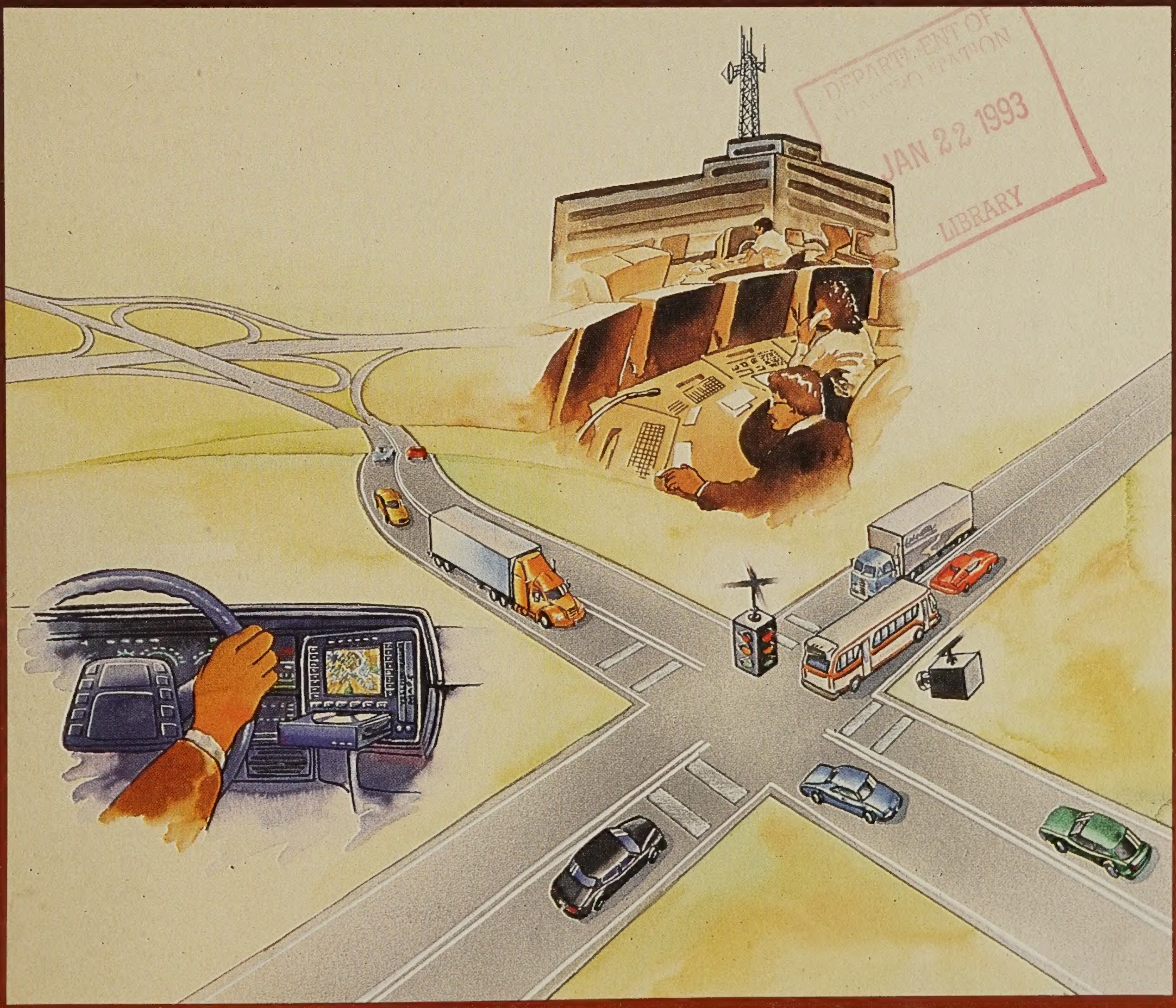

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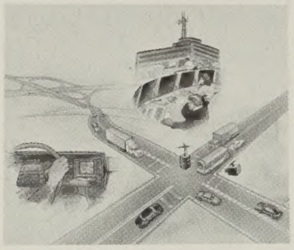

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COVER:
Elements of the Advanced Traffic Management System include traffic control centers and onboard navigation devices for private automobiles, commercial vehicles, and mass transit vehicles.
—Cover art is courtesy of reprint from the Intelligent Vehicle-Highway Society of America's "Strategic Plan for IVHS in the United States," May 20, 1992.

IN THIS ISSUE

Articles

Departments

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A • T • M • S Technology— What We *Know* and What We *Don't Know*

by Alberto J. Santiago

Introduction

As the backbone for the social and economic development of any country, a sound transportation system can promote business and facilitate communication by ensuring the proper movement of people and goods. Over the last few years, however, demand for the use of transportation facilities in the U.S. has increased at a rate much higher than that which can be absorbed by current systems. This phenomena, coupled with the lack of funding to construct new facilities and accommodate this additional demand, has been a major contributor to traffic congestion.

Recognizing the institutional impossibility of constructing new facilities that would satisfy current and future travel demand while preserving the environment, the Federal Highway Administration (FHWA) is pursuing the concept of Intelligent Vehicle–Highway Systems (IVHS).

IVHS is an ambitious multiyear, multibillion dollar research and demonstration program that aims at improving vehicle-highway system operation and management techniques for the post-interstate construction era. The main goal of the IVHS program, which will carry the FHWA into the 21st century, is to develop and implement state-of-the-art vehicle-highway management techniques and control systems that will effectively reduce congestion by optimizing the use of existing infrastructures. If successful, we will provide an increased level of safety, mobility, driver convenience, and environmental quality for both rural and urban areas.

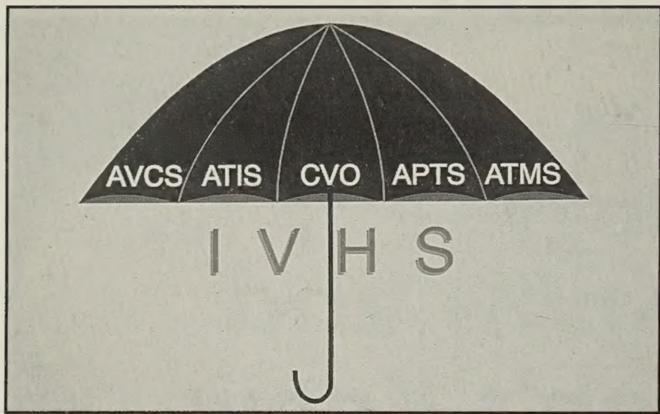
This article explores the basis for this vision, thereby inviting transportation professionals to involve themselves in defining our traffic management systems of the future.

IVHS Components

The transportation technologies that will develop under the IVHS program are divided into five interrelated components: Advanced Vehicle Control Systems (AVCS), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO), Advanced Public Transportation Systems (APTS), and Advanced Traffic Management Systems (ATMS).

The ultimate goal of Advanced Vehicle Control Systems is to develop and apply technologies in ways that substantially improve throughput, level of service, and safety. For example, AVCS is developing technology in which the driver no longer drives; he or she becomes a passenger. Without human intervention, cars could journey from one place to another on designated highways that are suitably instrumented. More specifically, the use of radar for steering within a lane and for sensing neighboring vehicles are examples of such technologies. Another example is a braking system that regulates vehicle speed and minimizes the time separation (headway) of platooned vehicles.

Advanced Traveler Information Systems is the framework through which information is made available, not only to the driver, but to the general traveler. ATIS is composed of several elements. The first of which is the development of invehicle route guidance systems. This includes audio-visual aids such as electronic maps and highway advisory radios that enable the driver to select the best route. A second element is the development of models that optimize network routing and usage. The third element is the dissemination of information to travelers that allows for pre-trip and/or en route planning. An example of such information would be the mes-



IVHS components.

sage that congested highways have affected bus schedules or that high-occupancy vehicle (HOV) restrictions have been lifted. Another element of ATIS is quantification of driver behavior. This would entail developing models that replicate how people select routes, how they react to highway incidents, and how they select their mode of travel.

Commercial Vehicle Operations addresses the special needs of commercial traffic. It encompasses many of the ATIS aspects and enables dynamic fleet management. CVO also encompasses invehicle diagnostic systems, automated vehicle identification and certification, and driver performance systems. These systems will alert professional drivers of possible vehicle malfunctions, log arrivals at checkpoints and/or jurisdictional boundaries, and measure driver performance (such as alerting a driver who is experiencing fatigue).

Advanced Public Transportation Systems addresses the needs of nondrivers: people who indirectly use the highway system. This component of IVHS is concerned with the optimal utilization of mass transportation systems such as buses, light rail, subways, and any form of high occupancy vehicles such as carpools and vanpools. APTS can make a significant difference in providing mobility as information on mass transit facilities will be made available to drivers. For example, once the origin and destination of a trip is determined, a driver could be made aware that re-routing his or her trip to use other transportation modes could make the travel time shorter and/or safer.

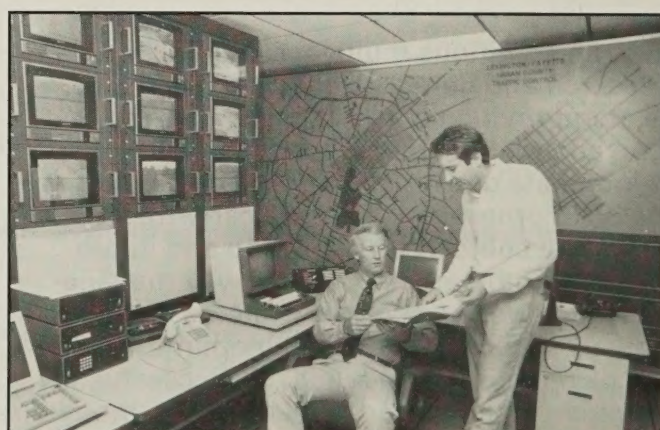
Most important of all aspects of the IVHS program is Advanced Traffic Management Systems, the very backbone of IVHS. ATMS consists primarily of three aspects. One aspect is the development of surveillance systems to monitor the operational status of a roadway network. A second aspect is the development of real-time, traffic-adaptive control systems which, through the feedback provided by the surveillance system, adapt network control such as traffic signals, freeway ramp meters, messages on electronic signs, etc., for optimal performance. A third aspect is the development of system operator support systems (expert systems, simulation models, etc.) to enable and facilitate real-time control and management of the network.

What We Can Do Today

In the 1990's, congestion reduction must be approached by spreading demand over existing facilities, optimizing their use, and providing control in an adaptive fashion. To do this, we need areawide ATMS operations centers deployed in all large metropolitan areas. Increasing the number of ATMS will help produce maximum traffic-moving capability of existing streets and highways throughout the country. The implementation of ATMS requires:

1. Deployment of areawide control system infrastructure, including necessary institutional arrangements and agreements, where such infrastructure is currently lacking. This will facilitate the collection of traffic data and other information required for real-time areawide control.

2. Research and development activities on advanced traffic management measures, such as wide-area detection, control, and assignment algorithms based upon real-time data. The products resulting from these activities *must* work to advance the state of the art and continue to push, in an accelerated manner, the state of the practice.



Ron Herrington (left) and Gary Green in the computer control center in Lexington, KY. Lexington is one of several cities with a computerized, traffic signal control and surveillance system.

3. Use of selected areas as real-world test beds to evaluate and demonstrate research results. This will increase the acceptability and implementation of research results.

While implementation of ATMS technology can do much to improve the flow of traffic on congested freeway and arterial streets, it can also provide the infrastructure and create the market for the more advanced invehicle guidance systems, automated vehicle identification and location systems (AVI/AVL), and automated control systems.

Some of the system requirements for ATMS include:

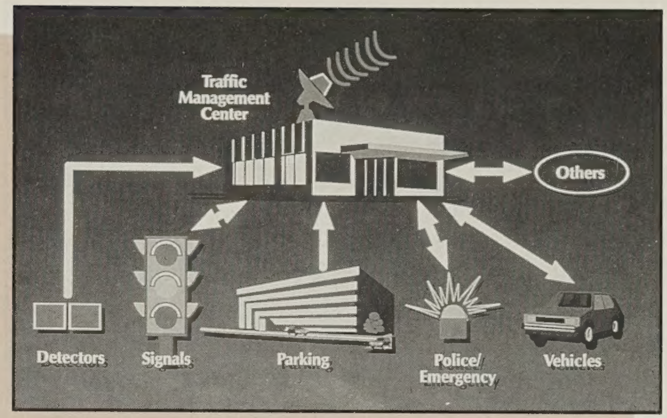
- Surveillance and detection systems. Surveillance and detection are crucial in a traffic control system. The surveillance and detection system could be a police officer at the corner or a smart set of detectors on the highway. In either case, a mechanism to transmit that information back to a control center is required.

- Real-time, traffic-adaptive control. ATMS must be responsive to traffic flow and work in real time. The implemented traffic management strategy should link real-time traffic monitoring, short-term travel forecasting, and electronic route guidance to integrate network-wide control and allow for a comprehensive traffic management system. Data that is transferred to the control center must be current so that an effective strategy can be devised and implemented quickly.

- Effective incident control and management. Incident management is crucial. However, before an incident can be managed, it must be detected and verified, and an appropriate response plan must be made. The response plan must integrate onsite tactics (vehicle clearance and required maintenance), diversion strategies (streets involved, changeable message signs, radio broadcasts, and traffic signal timing during diversion), and cover both surface streets and freeways.

- Route guidance information. ATMS must collect and disseminate routine guidance to vehicles based on actual traffic conditions. These systems will also be able to predict the number and type of vehicles that will be on a particular road segment and could conceivably give special instructions to different classes of vehicles.

- Integration of components. ATMS *must* integrate ATIS, CVO, APTS, and eventually AVCS. Also, ATMS must provide the technology for integrating freeways and surface streets such that travel demand can be managed at a network-wide, multimodal level.



ATMS sources of information.

In summary, the ATMS surveillance system identifies the presence of vehicles, locates disturbances in traffic flows, and identifies congestion points and accidents. Based on the traffic information collected, ATMS then permits real-time adjustment of traffic control systems. With intelligent traffic prediction algorithms, ATMS can also prevent traffic congestion by developing online traffic control measures based on anticipated degradation in the throughput of networks using current traffic volumes and origin-destination (OD) information. Ultimately, when in full integration with ATIS, CVO, and APTS, Advanced Traffic Management Systems can influence driver route choices and/or travel mode by indicating alternate routes to be followed (in case of incidents) or by simply redistributing part of the traffic to less congested routes during rush hours.

There are two major challenges in the development of ATMS: integration and forecasting. Integration will require the development of highly sophisticated systems and interfaces that must overcome hardware compatibility problems. That is, these systems must be flexible enough to interact with different equipment. Also, rather than analyzing and reacting to information, these systems must forecast and implement prior to degradation.

Immediate integration of these systems is vitally important. Congestion continues to grow, and it will become much more difficult to ensure our future mobility. Ironically, most of the technology needed to implement IVHS is already available. That is, many of the subsystems needed have been developed and, to a certain extent, have been implemented in isolation.

Preliminary ATMS applications in selected corridors have proven to reduce delay and travel time, improve the productivity of commercial fleets, enhance highway safety, produce energy savings, and improve air quality. However, the full development and implementation of ATMS requires the availability of comprehensive communication systems, surveillance systems, and proficient traffic analysis tools (such as traffic models).

The following three items need particular attention: communications, surveillance, and analysis.

Communications

We currently have most of the technology needed to satisfy the communications needs of ATMS. For instance, basic communication between detectors, controllers, masters, and a central computer is now available over different mediums. One must consider, however, that advanced control will likely require a substantial increase in the frequency and amount of data flowing among these components.

Of greater consequence is the need to establish communications between the traveler and the control center. This is the most effective way of influencing demand and, therefore, mitigating congestion. Providing accurate information on the operational status of the network to potential users will undoubtedly influence route selection, departure time, and possibly destination and mode. For example, a traveler might change his route if information on major obstructions affecting the planned route is available. He may even change his mode if an alternative is available and convenient.

One major pitfall is our lack of traveler behavior knowledge. How do people make choices relative to route, mode, and departure time (assuming they have that flexibility)? Before we engage in a proactive traffic control strategy, we must better understand what information will make travelers change their preset trip. How can we influence their decision-making processes? How amenable are they to change? Even if the information is always perfect and available, how many will take the advice? And, how many will make good decisions? All of these are crucial issues that need to be addressed and quantified to some extent. The success of proactive control depends on it.

Guidance information must be easily discernible and understood by drivers.

Surveillance

The critical element of any advanced traffic management and control system is reliable data. Surveillance systems now in place usually report volume and occupancy information on a preset basis at selected locations within a network. However, the number of stations and the amount of information yielded by these systems may not be enough to ensure optimal control.

Traditional surveillance systems will not suffice within an ATMS environment. ATMS will need information on usage by lane, oversaturated locations and/or locations with excess capacity, the location and occurrence of recurring and nonrecurring congestion, location of weather influencing traffic (snow, fog, rain, etc.), a much improved method of incident detection, and, possibly, hazardous materials tracking and vehicle classification.

Even though these needs must be satisfied, it is not likely that all of this information will come from a surveillance system that relies solely on detectors. Economically, it is impossible to fully instrument a roadway network to the extent needed by IVHS. Instead, novel approaches must be developed to "fuse" data from police reports, "probe" vehicles (those which have two-way communication with the control centers), commercial fleets, emergency vehicles, etc., with the "detector" data, and generate the information necessary to provide dynamic, traffic-adaptive control.

Analysis

Traffic analysis tools, for the most part, take the form of computer models. Because of the complexity of the congestion problem, it is no longer efficient to develop technical manuals or handbooks that outline a routine procedure to be followed for specific situations. It is adequate to develop a manual that addresses the issues of evaluating and optimizing the control or geometry of an intersection. It is not adequate to require practitioners to use the same manual to optimize all of the intersections within the same jurisdiction using this approach, as it does not take into account the impact of improvements made to the preceding or subsequent intersections. The major advantages of using traffic models are that they provide an environment where traffic control strategies can be tested and fine-tuned without having to disturb traffic, they avoid the risk of liability when problems in a strategy are detected only after implementation, and they save the capital required to acquire and install traffic control hardware so that strategies, which may or may not work, can be field tested.

It is imperative that traffic engineers "think" network-wide. Addressing a local problem will only result in the relocation of the same problem elsewhere. The scope of traffic control has grown to a more technically sophisticated science that requires the use of traffic models. This complexity stems from the fact that transportation planning, traffic operations, safety, mass transit, and other related surface transportation functions need to be integrated into a network-wide, transportation management system. Traffic models can do this and much more.

Traffic management, by definition, implies that more needs to be done with what we have. That is, it implies that we must maximize the use of current surface transportation facilities. The term "management" calls to mind the ability to study a situation, identify the possible options and, most importantly, activate a decision-making process that efficiently addresses the situation under study. A key factor in this process is the ability to develop quality alternatives. In many cases, the only viable way to evaluate and fine-tune control strategies is by using traffic models.

Proactive traffic management requires that practitioners define, explore, speculate, accommodate, and undertake engagement strategies that, for the most part, will not follow tradition. We cannot continue to time signals using 1930's methods and expect them to work. Present traffic conditions, such as driver behavior characteristics and type, number, and performance characteristics of vehicles, make these methods obsolete. Again, traffic models are the tools that will allow practitioners to test innovative control strategies suitable to address our current problems.

What We Need To Proceed

A lot has been accomplished; yet, a lot remains to be done. Some of the very basic modeling needs based on the current concept of IVHS include:

Traffic Models

- Test and Fine-Tune Traffic Control Strategies
  - no disruption of traffic
  - no risk of liability
  - reduced costs
- The Only Way to Evaluate Many ATMS Control Strategies

- Dynamic traffic assignment models.
- Real-time, traffic-adaptive signal control.
- Optimal route diversion models.
- System operators' support systems.
- Freeway-surface street integrated control.
- Generic simulation engines capable of testing any new control logic.
- Driver/traveler behavior models.

A key determinant of the success of Intelligent Vehicle–Highway Systems will be how users adjust their travel behavior in response to strategies designed to alleviate congestion conditions. Unfortunately, individual route choice modeling requires that explicit consideration be given to the tangled behavioral issues in driver/traveler decisions.

Due to the complexity of this factor, research in the area has concentrated on small, often isolated, components of the problem. For example, in an effort to gain further understanding, studies always confine the scope to approximately one origin and destination (OD) pair. Truly significant advances in the study and modeling of driver/traveler behavior will have to evolve largely from data sources that currently do not exist.

Another crucial activity is the development of simulation environments where the potential benefits from these technologies can be assessed. These are benefits to users, developers, State and local agencies, and other interested parties. For example, software that continuously regulates the speed and position of all vehicles can be used to simulate the effectiveness of Advanced Vehicle Control Systems. Occupancy of lanes, spacing between vehicles, merging, and exiting would proceed in accordance with protocol. When a vehicle leaves the roadway, the driver would recover conventional control. In fact, because a central computer may know each vehicle's immediate position and eventual destination, all vehicles on the automated highway could be directed in order to achieve some overall optimum such as maximum vehicle throughput. Disruptions in flow due to merging and lane changes could be minimized, and headway and lateral spacing between adjacent vehicles could be reduced to those levels needed for safe operation. From this simulation, one could assess the operational benefits of the system, the overall feasibility of the concept, and the technical merit by demonstrating strengths and deficiencies.

The worldwide, traffic engineering community has already outlined the systems of the future. These systems, which include ATMS, ATIS, CVO, APTS, and AVCS, hinge on the postulation that real-time, accurate traffic information will be the main weapon used to combat congestion. Given that these systems will enable the exchange of information between control centers and motorists, traffic professionals expect to maximize the use of networks by "spreading the demand" throughout the available facilities. But, how do we do this?

Let's briefly assume that these systems are installed. How would control center operators know how and when to divert traffic? How can they evaluate the effectiveness of a systemwide timing plan? How could they detect incidents and manage the network under emergency conditions? The first reaction is to answer by stating that these systems will have the smarts to perform such tasks. Where, or how, are these smarts going to be integrated into these systems?

The answer is very simple: these smarts are the output of traffic models. In essence, these systems must incorporate traffic models within them (transparent to the user) such that intelligent feedback can be given to the operators regarding what to do, when to do it, and how to do it, based on the specifics of the situation. The real benefit is that these tools are capable of considering the problems on a network-wide basis; therefore, implementation of the modeled recommendations will not simply relocate the problem from one location to another. Rather, the recommendations will be the best possible for the overall network. The bottom line is: *These systems will not operate without traffic modeling support.*

Summary and Conclusions

This article discussed some of the problems we are experiencing that have deterred our ability, as a profession, to provide adequate mobility. These include existing flaws in the state of the practice, our inability to bridge the gap between the state of the art and the state of the practice, and our professional inertia to change the way we do business.

We know what our problems are. We know that we cannot solve them with current technology or by accretion of new facilities. We are being challenged to develop a collective approach that maximizes the utility of our existing facilities by providing adequate management.

IVHS is an approach to managing and resolving these problems. In essence, it encompasses the fundamental restructuring of the U.S. transportation system in order to provide a viable, comprehensive solution to our surface transportation problems. As a profession, however, we are failing to develop a comprehensive strategic plan to implement IVHS. Most of the direction is coming from people other than those who actually operate our current systems. That is, the leadership being provided is not being influenced by practitioners—the same people we are expecting to use these systems once they are developed and deployed. We must engage in a grassroots campaign to incorporate practitioners' input into the plan. In effect, we are changing the way traffic engineering is, and will be, practiced in the United States.

In terms of technology, much of IVHS-ATMS could be implemented now. However, the present approach to an IVHS-type solution contains two basic flaws that would limit its effectiveness to mere improvement, rather than the full system redesign that may be needed:

1. We are attempting to apply advanced technologies with a mindset that promotes the use of procedures based on conditions and assumptions that predate and indeed have helped to create the existing problems.

2. We are focusing on advancing the state of the art and not paying enough attention to pushing the state of the practice. We must develop systems and solutions that can be implemented.

We must pay attention to these deficiencies and overcome them effectively. If we do, there is no question that IVHS will be a viable solution.

The tactical plan currently being used to execute the IVHS program is also helping to achieve the success of IVHS. This plan comprises two basic elements: research and development, and field operational tests. This tactic, although very appropriate, must be aggressively pursued and sustained until the practicing community adopts and effectively uses IVHS technologies. We must (and will) succeed in developing and demonstrating these technologies in real-world implementations to prove their technical adeptness, establish credibility, promote their use, and, most importantly, create ownership. However, without the practitioner, this will not happen.

Remember when the slide rule was the principal tool for mathematical and trigonometric calculations? All of a sudden, someone developed a handheld, battery-operated trinket called a calculator. How much has this development changed the accuracy of calculations and the way people work?

How would you feel if, at that time, you had been asked to participate in the development of the calculator? If by now you have made the connection, you are right on track; if not, we are asking you to participate in the formulation of IVHS.

Notwithstanding, the dilemma is: *How are we going to pull it off?*

Alberto J. Santiago is the acting branch chief of the Traffic Systems Branch in the Intelligent Vehicle-Highway Systems Research Division of the Federal Highway Administration's Office of Safety and Traffic Operations, R&D. He was selected to participate in the Department of Transportation Fellows Program, and he received the FHWA Administrator Superior Achievement Award in recognition of his outstanding technical contributions in the area of traffic analysis and modeling.

The Application of Ground-Penetrating Radar in Highway Engineering

by Kevin Black and Peter Kopac

Introduction

The demands upon our Nation's highway system continue to increase as the need for greater productivity extends the burdens it must carry. Increasing traffic as well as freight demands pose a significant challenge for improved construction quality and rehabilitation effectiveness.

This situation has generated the need for more efficient and expedient ways to identify and evaluate highway condition. One promising technology, which has been demonstrated to be effective, is ground-penetrating radar (GPR). GPR is a noninvasive, nondestructive tool that can be used in quality assurance investigations for new construction and in evaluation of structural condition prior to rehabilitation.

Radar (Radio Detection and Ranging) has been in use since the 1920's. The U.S. Army began 30 years ago to use a form of radar—ground-penetrating radar—to locate nonmetallic mines. The success of this program, as well as GPR's use in weather tracking and in mapping planetary surfaces from space probes, prompted the highway community to experiment with this technique for locating voids underneath pavements, determining pavement layer thicknesses, detecting delaminations in bridge decks, and investigating scour around bridge piers.

The Federal Highway Administration (FHWA) conducted its initial GPR research in the mid-1970's to investigate the feasibility of radar in tunneling applications. In the mid-1980's, FHWA's research focus shifted to the use of radar for the detection of subsurface distress in bridge decks. Under a 1985 research contract, a van-mounted radar system was developed for the FHWA for additional radar evaluation and testing. This van was loaned to State highway agencies and universities for use in their radar research efforts.

Highway departments have found that radar can provide useful information that was not previously accessible or available in a complete and continuous form. Because radar surveys are continuous rather than random, the radar technique can be much more objective and accurate than those methods presently used by agencies. Costs for performing radar investigations are generally considered reasonable. This article describes the theory, equipment, and applications involved in highway agencies' current use of GPR technology.

Theory

GPR operation requires an understanding of electromagnetic wave propagation and geophysical investigation concepts. Radio waves

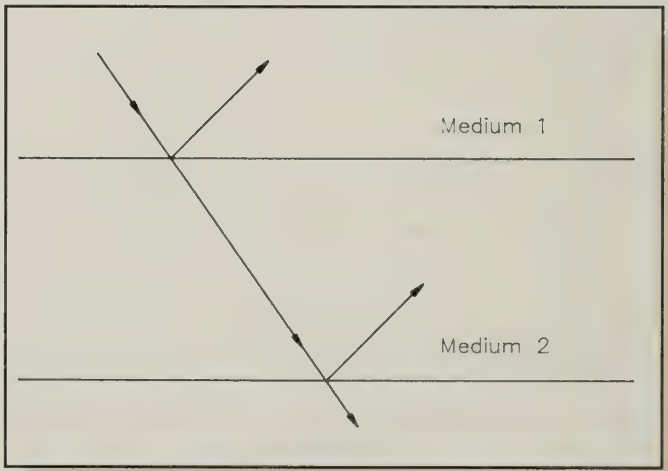


Figure 1.—Transmission and reflection of electromagnetic waves through multiple materials.

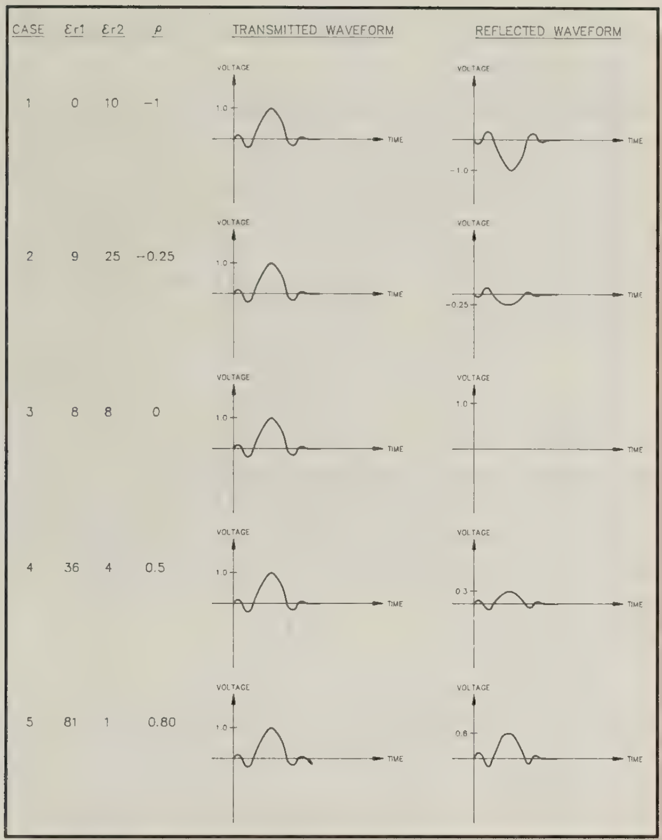


Figure 2.—Idealized interaction of transmitted waveform with five hypothetical material interfaces.

are those wavelengths on the electromagnetic spectrum between 0.001 m (0.04 in) and 10 m (33 ft). The waves travel through a vacuum at the speed of light—0.3 m (1 ft) per nanosecond.

When an electromagnetic wave encounters an interface between two materials of differing dielectric properties, one portion of the wave travels through the interface into the new material, and the rest is scattered or reflected in other directions (see figure 1). When the two materials have similar dielectric properties, most of the wave passes through the interface and little is reflected back. On the other hand, when the two materials have greatly different relative dielectric constants, a large reflection and a correspondingly small transmission occur at the interface. The relationship between the relative dielectric constants and the proportion of energy reflected at the interface is shown in equation (1):

$$p=(\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}})/(\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}) \qquad (1)$$

where

p= reflection coefficient
ε_{r1}= relative dielectric constant of medium 1
ε_{r2}= relative dielectric constant of medium 2

In equation 1, when ε_{r1} is less than ε_{r2}, p is negative; when ε_{r1} is greater than ε_{r2}, p is positive. The reflected pulse may thus be in phase or out of phase with the signal emitted. This reflection phenomenon is illustrated in figure 2 and provides much of the theoretical basis for understanding specific waveform signatures encountered in actual applications.

As radar waves pass through different materials, their speeds vary because of changes in the electromagnetic properties of these materials. The velocity is a function of the material's dielectric constant, and the velocity of an electromagnetic wave as it passes through different materials varies in inverse proportion to the square root of the materials' relative dielectric constants. For example, the velocity of an electromagnetic wave through a material with $\varepsilon_r = 4$ is half its velocity through air ($\varepsilon_r = 1$) and twice its velocity through a material with $\varepsilon_r = 16$.

Table 1 contains typical values of ε_r for some materials often encountered in the highway environment. The extremes of these values are for air ($\varepsilon_r = 1$) and water ($\varepsilon_r = 81$). Ranges of values are shown for construction materials; actual values will depend on such factors as aggregate type, binder or cement source, density, and moisture content. Accurate determination of ε_r for any given application can be found by coring a sample in the area of interest.

Another concept that must be considered in radar work is the relationship between wavelength and frequency which defines the resolution capability. Since velocity through a medium re-

Table 1.—Representative dielectric constants for construction materials

Material	Dielectric Constant ε_r
Air	1
Water (fresh)	81
Water (salt)	81
Sand (dry)	4-6
Sand (wet)	30
Silt (wet)	10
Clay (wet)	8-12
Ice (fresh water)	4
Granite (dry)	5
Limestone (dry)	7-9
Portland Cement Concrete	6-11
Roller-Compacted Concrete	5-7
Asphaltic Concrete	3-5

mains constant, there is an inverse relationship between wavelength and frequency. Resolution capability is a function of wavelength, as shorter wavelengths can discern smaller or finer anomalies than can longer wavelengths. Longer wavelengths, however, penetrate deeper but only resolve larger discontinuities.

The depth of radar penetration depends on wave frequency. Higher frequencies can only penetrate shallow depths (within 0.6 m [2 ft] of surface at 900 to 1,000 MHz). Although the depth is limited, the wavelengths are small, permitting resolution of smaller anomalies. Conversely, lower frequencies can penetrate much deeper (typically 30 to 40 m [100 to 130 ft] at 100 to 300 MHz), but the wavelengths are longer resulting in a reduced resolution capability.

This is not a serious limitation in highway work since problems close to the surface tend to be smaller in size, thus requiring the higher frequencies. Since aberrations at greater depths tend to be larger, they can be resolved by the lower frequency, deeper penetrating waves.

This dichotomy of increased depth with reduced resolution versus decreased depth with greater resolution results from electromagnetic wave theory as expressed in equation (2):

$$\lambda = c \cdot 1/f \tag{2}$$

where

λ = wavelength (distance)
c = velocity (speed of light)
f = frequency (1/time)

Interpreting the return signals relies on standard geophysical investigative techniques. In performing the analysis to determine whether an anomaly exists—and, if it does exist, its location and extent—the mechanics formula given in its basic form by equation (3) is used:

$$d = v \cdot t \tag{3}$$

where

d = distance

v = velocity

t = time

Since pulse velocity depends on the material's dielectric properties, equation (3) can be rewritten as:

$$d = c/\sqrt{\varepsilon_r} \cdot t \tag{4}$$

In the GPR application of equation (4), the measured time, t, represents the time from transmission to the time of reception at the antenna or a "round trip" time. Thus the true travel time for the signal to the point of interest is half the measured time. Adding this correction to equation (4) produces equation (5), which expresses the time-distance relationship used in GPR technology:

$$d = c/\sqrt{\varepsilon_r} \cdot t/2 \tag{5}$$

With this time-distance relationship defined, area (delaminations, debonding), volume (voids), and thickness (overlay) can be determined; spacings (rebar) verified; and quantities (excavations) calculated.

Equipment

The primary components of a GPR system are:

- An antenna.
- A transducer—this consists of a transmitter, receiver, and timing and control electronics.
- One or more display devices—these may be an oscilloscope, analog tape recorder, grey-level chart recorder, or a video monitor.

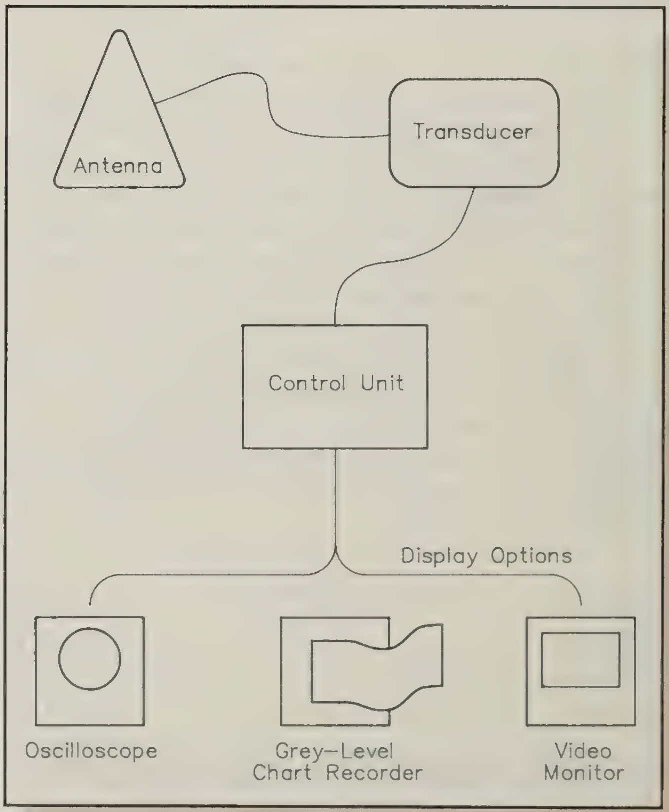


Figure 3.—Primary components of a radar system.

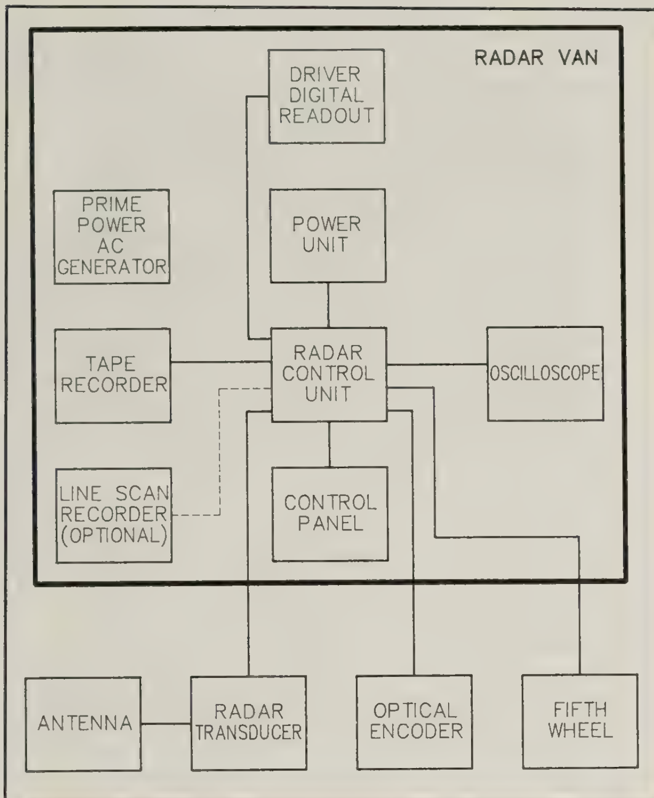


Figure 4.—Schematic of typical van-mounted GPR system.

Figure 3 illustrates these primary components. Typically, the antenna and transducer are located close to one another. The antenna, particularly, should be lightweight and maneuverable so that it may easily be positioned over the test area. The display devices are generally heavier and are often mounted in a van or cart for easy mobility. Alternatively, where real-time data interpretation is not a necessity, data can be stored on tape or disk to permit analysis in the office.

The GPR system also might include a mechanical or electrical unit (e.g., fifth wheel or electronic odometer) for precise distance and location information. A computer is an essential component for data storage, retrieval, and evaluation.

The overall system configuration will depend to a certain degree on the intended GPR use, but a typical schematic of a complete GPR system is shown in figure 4. The interior and exterior of a van-mounted radar system appear in figures 5 and 6. Instruments must be properly selected so surveys can be conducted with maximum accuracy.

GPR operates by generating the microwave signal and passing it from the control unit to the transmitter/receiver, through the antenna, and into the test surface. The reflected waves are received by the antenna and returned to the control unit for processing. The resultant stream of data can be further processed and displayed.

There are two main types of radar, based on the modulation of transmitted waves, currently being used in highway surveys. These types are short-pulse radar and continuous wave, frequency-modulated radar.

In short-pulse radar, the signal generated by the transmitter is amplitude-modulated to produce pulses of energy. The transmitted pulses are extremely short, only about one nanosecond in duration. The spaces between the pulses of energy, however, are tens of thousands of times as long as the pulses. This length lets the reflected signal be received before another pulse is generated. Signal frequency is fixed and is dependent on the phenomenon being investigated; typically, the frequency employed by GPR systems ranges from 100 to 1,000 MHz.

In continuous wave, frequency-modulated radar, the signal is swept in frequency in sawtooth fashion over time. The frequency difference de-

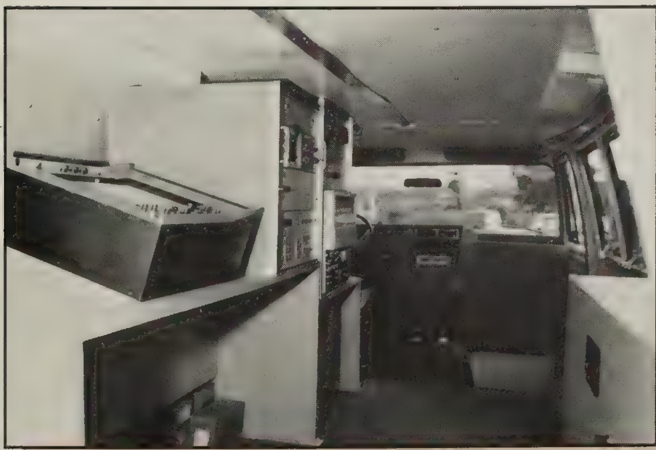


Figure 5.—Interior of FHWA's van-mounted GPR system.

Figure 6.—Exterior of FHWA's van-mounted GPR system.

pends on the time delay between transmission of the signal and reception of the corresponding echo. Thus, this can be used for distance measurement. The speed of frequency variation must be slow enough so that frequencies of the return from the surface and subsurface are essentially the same.

Antenna design is an important factor for both types of radar. The antenna serves to:

- Provide a smooth electromagnetic transition from the transmitter to the environment.
- Direct the radiated energy into the ground in a desirable pattern.

In general, the antenna directs energy in all directions, with most directed into the ground. The shape of the beam directed into the ground is of interest. If the beam is broad, a relatively large area—or "footprint"—can be covered on the ground. However, the return energy may be of low intensity since the signal is attenuated over the large area.

Antennas are generally classified as ground-coupled (in contact with the surface) or air-coupled (suspended above the surface, typically 0.3 m [1 ft]), depending on the condition that is to be investigated. Pavement surveys are usually conducted with air-coupled or air-launched antennas to take advantage of their ability to scan the surface rapidly, thereby reducing or eliminating the need for traffic control. Geophysical explorations, on the other hand, often use the ground-coupled systems that are more transportable and generally constructed for field use.

Applications

Ground-penetrating radar has been successfully used to identify many problems associated with highway structures and is gaining acceptance as a technique to replace older, less reliable methods. These methods are subjective and often inconclusive, prompting the need for rapid, objective, and nondestructive methods for surveying structural conditions. Moreover, some of these methods (for example, the chain drag) are too slow and costly to be used on large sections of interstate highway. Geophysical, pavement, and bridge investigations can thus all be conducted more reliably and efficiently using radar.

Delamination detection

Delaminations, a major cause of bridge maintenance problems, are separations of the concrete around the rebar layer due to the forces result-

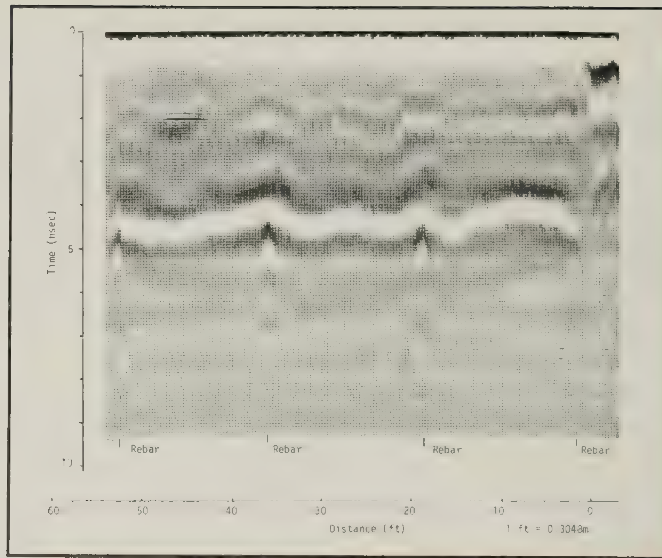


Figure 7.—Output from strip chart recorder.

ing from corrosion. An early test of GPR's capabilities was an evaluation of GPR as a network-level tool that could be used to quickly assess the general condition of bridge decks with respect to delaminations. *(1)*[1]

Inservice bridge decks were inspected at a speed of 65 km/h (40 mi/h) without closing the decks to traffic. The results of the evaluation were very encouraging, as distressed areas with a longitudinal dimension of 0.6 m (2 ft) or more could be detected. The surveys were performed using a strip chart recorder to obtain the type of display shown in figure 7. Data interpretation, however, was subjective, being based primarily on qualitative differences in apparent wave velocity and/or the attenuation of the inspection wave.

A research program sponsored by five New England States led to the further development and verification of GPR for bridge deck evaluation. *(2, 3)* The program involved both network-level surveys (to assess general condition; 30-percent GPR coverage) and detailed project-level surveys (to obtain a mapping of unsound areas; 100-percent GPR coverage). The focus was on asphalt-overlaid bridge decks where the subsurface distress included freeze-thaw damaged concrete as well as delaminated concrete.

Comparisons of GPR results with the traditional coring method of analysis showed GPR predictions of deck deterioration were within ±4.4 percent of the actual proportion of deck deterioration.

Survey speed, which varied up to 80 km/h (50 mi/h), had no significant influence on predictions; thus, both network and project-level sur-

[1]Italic numbers in parentheses identify references on page 102.

veys can be performed at high speed, if desired. For network-level surveys, 20 or more bridge decks can easily be surveyed in 1 day, depending mainly on their relative location.

Perhaps the biggest step forward in the New England research was the use of improved automated data interpretation techniques. The researchers developed quantitative analysis techniques to predict deterioration from the variations in the concrete dielectric constant as computed directly from the radar waveforms. Besides providing a better separation of return signals, the computer processing of signals permits noise and extraneous information to be removed. Also, better methods of displaying the information have now eliminated the obscurity that images such as figure 7 once projected. Some current systems provide the capacity to delineate the problem areas using a mapping technique as illustrated in figure 8. (Note that figures 7 and 8 are of different sites, and no comparison between them is intended.)

Voids beneath pavements

Voids often develop beneath concrete pavements because of consolidation, subsidence, and erosion of the support material. Many of the voids occur beneath joints where water enters the foundation soil and, aided by the pumping action of heavy traffic, carries out fine materials. A National Cooperative Highway Research Program (NCHRP) study in 1979 was the first to demonstrate the feasibility and practicality of using GPR to locate and measure voids beneath pavements. *(4)* The study showed GPR to be capable of spacially locating voids to within ±150 mm (±6 in) with a depth distinction of ±13 mm (±0.5 in).

Numerous void surveys have been performed for State highway agencies since the NCHRP research. These experiences have been somewhat mixed, as excessive amounts of water in the subbase and subgrade tend to disrupt the radar signal and give false readings. *(5, 6)* However, recent improvements in equipment and data interpretation techniques have enabled the detection of voids as small as 3 mm (0.12 in). *(5, 6, 7)* The average thickness of a void and an estimate of its area can be calculated to determine volume and the quantity of grout needed to fill the void for pavement stabilization. The estimated area can be determined more accurately when a three-antenna (or even a four-antenna) radar system is used. GPR can be very useful not only in detecting and locating voids before planning the stabilization of a concrete pavement, but also for checking on the effectiveness of complete stabilization. *(8)*

Pavement thickness

Determining pavement layer thickness is one of the simplest applications of GPR. The procedure, detailed in the American Society for Testing and

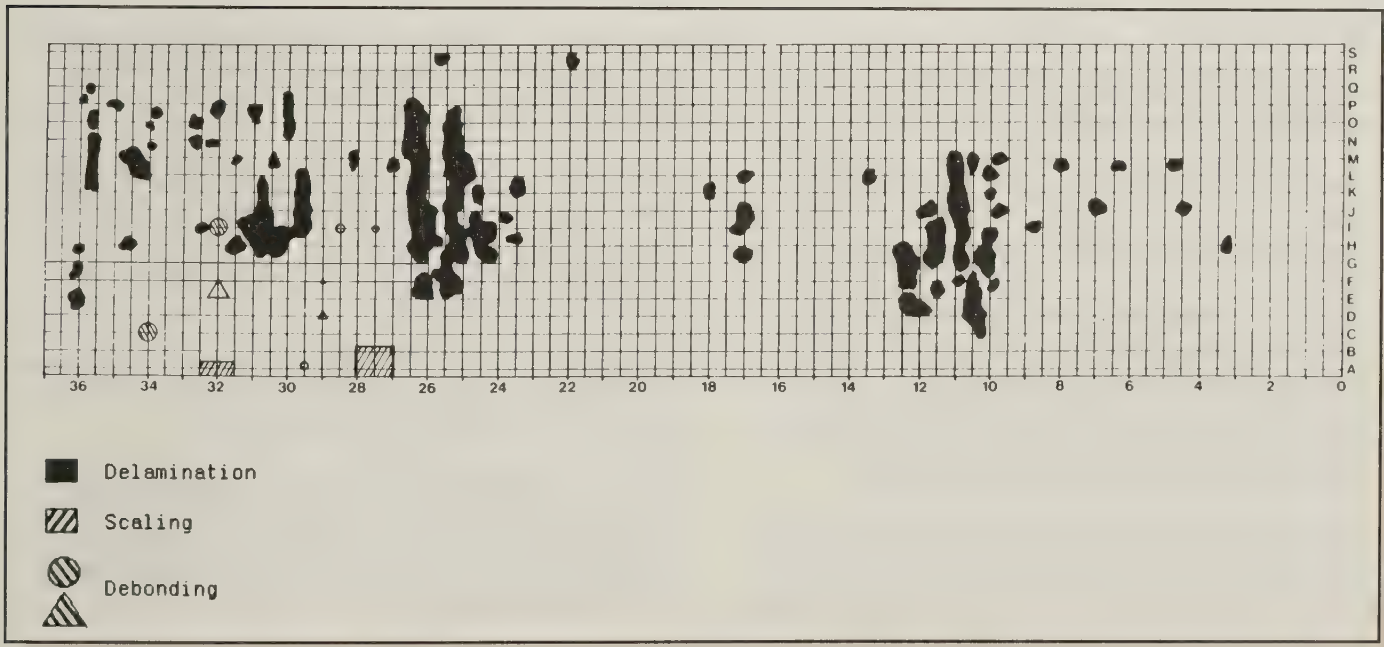


Figure 8.—Graphically-generated anomaly representation.

Materials (ASTM) Standard D 4748-87, can be used to determine the thickness of newly built pavements and overlays (to ensure thickness is as specified) or of older pavements (to obtain structural values or other inventory information). *(9)*

The procedure has some limitations. To determine the thickness of any individual pavement layer, the difference between the relative dielectric constants of adjacent layers must be large enough to reflect a sufficiently large echo from the interface. Also, when determining the thickness of reinforced concrete pavements, reflections from the bottom of the slab may sometimes be too weak to identify. *(10)* Further, the procedure is not recommended for wet pavements or pavements that exhibit a large variation in moisture content.

Despite these limitations, the advantages of determining thickness with GPR are considerable. With GPR, layer thickness to a depth of 0.6 m (2 ft) can be measured to an accuracy of ±6 mm (±0.25 in). In contrast, the standard deviation of core thickness measurements is about 6 mm (0.25 in) for portland cement concrete and can vary from 5 to 19 mm (0.2 to 0.75 in) for bituminous concrete depending on design thickness. Therefore, a large number of core samples must be taken to provide pavement thickness information with the desired degree of confidence. Any reasonably accurate nondestructive thickness method that permits 100-percent inspection has the potential for much future application.

Other applications

Other highway applications for GPR are being investigated. These include:

- Determining the degree of hydration of cement.
- Determining the water content of new concrete.
- Locating reinforcing bars and wire mesh.
- Detecting dowel misalignment.
- Detecting debonding of overlays.
- Evaluating scour around bridge piers.
- Back-calculating layer moduli (in conjunction with the falling weight deflectometer).

GPR has also been used for geophysical investigations such as profiling the bottoms of lakes and rivers and locating rock formations and fractures, cavities, abandoned mines, archeology sites, pipes, sewers, cables, tanks, and ice lenses. Geophysical applications have traditionally—and very successfully—been conducted using a strip chart recorder. Geophysical examinations can be easily identified on strip chart recorders because features having surface areas of more than 0.3 m (1 ft) develop an easily identified pattern. Smaller features are frequently much more difficult to discern unless computer enhancement is used.

Conclusions

There are many methods for conducting surveys and determining the properties of a feature before extensive maintenance or repair is considered. The older methods such as chain drag and coring are often time consuming, costly, or destructive, with definite limits on the amount of sampling that can be performed. The objective of sampling surveys should be to determine the most information at the least cost. This need becomes especially compelling given the vast amount of infrastructure evaluation that must be conducted over the next decade.

Ground-penetrating radar affords great potential as an expedient and cost-effective evaluation tool. Initial testing and evaluation have proved successful. As a result, ASTM has developed a test method for determining the thickness of bound pavement layers, and other testing standards are currently being developed. The future use of ground-penetrating radar in highway work will depend on the extent to which State highway agencies adopt it as a viable construction and maintenance tool.

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THE HIGHWAY ECONOMIC REQUIREMENTS SYSTEM: AN INTRODUCTION TO HERS

by Regina McElroy
Graphics by Robert Huheey

Introduction

In 1989 the Chairman of the U.S. House of Representatives Committee on Public Works and Transportation called for the "Department of Transportation (DOT) to accelerate its efforts to examine the costs, benefits and national economic implications associated with a broad array of [highway] investment options." *(1)*[1]

The DOT now has a model which simulates improvement selection decisions based on the relative benefit/cost merits of alternative improvement options. The newly developed Highway Economic Requirements System (HERS) uses incremental life-cycle benefit/cost analysis to define the "near-optimal" cost-effective set of appropriate improvement options given user defined policy scenarios. *(2)*

HERS is designed to select the "best" improvements, reducing the total cost incurred by highway users and agencies while ensuring an acceptable economic return on the investment of public funds. The model recognizes reductions in direct user costs (travel time, incidents and vehicle operating costs) as highway-user benefits. Also considered as benefits are reductions in maintenance costs and the "residual value" of an improvement.

HERS procedures represent a dramatic change in traditional, National level, highway investment analysis. Other investment decision simulations are not sensitive to user benefits and are not intended to produce "optimal" solutions through the economic comparison of numerous alternatives.

This article provides an introduction to the logic design and capabilities of the HERS model. Initial HERS information will be reported in the upcoming 1993 *Status of the Nation's Highways, Bridges and Transit Systems: Conditions and Performance Report to Congress (C&P Report).*

[1]Italic numbers in parentheses identify references on page 111.

Background

The HERS model is distinguished from traditional highway investment analysis by two important features: The analytical technique and the software user interface.

Analytical technique

Using empirically supplied current highway conditions, traffic forecasts, and established engineering relationships predicting the impact of highway condition on performance, HERS will identify deficiencies and simulate highway improvements that could satisfy user objectives. These HERS-generated, system improvement sets are evaluated, and reports on initial improvement costs, user impacts, and physical conditions are provided.

Numerous alternatives are considered to correct each section deficiency and the economically "best" *section* improvement alternative is selected. These best improvements are then compared to find the best *system* solution. Alternatives are evaluated through comparison of the benefits and costs generated through simulated implementation of each option under consideration. This process tends to produce the most economically beneficial highway investment strategies.

Use of this technique has several implications:

- *User cost considerations* are key to improvement selection decisions. In HERS, the question is: "What impact does system condition and performance have on highway users?" rather than "What impact do highway users have on system conditions and performance?"

- *Several potential improvement options* for any deficiency are identified and analyzed.

- The *economically "best" time* to implement an improvement is considered.

Software user interface

The software user interface is unique and allows for the straightforward development and analysis of policy scenarios. The model is accessible; it operates on a personal computer and is user-friendly. The analyst may readily control the following variables:

- *Deficiency levels:* The user can adjust the deficiency levels used in the HERS procedure to target highway sections for potential improvement. (See discussion of deficiency triggers, below.)

- *Improvement selection criteria:* The user controls the benefit/cost thresholds, establishes funding or system condition constraints, assigns relative importance to the various user benefits, and specifies user-cost objectives by highway functional class or vehicle type categories.

- *Input parameters:* Inputs such as improvement costs and the discount rate are easily modified by the user.

- *Analysis objective:* The system will operate in one of two modes: It will predict system conditions and performance given varying funding levels, or it will estimate the funding required to achieve a user-specified level of system performance.

Why HERS?

Interest in quantifying highway investment requirements—current and future—was established with the 1968 Congressional requirement for a biennial "Needs Report." The continuum in figure 1 summarizes the developmental history of highway investment analysis techniques.

The first Needs Report, in 1968, provided a summary of independently assessed State highway needs. The States reported the investment level required to correct *all* current and anticipated pavement, alignment, and capacity deficiencies to the year 1985 ("full needs"). National standards for system classification, sufficiency rating criteria, or inventory data were not available. This first "era" was characterized by the perception of unlimited capital investment resources, and system expansion was the goal. *(3)*

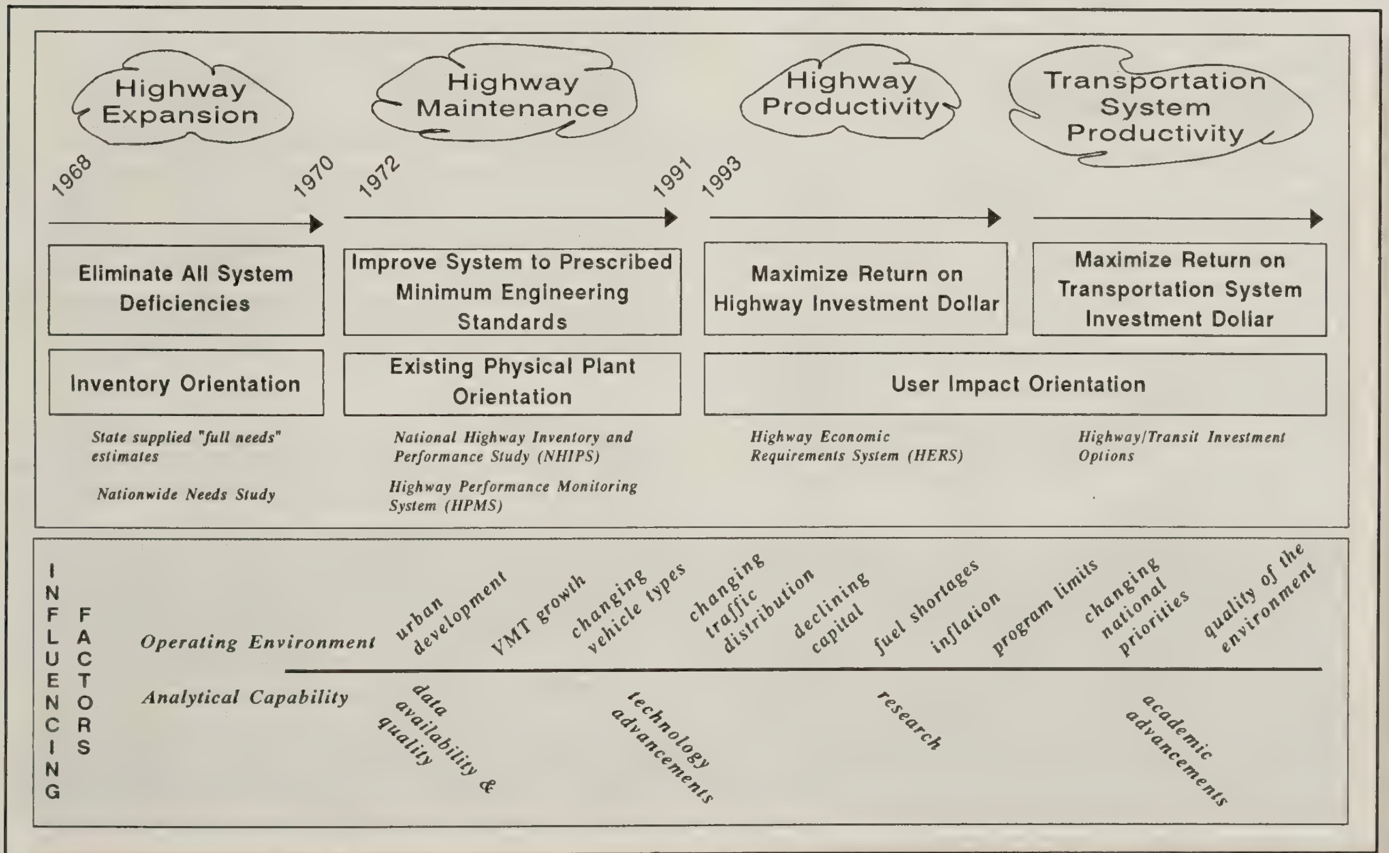

Figure 1.—Development of highway investment analysis techniques.

By the early 1970's, the demand for highway travel was increasing dramatically, but investment resources were limited. The need to prioritize capital improvement projects had become apparent.

The 1972 report benefitted significantly from improved data collection and analytical techniques. The *1970 National Highway Functional Classification and Needs Study* provided standardized information on physical conditions and needs by functional class.

Further, the concept of *minimum tolerable conditions* (MTC) was introduced. The MTC's represented a consensus of highway engineer expert opinion regarding highway safety, performance, and physical design. Each functional class was assigned an appropriate MTC level. For the first time, "needs" estimates represented the cost to provide a standard level of condition appropriate for a particular system's function (as opposed to jurisdiction).

The 1972 report included an assessment of investment priorities as well as an analysis of various alternatives to full needs. Relatively sophisticated modeling techniques were used to evaluate alternative investment options intended to "maintain (or preserve) the physical system." This report exhibited an important new orientation toward "system preservation" and marked the beginning of highway investment analysis as conducted today. *(4)*

In the mid-1970's, the notion of *performance-related investment* was taking hold as the appropriate way to express highway investment options given constrained funding. The *1976 National Highway Inventory and Performance Study (NHIPS)* provided the data and analytical modeling techniques necessary to establish the foundation for designing a framework to evaluate the tradeoffs between capital investment and changes in highway system conditions and performance. *(5)*

The *Highway Performance Monitoring System (HPMS)* was introduced in the 1983 report. The HPMS was the product of a long-term research and development effort initiated by the Federal Highway Administration (FHWA) to establish a continuous data collection system and develop analytical models to project future investment requirements based on the current state of the highway system. Although the coordinated HPMS data base and analytical package is highly regarded, it does not explicitly consider the relationship between user benefits and improvement costs. *(6)*

A shift from a primarily engineering orientation to one which includes economics, or user costs, characterizes the third era depicted on the continuum. The user impact orientation of HERS allows decision makers to compare productivity, or return on investment, for various scenarios.

The next mark on the continuum is expected to be the expansion of HERS from an exclusively highway investment analysis tool to one that includes options for alternative surface transportation system improvements. The benefit/cost framework of HERS can accommodate the inclusion of multimodal improvement options. The first step in this HERS evolution is to incorporate transit options.

Relationship of HERS to HPMS

HPMS system overview

A flowchart of the HPMS analytical procedure is presented in figure 2. As with HERS, the model predicts resulting highway conditions, identifies deficiencies, and selects potential improvements to correct the deficiencies based on user-specified travel demand.

However, when the HPMS model identifies a deficiency and it simulates the improvement selection decision process, only one pre-determined improvement is selected for each deficiency. Cost-effectiveness is not considered.

The HPMS model can also test the impact of constrained system investment. The improvement selection decision process is extended to include prioritization of the individual improvements necessary to correct all deficiencies. The prioritization procedure is primarily a function of changes to physical conditions as opposed to user cost impacts.

The HPMS uses a cost effectiveness index to measure system performance and determine decisions given a constrained funding objective. It is derived from the status of physical characteristics (pavement, alignment, etc.). Although it is understood that user costs vary with physical conditions, they are not directly calculated.

Use of HPMS in HERS development

Development of HERS assumed that the HPMS data base would be used and that many of the procedures from the HPMS analytical models would be shared as well. The contract to develop HERS did not include provisions for developing new engineering relationships or collecting additional highway inventory data.

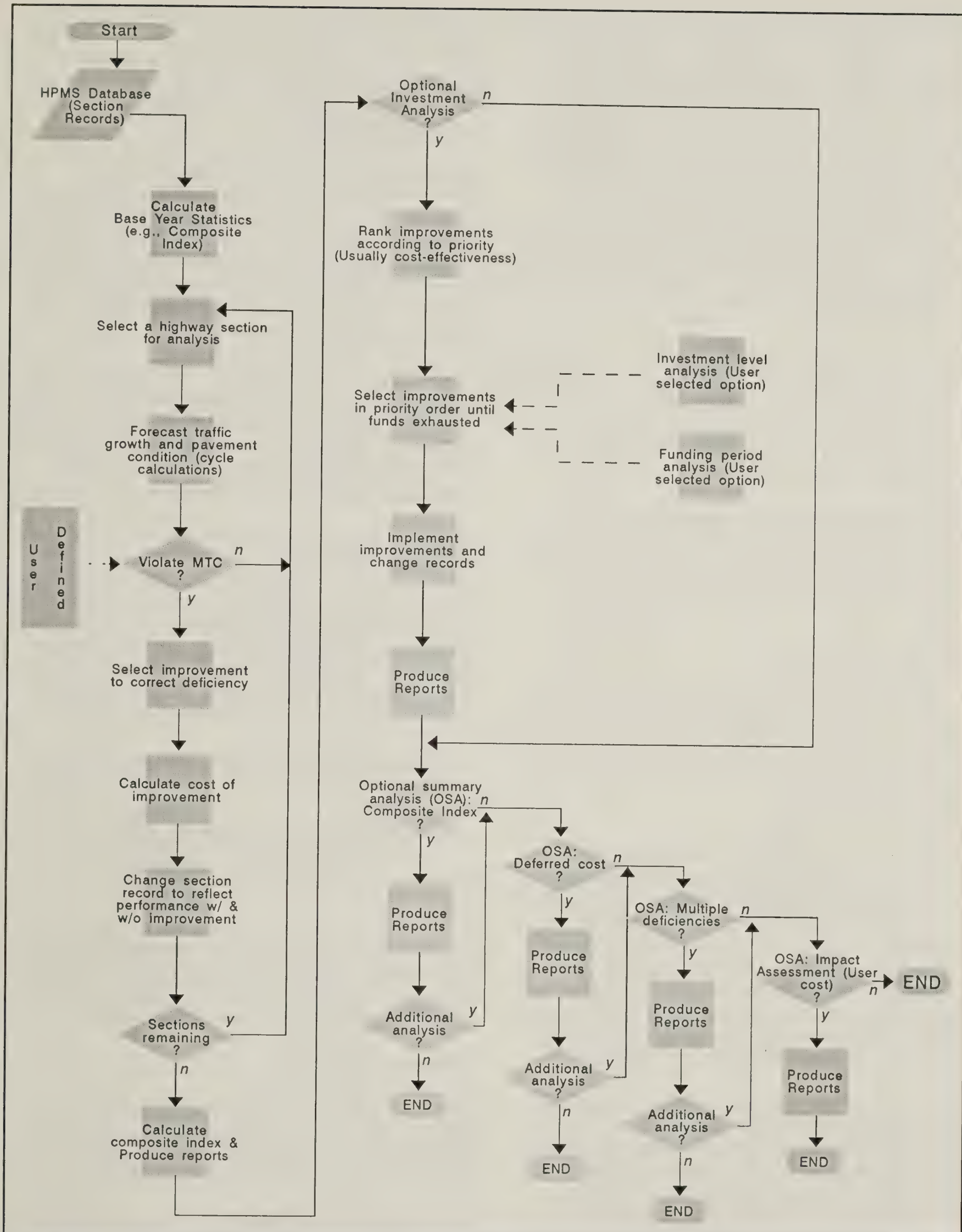

Figure 2.—Overview of HPMS analytical procedure (funding period).

The comprehensive HPMS data base is the most detailed description of the Nation's highway conditions available. It is a stratified random sample of approximately 105,000 sections of non-local roads. The data base is updated annually.

The HPMS analytical procedures have been extensively reviewed by government oversight agencies such as the Government Accounting Office (GAO) and by many transportation professionals, and the procedures have been found reliable and credible. The HERS model could not have been developed without the foundation provided by HPMS.

However, the unique features of HERS—its deficiency identification and improvement selection process, its extraordinary computation requirements, and its increased sensitivity to user costs— necessitated significant modifications to the HPMS procedures.

In fact, the forecasting procedure was the only HPMS process applied directly to HERS. It should be noted, however, that even when the HPMS procedures were modified, the underlying engineering relationships were preserved.

HERS system description

The HERS system will run on a 386-class microcomputer. The main HERS program has 74 subroutines and 425,000 bytes of source code and is written primarily in standard FORTRAN 77.

HERS system overview

A schematic overview of the HERS procedure is presented in figure 3. The user first defines a policy scenario for analysis. For example, the user may be interested in system user-cost levels resulting from a constrained highway investment budget. By changing the parameters in the HERS "RUNSPEC" file, the user indicates the level of available investment, acceptable values for project benefit/cost ratios, levels at which a section will be found deficient, and so on.

The user also determines the length of the overall analysis period (OAP) and the length of the funding periods. Generally, the highway system will be evaluated over a 20-year horizon (OAP) divided into four funding periods of 5 years each. HERS will implement no more than one improvement type per deficient highway section for each funding period.

The HERS analysis process starts by forecasting traffic growth and pavement condition for each highway section in the HPMS data base. The model then proceeds to the first pass where it evaluates each section for unacceptable conditions. Unacceptable conditions refer to deficiencies that the user determines must be corrected regardless of economic attractiveness. A potential least-cost improvement is identified to correct each deficiency.

User benefits and costs associated with the least-cost improvement are simulated and used to generate an incremental benefit/cost ratio (IBCR). The selected improvements are then prioritized according to their IBCR. Depending on the user-defined constraints (e.g., available funding), these improvements are placed on a list for potential selection.

A deficiency that violates the unacceptable conditions standard will always be improved. However, each potential improvement selected in the first pass will be re-evaluated in the second pass to consider the economic feasibility of implementing a higher cost, more aggressive option.

In the second pass, highway sections violating the user-defined "serious deficiency level" or "deficiency level" are evaluated. All potential improvements are identified and considered for implementation via the incremental benefit/cost procedure. Improvements are selected according to their IBCR's until some user defined constraint is violated. The best improvements are simulated, and final reports are produced.

The unique features of HERS are described in greater detail below.

Deficiency Identification

Deficient characteristics

HERS checks eight characteristics of each highway section for deficiencies: pavement condition, surface type, volume/capacity (V/C), lane width, right shoulder width, shoulder type, horizontal alignment, and vertical alignment.

Deficiency criteria

There are three levels of deficiencies within the HERS framework: unacceptable level, serious deficiency level and deficiency level. These deficiency triggers serve two important functions.

First, they allow the user to control computation time. HERS currently requires well in excess of 1 working day to evaluate a scenario using the full sample set. The "run time" may be reduced, without losing significant accuracy, by judiciously setting the deficiency levels.

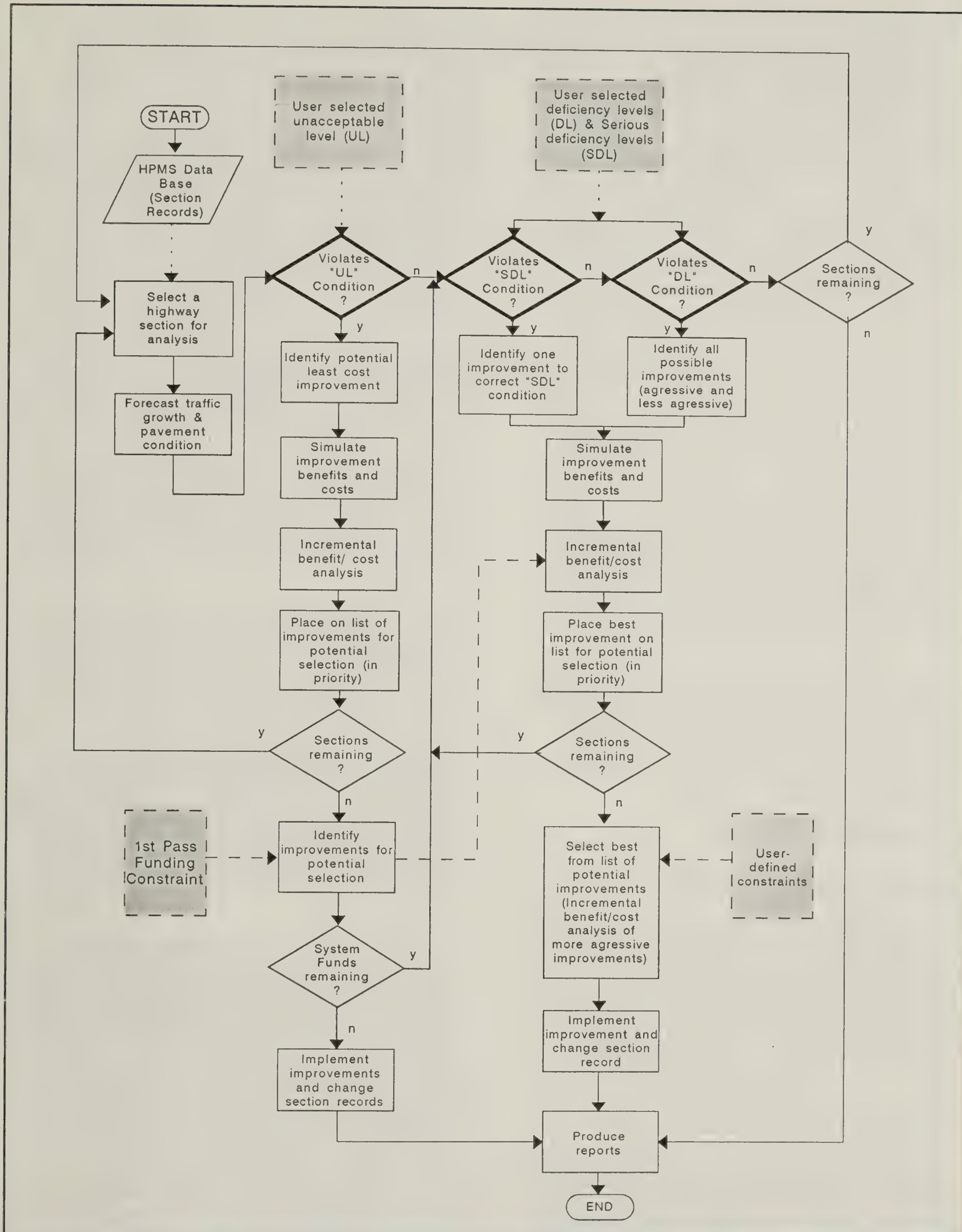

Figure 3.—Overview of HERS funding period analysis procedure.

Second, they allow the user to establish the allowable condition of a section. There is a lack of consensus concerning how the MTC's should be established. For example, it has been suggested in policy debate that the MTC for congestion should be lowered from a level of service "D" to "E" or "F." The impact of such a policy change can be readily tested using HERS.

Highways violating the "unacceptable level" standard will always be corrected (assuming available funds) with, at least, an inexpensive improvement. There is no requirement for these improvements to pass the benefit/cost test.

Serious deficiency level (SDL) standards are used to reduce the number of improvements analyzed to correct a deficiency, reducing the HERS run time. If the SDL for a given section characteristic is violated, only one improvement that corrects the SDL deficiency will be considered.

The HERS model will analyze up to six aggressive and nonaggressive improvement options for any section violating a user-defined deficiency level (DL). The greater the number of potential improvements evaluated, the closer the final set of system improvements will be to optimal.

The closer a deficiency trigger is set to the MTC, the fewer the number of potential improvements that will be analyzed (decreases computation time). The closer the trigger is to the design standard, the larger the number of potential improvements that will be analyzed.

Improvement Selection

Improvement options and costs

Improvement types considered by HERS consist of various combinations of pavement, widening, and alignment options. The HERS model selects from among 28 improvement types. The options range from least aggressive (e.g., resurfacing) to more aggressive (e.g., reconstruct with improved alignment).

Life-cycle incremental benefit/cost analysis: An overview

HERS uses benefit/cost analysis (BCA) to select the best improvement options for each user-defined funding period. The heart and soul of the BCA procedure is the benefit/cost ratio (BCR):

$$\frac{\text{User Costs + Agency Costs + Residual Value}}{\text{Improvement Cost}}$$

For each improvement option, user costs and ongoing agency maintenance costs are calculated. Also calculated is the amount by which implementing this improvement will reduce the cost of subsequent improvements (residual value). Improvement cost refers to the initial cost of the improvement.

The IBCR is calculated by comparing the BCR (or IBCR) from one improvement option to the BCR (or IBCR) associated with another base case alternative. The BCR, as used in HERS, is expressed in "present value." That is, it represents the stream of benefits and costs over the overall analysis period, discounted back to the funding period of interest.

The key concept underlying BCA is the sequential comparison of alternative options until the "optimal" action is found. HERS evaluates alternative options in three dimensions:

1. Alternatives are compared to the option of postponing any improvement to address the deficiency until a subsequent funding period. The question addressed in the first dimension is: "Should the deficiency be corrected now or later?"

2. Assuming that the above analysis finds addressing the deficiency in the current funding period to be economically acceptable, HERS proceeds to the second dimension. The option with the highest IBCR relative to the "postpone any improvement option" is compared to more aggressive alternatives that could correct the deficiency. This is done in a sequential fashion until the improvement with the highest IBCR is identified. The question addressed in the second dimension is: "What is the best improvement to correct this section deficiency?"

3. After all HPMS highway sections have passed through the first two dimensions of analysis, improvements are selected in order of IBCR for system implementation until some user-defined scenario constraint has been violated (e.g., funds are exhausted). The question addressed in the third dimension is: "Given the user- defined system constraint, what mix of improvements will generate the highest return on the investment dollar?"

A detailed flowchart of the HERS benefit/cost and improvement selection procedures is presented in figure 4.

Summary

The HERS model represents a significant advancement in the methodology available to estimate National level highway investment requirements. Results from this model will provide a "highway-user dimension" to needs analysis.

The system is designed to readily accommodate necessary refinements as new research findings become available. It is anticipated that future versions of HERS will include an expanded list of improvement options (e.g, new construction on new alignment, demand management strategies, and other-mode options), additional benefits (e.g., National economic impacts), and additional costs (e.g., air and noise pollution).

Throughout the HERS development process, one of the more important goals was to produce a working model that would use the best data and highway engineering knowledge available. To facilitate this process, the contractor designed HERS using an open framework, or modular, structure. The model is viewed as a "work in progress" with the FHWA's intent being to update and refine HERS as the results of various research efforts become available.

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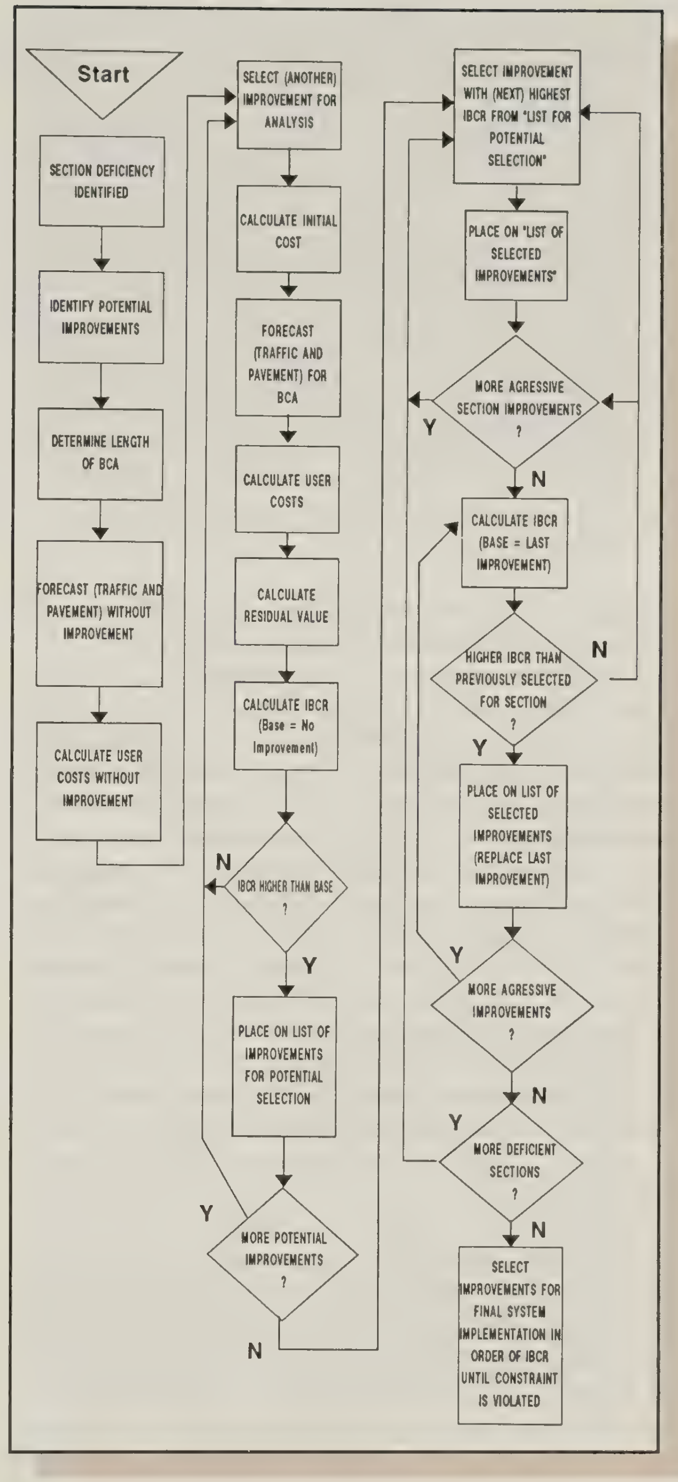

Figure 4.—HERS benefit/cost and improvement selection procedures (general case, second pass).

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Technology Transfer ★☆★☆★ ★☆★☆★☆★ *American Style*

by George M. Shrieves, William L. Williams, and William Zaccagnino

The following article is adapted from remarks and a paper, entitled Technology Transfer in a Multilevel Government Country, presented by George Shrieves at the International Conference on Technology Transfer and Diffusion for Central and East European Countries at Budapest, Hungary, on October 12-14, 1992.

*In his opening remarks, he established a parallel between the multilevel government of the United States and the prospects for a united Europe. "The challenge is for you to consider what parts of our U.S. internal program may be applicable to a united Europe. This assumes that a united Europe, at least for technology transfer purposes, would have three levels of government somewhat comparable to our Federal, State, and local levels. * * * Also, the role of our States, compared to the role of our Federal Government, has changed over the years—generally to a stronger central government at the expense of the States. My comments are not meant to be a history lesson. I only want to make the point that, somewhere in our diverse political structure, there is a parallel to a united Europe."*

Introduction

The task of moving the results of research and development from the laboratory and innovative technologies from other sources into practice has long been assigned to the Federal Highway Administration (FHWA) for a number of reasons. One hundred years ago, the States were vastly unequal in road building skills; the South and West lagged far behind the practices of the Northeast. Railroads spanned the country and encouraged westward migration, but feeder roads to the railroads and ports were needed. Better roads meant better delivery of farm products, better mail, better schools, better medical care, more social interaction—in short, better social and economic welfare (still a need today in the United States and, I think, a parallel in Europe).

The FHWA's emphasis on technology transfer continues an evolution that began in 1893 with the Office of Road Inquiry. The Office, the first among the FHWA's preceding organizations, had technology transfer as one of its primary functions. In the 1890's, demonstration trains, known as "good road trains," traveled throughout the country fitted with construction and roadbuilding machinery and equipment, section models of macadam, and models of other types of road construction. These trains carried road experts and "object lesson road" construction teams. Each construction team was shipped from place to place by rail, and it built eight to nine 1.6- to 2.4-km (1- to 1.5-mi) roads per year that could serve as examples of proper drainage, stone surfacing, and road maintenance. *(1)*[1]

In more recent decades, reasons for the prominent role of FHWA include the widespread and decentralized nature of the highway program and FHWA's ability through its field structure to reach the 50 State highway agencies, the more than 37,000 local units of government, and the U.S. territories. Another reason is the extensive effort and resources required to obtain widespread application of new products and technologies. Further, there are national interests, primarily economic, in ensuring widespread application.

The FHWA's current program reflects the philosophy of the good road trains. New technologies, such as new asphalt and concrete mixes and con-

A hundred years ago, decent roads were a top priority.

[1]Italic numbers in parentheses identify references on pages 119 and 120.

struction techniques, pavement construction testing equipment, traffic operations and management equipment, and geographic information systems, are transported in mobile field laboratories. Other methods used for reaching the users of the technology are publications, videotapes, CD-ROM, technical summaries, projects, site visits, equipment loans, exhibits, workshops, symposia, interactive videodiscs, and training.

FHWA's Technology Transfer Mission

The FHWA's technology transfer mission is to ensure the timely identification and assessment of innovative research results, technology, and products and the application of those that are determined to be of potential benefit to the highway community. These technologies and products are developed, implemented, and promoted with the FHWA's partners in State and local agencies, private industry, universities, and others in the national and international highway communities.

It is clear that technology transfer has always been an integral part of the FHWA mission. Recently, the highway network in the United States has experienced numerous changes. There has been a growth in the number and size of trucks and other traffic, and traffic on our highways has grown to the point that many of them routinely are congested. At the same time, the Interstate Highway System is virtually complete, and new highways are only infrequently being built, while many existing miles are wearing out. One answer to these concerns is introducing new technologies to the reconstruction, rehabilitation, and resurfacing of existing highways as well as to the construction of new highways. The Nation is faced with doing a better job with the highways that it has.

While the FHWA has a strong and growing technology transfer program across the United States, the success of the program is dependent for its success on other public and private organizations advancing the agency's efforts further in the highway community.

The Organization

The FHWA's technology transfer mission involves the whole agency, with primary responsibilities resting in three offices—Office of Technology Applications, National Highway Institute, and the Office of International Programs—as well as more general responsibilities in all of the program offices, the 9 regional offices, the 52 division offices, and the 3 Federal Lands Highway Divisions.

In 1890's construction teams built "object lesson roads."

Office of Technology Applications

The Office of Technology Applications (OTA) works in all areas of highway technology, including asphalt and concrete pavements, structures, geotechnology, hydraulics, traffic operations and management, and motor carriers. The office also includes activities related to the Local Technical Assistance Program (LTAP) and implementation of the approximately 100 products anticipated from the Strategic Highway Research Program (SHRP).

The technologies and products identified in the OTA's assessment are developed, implemented, and promoted with State and local agencies, private industry, universities, and others in the national and international highway communities. The OTA works closely with FHWA program and field office staffs. In addition, the OTA is expanding its alliances with partners in the highway community to broaden the network through which technology can reach its users. The office has a key responsibility for the FHWA's Technology Applications program.

National Highway Institute

For the past 22 years, through its National Highway Institute (NHI), the FHWA has developed and presented to the State highway agencies technical training that is not readily available from other sources and which these agencies would not ordinarily develop for themselves. Nearly 100 different short technical courses (1 to 5 days) are offered nationally through the NHI, primarily to the States. In fiscal year 1991, 405 presentations of these short courses were presented to a total of 14,000 participants.

State and local government personnel and private sector personnel are charged a fee for the

NHI's short courses; the fees for State and local personnel are half the cost of instruction while private sector personnel pay full fees. State and local agencies pay fees ranging from a total of $1,000 for 1-day courses to $4,000 for 4- or 5-day courses. (2) The $1,000 to $4,000 fees cover 30 to 40 students.

A considerable portion of the NHI State Program budget is spent to offer comprehensive, graduate-level curricula needed by mid-level highway engineers and managers to supplement their previous academic studies. Three of these courses are Highway Pavements, Highway Materials Engineering, and Environmental Training Center. These comprehensive graduate-level courses, ranging from 2 to 6 weeks, are aimed at the top two or three people in highway departments who will serve as the State's pavements engineer, materials engineer, or environmental specialist.

The NHI's mission was expanded under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) to also address international and private highway sector training needs.

Office of International Programs

The FHWA is working to expand its program of interaction internationally. The agency is formalizing its scanning process for finding transportation technology that can aid the United States in improving the durability of its infrastructure and the safety and operation of its facilities. As the international network expands, the agency will increase the number of focused technical trips abroad to facilitate the exchange of technology in various fields. The FHWA will continue strong participation in committees and task forces of the Organisation for Economic Co-operation and Development and of the Permanent International Association of Road Congresses.

The FHWA has already begun to draw on other countries for asphalt pavement technology. For instance, in late 1990 a 21-member study group representing the FHWA, the American Association of State Highway and Transportation Officials (AASHTO), the National Asphalt Pavement Association, The Asphalt Institute, the Strategic Highway Research Program, and the Transportation Research Board (TRB) toured six European countries. (3) In May 1992, a similar group traveled to Europe to explore portland cement concrete pavement technology.

Other international activities have included Integrated Highway Information System seminars in 10 European countries, including in Eastern Europe, and a presentation at the 1991 Conference and Exhibition of the Transportation Association of Canada (held in Winnipeg, Manitoba) about portland cement concrete technology, including demonstrations in the FHWA's concrete technology mobile laboratory. The FHWA also has continued to support and participate in the planning of a major Pacific Rim Conference scheduled for 1993 in Seattle, Washington.

Technical program and field offices participation

In the overall design of the FHWA technology transfer program, FHWA's technical program offices and field offices are enlisted in the outreach process to ensure that new technology and innovations get into the hands of the users as quickly as possible. Staffs in the technical program offices often serve as the project managers for onsite technology demonstrations, bringing their expertise along with them and gaining an opportunity to further expand their expertise by interacting with other experts in their field. These demonstrations consistently draw groups of State and local government and private sector highway community personnel. Field office staff also serve as instructors for NHI's courses, including serving as national instructors.

FHWA field office staffs are in continual contact with the State transportation agencies. The FHWA's regions and divisions have participated in or helped finance a variety of technology transfer activities with State and local groups, such as Intelligent Vehicle-Highway Systems Congestion Management Sessions, an exhibit on the mobility of the elderly, Arterial Traffic Control Sessions involving local jurisdiction in a regionwide management planning session, numerous site visits to interact with State and local officials, numerous NHI training courses, and general interaction between the field offices and others in the highway community in their technology transfer efforts.

Technology Applications Program

Under the FHWA Technology Applications Program, the Office of Technology Applications and program office subject area specialists prepare manuals and other material, conduct demonstrations, work closely with FHWA and State staffs in the subject areas, and ensure that products reach the users nationally and internationally by working closely with contacts in the public and private sectors, universities, and other organizations.

Field office technology transfer and program staffs provide the focal points for the technical expertise needed to successfully promote and deliver new products and ensure those products are integrated into future Federal-aid highway projects and are implemented through highway and motor carrier programs. FHWA division office and State staffs are in the best position to reach the broadest group of users in the various subject areas.

The technology applications program is focused in four project categories: demonstration projects, application projects, test and evaluation projects, and special projects. Technical activities are assigned to one of the categories depending on the stage the technology is in, and, after development, what technology transfer or marketing approach would be most useful in reaching the intended users.

- Demonstration Projects—Efforts to promote nationwide a proven material, process, method, equipment item, or other feature that the FHWA has targeted for adoption by the highway community. These projects bring the technology to locations around the United States and provide hands-on demonstrations to government and nongovernment representatives.

- Application Projects—Individual efforts to assess, refine, or disseminate an emerging technology. Such efforts may include contracts, regional or national seminars or workshops, specifications, notebooks or pamphlets, instructional/how-to guides, open houses, and focused clearinghouses that are not part of demonstration or test and evaluation projects.

- Test and Evaluation Projects—Efforts to evaluate innovative or emerging technologies that have been identified as having a great potential for use nationwide. FHWA provides funding to States to construct experimental projects. Test and evaluation projects allow State highway agencies to evaluate new or innovative highway technology, or alternative standard technology, under actual construction and operating conditions. Technologies may include materials, processes methods, equipment items, traffic operational devices, or other features that have not been sufficiently tested under actual service conditions to merit acceptance without reservation in normal highway construction or that have not been accepted but need to be compared with alternatively acceptable features for determining their relative merits and cost effectiveness. *(4)*

- Special Projects—Evaluation efforts of industry and the FHWA in conjunction with interested States to evaluate a material, process, method, or other feature. An effort begins with a technology sharing meeting, and it progresses through a work plan and several control experiments (or operational tests) to a closeout evaluation. These special projects can lead to a demonstration, test and evaluation, or a combination of the two types of projects.

The implementation of products under the SHRP and the LTAP, which are described later, are also a part of the FHWA's Technology Applications Program.

Another part of the FHWA's technology transfer effort—the technical training programs administered by the National Highway Institute—is coordinated closely with these technology applications project activities to ensure that training related to the latest technologies is developed and presented to the States on a timely basis.

Grants for Research Fellowships

Each year since October 1983, the FHWA, through the NHI, has awarded research fellowship grants to students from universities across the United States. Under the Grants for Research Fellowships (GRF) Program, undergraduate and graduate students are provided with a monthly stipend, academic credit, and an opportunity to undertake highway-related research, development, or technology transfer study projects at the FHWA's Turner-Fairbank Highway Research Center (TFHRC).

Originally designed to acquaint the academic community with TFHRC facilities and capabilities, the GRF Program aims to:

- Bring talented students into highway research.

- Merge academic study with practical applications for students majoring in transportation and related disciplines.

- Extend and strengthen ties among the FHWA and universities offering transportation-related academic programs with research potential.

- Encourage graduate students to pursue research and teaching careers in highway transportation.

Former GRF students are now transportation professors and professionals in the field, including FHWA and State highway agency employees. *(5)*

A second program directed to university students is the Dwight D. Eisenhower Scholarship Program. This program was created under the

ISTEA as a transportation research fellowship program to also help attract qualified students to the field of transportation engineering and research. *(6)*

Strategic Highway Research Program Product Implementation

As the 5-year SHRP approaches its end, the FHWA is taking a central role in the implementation of the program's products. From the mid-1980's, the FHWA has worked with the SHRP's staff as they developed the program and conducted their research.

The result of the SHRP's research efforts will help to improve the durability and longevity of the Nation's highways for both the transportation industry and State highway agencies. The FHWA is preparing to ensure that the nearly 100 products that are resulting from the SHRP will receive full consideration. The FHWA will be working with the AASHTO and the TRB in this implementation effort. The SHRP has estimated the potential savings to the highway program from full implementation of these products to be hundreds of millions of dollars annually.

The SHRP's efforts have already resulted in useful products ready for implementation. The steps for the adoption and use of the SHRP's new asphalt binder and mixture specifications include round-robin testing by the States and producers, adoption of standards by the AASHTO Subcommittee on Materials, field verification and validation, and eventual changeover to the new standards and their full-scale use. The Concrete and Structures Working Group recommended and established priorities for a variety of products including concrete permeability, concrete design and construction aids, concrete freeze-thaw and durability, high performance concrete, cathodic protection of bridge components, bridge protection and rehabilitation, rebar corrosion rate measuring device, and others.

In the highway operation area, the SHRP Executive Committee recommended priority implementation for the portable sign stand, flashing stop/slow paddle, portable speed bump, diverging lights, and opposing traffic lane divider. Evaluation and promotion plans for State participation are being developed for each of these items.

The FHWA will continue the Long-Term Pavement Performance (LTPP) Program under its research program for another 15 years following the SHRP's effort. Notwithstanding the continuation of the research program, early implementation items under LTPP have been identified by the SHRP: distress identification manual, Georgia digital faultmeter, resilient modulus test procedures, and falling weight deflectometer quality assurance software.

The expanded FHWA technology transfer program will pick up more implementation projects as the SHRP winds down and as more projects become available. Major technology transfer emphasis will begin in 1993 at the completion of the SHRP.

Local Technical Assistance Program

A significant number of users in the highway community are represented by local highway agencies. The FHWA interacts with them through its LTAP. The LTAP (formerly the Rural Technical Assistance Program) serves as the primary channel through which innovative transportation technology is prepared and delivered to both urban and rural local communities in the United States. In 1982, a network of technology transfer centers was established to work with local transportation agencies in addressing their specific goals and to present new technology and product alternatives to meet those goals. The number of centers has grown from the initial 10 centers to 50, with 1 more anticipated in 1993. Funding for the operation of the centers accounts for the major portion of the LTAP budget.

During the program's 10-year history, a cooperative spirit of networking has developed among the local highway agencies, the States, universities, and the Federal Government. This cooperative spirit has helped to make the LTAP a very successful program. The program provides a way for local governments and agencies with limited resources to have access to new technologies to help them operate their transportation programs more efficiently and economically. Each year, technology transfer centers have conducted over 1,600 training courses with a total attendance of over 46,000, demonstrated 1,700 roadshows (onsite exhibitions of new technology) with almost 10,000 in attendance, and provided over 90,000 publications and loaned over 9,500 videotapes to local engineers. The centers have also developed and mailed out technical quarterly newsletters to over 140,000 personnel each year.

Intermodal Surface Transportation and Efficiency Act of 1991

The ISTEA gave authority to the FHWA to expand on the existing LTAP. FHWA changed the title of the program following the changes included in the ISTEA to better reflect the new coverage of the program. This expanded program authorizes the U.S. Department of Transportation (DOT) to carry out a transportation assistance program, including making grants and entering contracts for education and training, technical assistance, and related support services. These grants are intended to assist rural local transportation agencies in developing expertise, improving roads and bridges, enhancing programs for moving passengers and freight, and preparing and providing training packages, guidelines, and other material.

In addition, these grants may be used to identify, package, and deliver usable highway technology to assist urban transportation agencies in developing and expanding their ability to effectively resolve road-related problems and to establish, in cooperation with State transportation agencies and universities, urban technical assistance centers (in States with 2 or more urbanized areas of 50,000 to 1 million population) and rural technical assistance centers. At least two of the centers must be designated to provide assistance that includes a "circuit rider" program, providing training on intergovernmental transportation planning and project selection and on tourism and recreational travel to American Indian tribal governments. *(6)*

Activities have begun in cooperation with the Bureau of Indian Affairs (BIA) of the U.S. Department of the Interior to establish four centers to specifically address the needs of American Indian tribal governments. Funding for the development and operation of these centers is provided by the FHWA and the BIA. These centers are 100 percent federally funded.

Although many of the benefits of the technology transfer program are not monetarily quantifiable, participants in the LTAP-related training programs have given some indication of potential savings from using the training and new technology. In Kansas, jurisdictions with participants in the Bridge Inspection and Rating and Bridge Rehabilitation workshops could save $270,000 over a 3-year period by repairing a bridge versus replacing it. New York local officials estimated $3.5 million savings compared to a total cost of $132,700 to attend LTAP workshop sessions. Pennsylvania's roadshows, "roads scholar" program, workshops, and technical assistance saved municipalities more than $4 million. One local government agency in Texas saved $500,000 per year by implementing the Road Surface Management program.

Strategic Highway Research Program Technology for Local Agencies

The FHWA is working with its partners in local agencies to identify relevant products for local highway agencies from the SHRP and prioritize, package, and deliver these products to the technology transfer centers. Many of the new technology items identified by the SHRP will be of interest to the LTAP community, such as pavement maintenance techniques, snow fence technology, and new work zone devices to improve safety. Examples of promotional tools about a product are the SHRP videotape and flyer on new snow fence technology; the videotape and flyer were distributed to the LTAP centers during 1992. New products under development will be distributed to the centers as they become available.

New Products

In addition, the FHWA recently revived a program to develop new products for the LTAP centers and their clients. The FHWA requested ideas for needed products from the center directors, and FHWA and State highway agency personnel worked with center directors to identify the high priority needs. During the latter part of 1992 and into 1993, committees made up of representatives from various segments of the highway community will select a list of products to develop, and other technical panels will devise plans for developing the identified products and the means for promoting and implementing them among local jurisdictions.

Partnerships

The FHWA's technology transfer mission strongly emphasizes continuing partnerships in the highway community. The FHWA works within the highway community through technical advisory committees, national and international conferences, various committees and task forces, and other direct and indirect interactions.

The highway community identifies needs so the national research and development of technology products and operational tests and evaluations can be focused. Input for the projects to be assessed, developed, and promoted comes from the public and private sector, universities, and others in the highway community. Proposed projects are screened in the OTA and forwarded to Research and Technology Coordinating Groups (RTCG's) in pavements; structures; intelligent vehicle-highway systems; safety; motor carriers; and policy, planning, environment, and right-of-way. The RTCG's—which are made up of various technology transfer and technical program office representatives, other Federal officials, and other technical experts—provide guidance and direction during the development of test and evaluation, demonstration, application, and special industry projects. Effective promotion of the products relies heavily on the strength of the partnership.

The FHWA has a continuing and expanding relationships with many of the highway associations and organizations in the United States as well as a number internationally. These organizations include TRB, AASHTO, American Road and Transportation Builders Association, American Public Works Association, Portland Cement Association, The Asphalt Institute, and Intelligent Vehicle-Highway Systems Society of America (IVHS America).

Transportation Research Board

The TRB, a unit of the National Research Council, supports research efforts concerning the nature and performance of transportation systems, disseminates research information, and encourages the application and implementation of appropriate research findings. The continual interaction occurs through a variety of forums and media:

- TRB Annual Meeting—Annually 300 to 400 FHWA personnel participate among the 5,000 international public and private sector registrants at the TRB's annual meeting. Participation includes attendance at numerous technical and specialty workshops and TRB technical committee meetings. The FHWA also hosts exhibits that display the latest technology and provide literature and publications to participants.

- FHWA personnel interact with TRB professionals through daily committee and panel contacts, facilitating a continuing forum of exchange of technical program information to keep the TRB up-to-date on FHWA research areas.

- The FHWA continues to contribute publications to the TRB-managed Transportation Research Information Service (TRIS) data base.

American Association of State Highway and Transportation Officials

The FHWA and the AASHTO have had a long relationship, covering much of this century. The AASHTO is the national representative of the State highway and transportation agencies. Through the AASHTO, standards and specifications are reviewed and approved by the States and subsequently adopted by the FHWA for use on Federal-aid highway projects. Consequently, since the States are responsible for the planning, design, and construction of highways nationally, the AASHTO is critical to the adoption and use of new highway technology among its members.

Intelligent Vehicle-Highway Systems Society of America

The FHWA and IVHS America—a national, nonprofit organization—have a relatively newly established relationship. But recognizing its importance, the DOT has chartered the organization as a Utilized Federal Advisory Committee.

The Intelligent Vehicle-Highway Systems (IVHS) Program is a public-private partnership, involving the participation of government, industry, academic institutions, and international automotive and electronics standards-setting organizations, acting independently and in concert. Four modal administrations within the DOT are involved in the IVHS Program: the FHWA; the National Highway Traffic Safety Administration; the Federal Transit Administration; and the Research and Special Programs Administration. IVHS America, with its executive committee consisting of one-half private representatives and one-half public representatives, provides the national forum for communications, consensus building, national program coordination, and related national and international activities for all of the involved partners in the program. *(7)*

University Transportation Centers

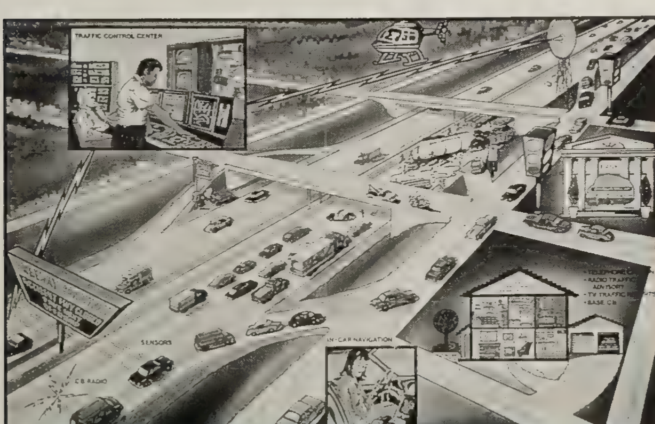
The University Transportation Centers (UTC) Program was established under the Surface Transportation and Relocation Assistance Act of 1987, which directed that 10 university transportation research centers be established. The ISTEA of 1991 directed the additional of three centers. (8) The FHWA, the Federal Transit Administration, and the Research and Special Programs Administration cooperate in the administration of the program. In 1987, the 10 University Centers—one in each of the 10 Federal regions—were established at existing transportation research universities. They were provided $1 million each per year to be matched by an equal amount from sponsors they arranged, such as industry and State highway agencies, to do research and education. The 10 centers developed consortia among a total of 68 universities. Universities must have an active technology transfer program and dedicate at least 5 percent of their funds to technology transfer.

The centers respond to a need to increase the availability of transportation professionals who can respond to the new challenges of the next 30 years. A primary emphasis of the UTC Program has been to produce individuals with master's degrees that reflect multimodal and multidisciplinary skills. As of the end of fiscal year 1991, more than 400 university students and 350 faculty from the program's universities have been involved in the program. *(9)*

Pan American Institute of Highways

Horizontal transfers among developing countries are frequently more effective and are usually a less expensive means of transferring basic technologies. Such transfers can result in savings that can then be used for more advanced transfers from the developed countries. At its October 1986 meeting, the Pan American Highway Congress (PAHC) resolved to strengthen the technology transfer activities for Latin America by establishing a Pan American Institute of Highways (PIH). The FHWA was asked by the PAHC to take a lead role in developing and implementing the concept. In cooperation with a number of leaders from the Latin American highway community, the FHWA modeled the development of the PIH on its experience with the National Highway Institute (and the Federal-State relationship inherent in it) and the similar system used in the network of 50 technology transfer centers under the LTAP.

The Pan American Highway Congress approved the charter and bylaws of the PIH at their May 1991 meeting in Montevideo, Uruguay, and asked the FHWA to continue the administering of the program for the next 4 years. The immediate focus of the PIH is to create an environment for sharing technology by fostering a network mentality. Activities to date include



IVHS is a top technology transfer program.

establishing national coordinating centers in Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, Peru, Trinidad and Tobago, United States, Uruguay, and Venezuela. The PIH is collocated with the NHI. Currently, career NHI-FHWA staff serve as Director General and Executive Director. Also, the PIH headquarters has four contract staff and loaned staff from Argentina, Uruguay, Costa Rica, and Brazil. As of August 1991, 26 individual technology transfer centers were in operation under the PIH. *(2)*

The networking process is working well. PIH members are becoming more frequent and fruitful. The concept of member countries sending loaned staff to work for a year at the PIH headquarters and then return to take back in person technology transfer experience and products is also working very well.

Conclusion

In a multilevel government, a network encompassing Federal, State, and local governments; universities; private industry; and highway organizations is critical to the speed of delivery and adoption of new technology. Technology transfer requires a structured program with champions from throughout the highway community who will convey the innovations in innovative ways. There must also be a simple vision that everyone can relate to and support; the new technology must make sense to the user and have a favorable cost-benefit. It also takes followup to ensure that the technology progresses to all appropriate users, that those users have all the information they need to implement the technology, and that the technology is applied and becomes a part of the state of the practice. Additionally, the States must be permitted to be flexible and innovative; if users of the technology are not stifled, they will probably change what you give them into something better.

Technology transfer is just as important today as it was 100 years ago. The problems are just as real, and the need for solutions is just as pressing. Today, the technology is IVHS, robotics, compost materials, and other innovations we must have for the 21st century.

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ALONG THE ROAD

"Along the Road" is a new, regular department of Public Roads. The information presented here is a hodgepodge of items of general interest to the highway community. But this is more than a miscellaneous section and more than a dumping ground for bits and pieces of information with no other home; Along the Road, especially as it evolves, is the place to look for information about current and upcoming activities, developments, and trends. Your suggestions and input are welcome. Let's meet along the road.

The Evolution of *Public Roads*

Background

Since its first issue in May 1918, *Public Roads* has been a journal devoted to the publication "of the results of researches, experiments and studies of those connected with this Office (the forerunner of the Federal Highway Administration), and of highway officials of the various States. . ." Almost from the beginning, *Public Roads* has been exclusively a house research journal for engineers, scientists, and economists.

Now, however, with the emphasis on intermodalism—highways as a part of a comprehensive transportation system that includes all modes of transportation in efforts to meet increasingly complex social needs—*Public Roads* is broadening its scope and audience to address critical national transportation issues and subjects of interest to highway industry professionals as well as advances in research and technology. While *Public Roads* will still be predominately a research-oriented publication, the result of this evolution will be that *Public Roads* is the magazine of the entire FHWA.

In this new format, *Public Roads* will fill a void in the transportation community not currently occupied by academic journals, trade publications, or association magazines. The expanded audiences will include technical personnel interested in the latest highway research and technology; international, national, State, and local transportation officials; and others interested in the highway industry. The magazine has a limited free mailing list to universities and government officials. It is anticipated that subscriptions will increase with the expanded scope and audience.

Evolutionary Changes

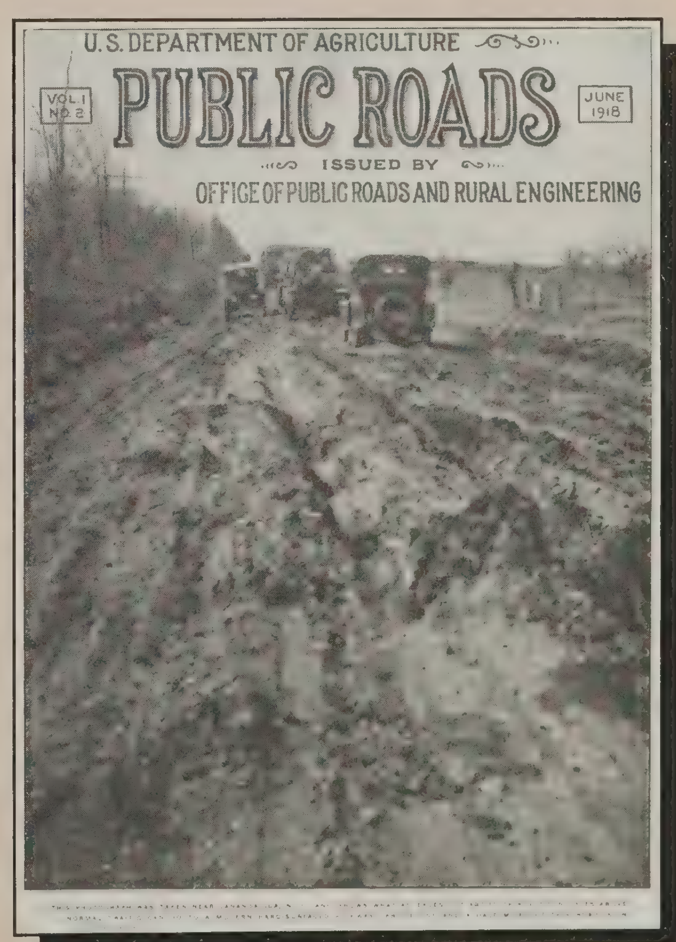
1. CONTENT. The content will reflect the expanded scope and will emphasize the following themes:

   a. The commitment of the FHWA to continue to be a world leader in promoting highway research and technology transfer.

   b. The transition to a transportation system that is more fully integrated to meet the more complex needs of society.

      (1) Intermodalism: highways must be integrated into a complete transportation network that includes railways, airports, waterways, etc.

      (2) Social factors such as environmental quality and traffic congestion must be taken into account in new projects.



(3) Intermodalism and social factors require that the FHWA work much more closely with State and local governments to plan the overall impact of new highway projects.

2. DESIGN. The design will mix a variety of elements—text, photos, charts, and illustrations—into one comprehensive, unique, well-balanced whole. The magazine will look sharp and fresh, while still conveying a large amount of information. It will communicate through a balance of text and visual elements and through a balance of substantive feature articles and technical articles.

   Some specific design changes include: use of full color in some internal sections of the magazine, more photographs and color photographs, and a more lively layout.

3. TIMELINE. The timeline for making these changes is from December 1992 to December 1993. The first changes involving the expanded scope and content of the magazine will be in the December 1992 issue. More text/content changes will be made in the March 1993 and June 1993 issues. The graphic design and color changes will first be apparent in the June 1993 issue, and subsequent adjustments may be made in the September and December 1993 issues.

Standing in front of an FHWA display at last year's TRB Annual Meeting are (from left) Louis Colucci, FHWA Deputy Administrator Eugene McCormick, FHWA Executive Director E. Dean Carlson, FHWA Administrator Thomas D. Larson, Tommy Beatty, and Martha Soneira.

72d TRB Annual Meeting
January 10-14, 1993

General Information

The Transportation Research Board's 72d Annual Meeting will be conducted on January 10 through 14, 1993, in Washington, DC, at the Sheraton Washington, Omni Shoreham, and Washington Hilton hotels. Nearly 6,000 transportation administrators, engineers, practitioners, researchers, consultants, educators, industry personnel, and journalists are expected for the exchange of transportation information and research findings. The meeting will include approximately 250 sessions with some 1,300 presentations covering all aspects of transportation research and practice. In addition, 6 specialty workshops will be held on Sunday, January 10, and 200 committee meetings will take place over the 4-day period.

One of the highlights will be the presentation by the 1993 TRB Distinguished Lecturer Bryant Mather, director of the Structures Laboratory of the U.S. Army Corps of Engineers Waterways Experiment Station. Mr. Mather's presentation, "Concrete in Transportation: Desired Performance and Specifications," is scheduled for Monday, January 11, 6:00 p.m., at the Sheraton Washington.

Most activities relating to the work of TRB's Group 1 (Transportation Systems Planning and Administration) will be at the Washington Hilton (intercity rail, aviation, water, and freight activities will be at the Omni Shoreham). Activities of Group 2 (Design and Construction of Transportation Facilities) will be held at the Sheraton Washington and Omni Shoreham. The Sheraton Washington will be the principal site for activities of Group 3 (Operation, Safety, and Maintenance of Transportation Facilities). Free shuttle bus service will be available between the hotels from Sunday through Thursday.

Registration Information

The registration fee covers admission to all sessions listed in the program; however, admission to Sunday workshops is separate and may require an additional registration fee. There is no fee for current chairs of TRB councils, committees, task forces, and panels; employees of official sponsors (the State highway and transportation departments, American Association of State Highway and Transportation Officials (AASHTO), U.S. Department of Transportation, Association of American Railroads, U.S. Army Corps of Engineers, National Asphalt Pavement Association, and Motor Vehicle Manufacturers Association); and official TRB university or transit liaison representatives.

For those who did not preregister by December 10, on-site registration begins Sunday, January 10, at 2:00 p.m. at all three hotels. Please direct any questions about registration and fees to Angelia Arrington, Reggie Gillum, or Anita Brown at 202-334-2362 or 334-2382 or fax 202-334-2003.

NCHRP Projects Selected for Fiscal Year 1994

The AASHTO-sponsored National Cooperative Highway Research Program announces the following 30 new projects for fiscal year 1994:

Project No.	Title
1-31	Assessment of Ride Quality Specifications for Asphalt and Portland Cement Concrete Pavement
1-32	Systems for Design of Highway Pavements
3-47	Capacity Analysis Techniques for Interchange Ramp Termini
3-48	Capacity Analysis for Intersections with Traffic Actuated Controllers
3-49	Capacity and Operational Effects of Raised Medians, Two-Way Left-Turn Lanes, and Suburban Development
3-50	Driver Information Overload
3-51	Comparative Analysis of Data Transmission Mediums for Signal, DEI, and Freeway Surveillance Systems
4-19	Aggregate Tests Related to Performance
8-32	Transportation Planning, Programming, and Finance
9-7	Field Procedures and Equipment to Implement SHRP Asphalt Specifications
9-8	Development of an Objective Procedure for the Design of Stone Mastic Asphalt Mixtures and Criteria for Their Use
10-41	Evaluation of Portland Cement Concrete Overlays with Bond Breakers Over an In-Place Concrete Pavement
10-42	Development of Constructibility Review Process for Highway Facility Designs
10-43	Movable Bridge Maintenance, Inspection, and Evaluation
12-40	Fatique Criteria of Modular Bridge Expansion Joints
12-41	Rapid Replacement of Bridge Decks
17-10	AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals
17-11	Determination of Safe/Cost Effective Roadside Slopes and Associated Clear Distances
20-31	Public Policy for Freight Transportation
20-32	Development of a Standard Terminology for Transportation Research
20-33	Facilitating the Implementation of Research Findings
20-34	Developing Measures of Effectiveness for Truck Weight Enforcement Activities
20-35	SHRP Follow-Up Studies
20-36	Highway Research and Technology International Information Sharing
20-37	Strategic Plan for the NCHRP
22-11	Evaluation of Current Roadside Barriers and Other Safety Appurtenances to Accommodate Vans, Minivans, Pickup Trucks and 4-Wheel Drive Vehicles as Described in the ISTEA 1991
25-7	Improving Travel Data Required for Mobile Source Emission Estimates
25-8	Impact of Highway Capacity Improvements on Air Quality and Energy Consumption
25-9	Impacts of Highway Runoff on Receiving Waters and Environmental Impacts of Construction Materials on Groundwater
25-10	Estimating the Secondary Impacts of Proposed Transportation Projects

Project Statements, inviting proposals for research on most of these projects, are scheduled to be issued during the first half of 1993, and research is expected to begin in late 1993. As usual, the preliminary announcement containing more details on these problems will be distributed in December to all those on the NCHRP project-statement mailing list; copies will be available at the Transportation Research Board Annual Meeting in January.

Prospective proposers may be added to the mailing list by writing to Program Officer, Cooperative Research Programs, Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, DC, 20418.

Transportation Trivia
(Did you know?)

The Intelligent Vehicle-Highway Systems (IVHS) Program includes research, development, and operational tests of innovations and technologies that will enhance the mobility, efficiency, and safety of the Nation's surface transportation system. Certainly, motor vehicle crashes affect the mobility, efficiency, and safety of our roadways and motoring public, so the following information from the National Highway Traffic Safety Administration (NHTSA) and the Federal Railroad Administration (FRA) provides another perspective of the importance of the IVHS program.

Motor vehicle crashes in 1990 alone cost the Nation more than $137 billion. NHTSA Administrator Marion C. Blakey said, "This staggering economic burden amounts to more than 2 percent of the gross domestic product. It includes medical costs, property damage, insurance administration, lost productivity, and other costs. No cost accounting can adequately measure the enormous human loss in terms of grief, pain, and suffering that result from motor vehicle deaths and injuries. Fortunately, the traffic fatality rate per 100 million miles of motor vehicle travel dropped from 2.8 in 1982 to an historic low of 1.9 today. This decease, resulting from Federal, State, and community traffic safety efforts during the past decade, is keeping the social costs of motor vehicle crashes from being even higher." The crashes reported in 1990 resulted in more than 44,500 deaths, 5.4 million injuries, and 28 million damaged vehicles. Although about 34 percent of the crashes were attributable to drinking and driving, the NHTSA noted that alcohol involvement is significantly understated in police reports, which identify only about half of the drivers who use alcohol.

The number of people killed or injured as a result of accidents at railroad crossings continued to decline in the first 6 months of 1992, according to the FRA. During the January to June period in 1992, there were 263 fatalities at highway-rail crossings. This is a 15 percent drop from the 308 killed over the first 6 months of 1991.

Conference on Advanced Traffic Management Systems

This conference will be held at the Tradewinds Resort in St. Petersburg Beach, Florida, October 3-8, 1993.

The objective of the conference is to bring together transportation professionals from the academic, private and public sectors, fostering discussion and bridging the gap between theory and practice on advanced traffic management systems.

Sessions are tentatively planned on the following topics:

- Interfaces with ATMS: ATIS, CVO, and APTS.
- Real-time applications of ATMS technologies.
- Experiences learned from IVHS field operational tests.
- Support systems for ATMS.
- Issues in the development and application of traffic models.
- Human factors issues related to IVHS.

The conference is sponsored by the Federal Highway Administration (FHWA), the University of Waterloo, the University of Florida, and the IVHS America Advanced Traffic Management Systems Committee. The conference will be chaired by Alberto Santiago of FHWA and Sam Yagar of the University of Waterloo.

For more information, contact Al Santiago at (703) 285-2092. To propose a paper or presentation for the conference, please submit a summary of any length (figures and/or tables may be included if you feel it will help) to the following address:

ATMS CONFERENCE c/o San Yagar
McTrans Center
Transportation Research Center
512 Weil Hall
University of Florida
Gainesville, Florida 32611-2083

Fax number (904) 392-3224

e-mail address
UFTRCONERVM.NERDC.UFL.EDU

RECENT PUBLICATIONS

The following are brief descriptions of selected publications recently published by the Federal Highway Administration, Office of Research and Development (R&D). The Office of Engineering and Highway Operations R&D includes the Structures Division, Pavements Division, Materials Division, and Long Term Pavement Performance Division. The Office of Safety and Traffic Operations R&D includes the Intelligent Vehicle-Highway Systems Research Division, Design Concepts Research Division, and Information and Behavioral Systems Division. All publications are available from the National Technical Information Service (NTIS). In some cases, limited copies of publications are available from the R&T Report Center.

When ordering from the NTIS, include the PB number (or the publication number) and the publication title. Address requests to:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Requests for items available from the R&T Report Center should be addressed to:

Federal Highway Administration
R&T Report Center, HRD-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
Telephone: (703) 285-2144

Chemical Modification of Asphalts, Publication No. FHWA-RD-91-123

by Materials Division

Prominent among the damages occurring to asphalt cement concrete pavements are cracking and rutting. The occurrence of such damage is dependent upon many factors including the properties of the asphalt, which are, in turn, dependent upon its molecular structure. Experiments to test this hypothesis included the modification of asphalt cements by reacting them separately with maleic anhydride, chromium trioxide and furfural in the presence of hydrochloric acid. Six different asphalts were used in these exploratory reactions. The original and chemically modified asphalts were subjected to laboratory tests. These data show that the chemically modified asphalts have potential for use in the highway pavements to help avoid cracking and rutting in such pavements. The adhesion to aggregate by the modified Wyoming pedestal test was performed. The chemical modification of asphalts improves the adhesive bond between asphalt and aggregate in an asphalt mixture implying an increased resistance to stripping. The presence of polar and polymerizing groups in the modified asphalts play a major role in controlling the adhesion to aggregate. The infrared spectra (IR) and high pressure-gel permeation chromatography (HP-GPC) support this hypothesis.

This publication may only be purchased from the NTIS. (PB No. 93-105955/AS, price code: A08.)

Inform Evaluation, Volume I: Technical Report, Publication No. FHWA-RD-91-075

by Intelligent Vehicle-Highway Systems Research Division

INFORM (INformation FOR Motorists, formerly known as the Integrated Motorist Information System—IMIS) is a corridor traffic management system designed to obtain better utilization of existing failities in a 40-mile (64.4km) long highway corridor on Long Island, New York. The system includes integrated electronic traffic monitoring, variable message signing, ramp metering, and related strategies to optimize traffic flow through a heavily congested corridor.

The evaluation of INFORM was conducted using extensive field data, surveys, and data collected through the system. The Technical Report presents the overall results of the evaluation, including comparisons of vehicle miles of travel, vehicle hours of travel, speed, occupancy, ramp delays, and equipment failures, motorist perceptions, and other congestion-related measures for the a.m. and p.m. peak periods. Incident case studies were used to evaluate motorist response to and effectiveness of variable message signing strategies. In addition to presenting the quantitative results, the Technical Report documents the many lessons learned in the design, implementation, operation, and evaluation of INFORM.

This volume is one of two reports on the INFORM Evaluation. The other volume is: FHWA-RD-91-076 Volume II: Executive Summary.

This publication may only be purchased from the NTIS. (PB No. 92-177260/AS, price code: A08.)

The following new research studies reported by the FHWA's Office of Research and Development are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description:

- **FHWA Staff and Administrative Contract Research, contact *Public Roads*.**
- **State Planning and Research (SP&R), formerly called Highway Planning and Research (HP&R), contact the performing State highway or transportation department.**
- **National Cooperative Highway Research Program (NCHRP), contact the Program Director, NCHRP, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418.**

NCP Category A—Highway Safety

A.1: Advanced Traffic Control Methods and Devices

Title: Development of a Prototype Truck Warning System

Objective: A prototype truck warning system will be fabricated and installed on three ramps on the Capital Beltway in Maryland and Virginia. The sites for installation were determined from a previous study.

Performing Organization: Cooperative Agreement

Sponsoring Organization: FHWA

Expected Completion Date: October 1995

Estimated Cost: $400,000 (FHWA)

A.4: Special Highway Users

Title: Pedestrian/Bicyclist Research Program

Objective: Provide engineering, statistical, human factors, and administrative support in the rapid planning, development, and conduct of activities within this program.

Performing Organization: University of North Carolina

Sponsoring Organization: FHWA

Expected Completion Date: September 1994

Estimated Cost: $4,410,043 (FHWA)

A.5: Highway Safety Design Practices and Criteria

Title: Experimental Plans for Accident Studies of Highway Design Elements

Objective: Develop six to eight data collection and analysis plans for the following areas: intersection sight distance, alignment interchanges, access control, clear zones, ditches, rollovers, and roadside hardware.

Performing Organization: Bellomo-McGee, Inc.

Sponsoring Organization: FHWA

Expected Completion Date: November 1995

Estimated Cost: $427,706 (FHWA)

Title: Experimental Plans for Accident Studies of Highway Design Elements (I)

Objective: Six to eight data collection plans will be developed for the following areas: intersection sight distance, alignment interchanges, access control, clear zones, and ditches.

Performing Organization: Midwest Research Institute

Sponsoring Organization: FHWA

Expected Completion Date: November 1995

Estimated Cost: $567,716 (FHWA)

A.6: Human Factors Research for Highway Safety

Title: Intersection Geometric Design for Older Drivers and Pedestrians

Objective: Determine the needs and capabilities of older road users at intersections, identify geometric aspects of intersections that can be modified to better serve the older user, identify suitable operational and TCD implementation changes where geometric changes are not feasible, and develop guidelines for recommended changes.

Performing Organization: Scientex

Sponsoring Organization: FHWA

Expected Completion Date: October 1995

Estimated Cost: $700,000 (FHWA)

NCP Category B—Traffic Operations/ Intelligent Vehicle-Highway Systems (IVHS)

B.1: Advanced Traffic Management Systems

Title: Network-Wide Optimization Models

Objective: Develop traffic model(s) that optimizes the operation of urban networks composed of freeways and surface streets. Key features of the model(s) will be optimization of signal controls, ramp metering, and their integration.

Performing Organization: Farradyne

Sponsoring Organization: FHWA

Expected Completion Date: November 1995

Estimated Cost: $1,405,212 (FHWA)

B.2: Advanced Traveler Information Systems

Title: Human Factors in ATIS and CVO Design Evolution

Objective: Investigate preliminary issues and provide early human factors guidance and recommendations regarding continuing IVHS development within each HPNPA.

Performing Organization: Battelle Human Affairs

Sponsoring Organization: FHWA

Expected Completion Date: February 1996

Estimated Cost: $3,401,337 (FHWA)

B.4: Advanced Vehicle Control Systems

Title: Human Factors Design of Automated Highway Systems

Objective: Identify and investigate the most critical human factors issues associated with automated vehicle control systems. Assess and develop countermeasures to expected changes in drivers' risk-taking behavior under automated highway conditions.

Performing Organization: Honeywell

Sponsoring Organization: FHWA

Expected Completion Date: April 1996

Estimated Cost: $3,501,685 (FHWA)

NCP Category D—Structures

D.1: Bridge Design

Title: Curved Steel Bridge Research

Objective: Conduct fundamental research into the structural behavior of curved steel flexural members and bridges and address construction issues in order to provide adequate information to develop and clarify design specifications.

Performing Organization: HDR Engineering

Sponsoring Organization: FHWA

Expected Completion Date: October 1997

Estimated Cost: $2,495,760 (FHWA)

Title: Behavior of Adhesive Joints in Highway Structures

Objective: Identify and characterize long-term performance and failure modes of appropriate steel to steel, steel to concrete, wood to wood, and composite to traditional structural material adhesives. Bond behavior, creep, shrinkage, and moisture effects will be evaluated through analysis and tests.

Performing Organization: Texas Research Institute, Austin

Sponsoring Organization: FHWA

Expected Completion Date: October 1996

Estimated Cost: $1,000,000 (FHWA)

D.2: Bridge Management

Title: Nondestructive Evaluation (NDE) Monitoring

Objective: Obtain a method for reliable classification of an acoustic emission signal source. Obtain a device that will indicate the cumulative fatigue loading of a typical highway bridge. Obtain related nondestructive evaluation (NDE) automated decision procedures.

Performing Organization: West Virginia University

Sponsoring Organization: FHWA

Expected Completion Date: July 1996

Estimated Cost: $1,000,000 (FHWA)

D.4: Corrosion Protection

Title: Long-Term Effects of Cathodic Protection (CP) on Prestressed Bridge Members

Objective: Address the loss of bond between prestressing steel and concrete and develop selection criteria so as not to compromise the structural integrity of the bridge.

Performing Organization: Florida Atlantic University

Sponsoring Organization: FHWA

Expected Completion Date: October 1997

Estimated Cost: $500,000 (FHWA)

NCP Category E—Materials and Operations

E.3: Geotechnology

Title: Deep Foundations Load Test Data Base

Objective: Develop load test data through instrumentation and monitoring of active bridge construction sites. Collect and evaluate load test data and soils information for inclusion in a central data repository. Develop statistical correlations from the data base to prepare new design aids (charts, curves, and tables) for pile and drilled shaft design procedures.

Performing Organization: Small Business Administration

Sponsoring Organization: FHWA

Expected Completion Date: October 1994

Estimated Cost: $508,457 (FHWA)

E.4: Paints and Coatings for Highways

Title: Characterization of the Environment

Objective: Identify the components that contribute to the corrosivity of the atmospheric environment and develop methods to quantify and better define them with respect to the contribution in the deterioration of highway structural and corrosion protection materials.

Performing Organization: Ocean City Research

Sponsoring Organization: FHWA

Expected Completion Date: October 1998

Estimated Cost: $425,000 (FHWA)

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